IRRIGATION TIMING AND TARNISHED PLANT BUG MANAGEMENT — IMPLICATIONS FOR LATE SEASON SUSCEPTIBILITY TO TARNISHED PLANT BUG AND CROP TERMINATION DECISIONS

Tina Gray Teague
Arkansas State University
University of Arkansas Agricultural Experiment Station
Jonesboro, AR
Diana M. Danforth
Department of Agricultural Economics and Agribusiness, University of Arkansas
Fayetteville, AR

Abstract

Late season termination for tarnished plant bug control (*Lygus lineolaris* (Palisot de Beauvois)) in cotton was evaluated in a 2008 field trial in Marianna, Arkansas, across three different irrigation scenarios: early start of irrigation initiated at squaring, late start irrigation delayed until first flowers, and no irrigation. Plant bug numbers were low through early and mid-season, but around the time of cutout, pest pressure surged, creating ideal conditions for validating the COTMAN decision guide.

Late initiation of irrigation resulted in delayed crop maturity, and no irrigation resulted in early cutout. For plant bugs, crop delay meant extended availability of squares into late July and August. Plant bug nymph numbers were almost 10 times higher in mid-August on un-sprayed cotton grown with delayed irrigation compared to cotton grown with early initiated irrigation or no irrigation. Pest numbers were maintained below thresholds in insecticide sprayed treatments across the three irrigation treatments.

Seedcotton and lint yields were similar across plant bug treatments; late season infestations had no significant effect on yield or fiber quality. Yield was significantly higher with an early irrigation start compared to no irrigation or delayed irrigation. The COTMAN insect control termination endpoint of NAWF=5+250 DD60 was more than sufficient for plant bug control termination under all three irrigation regimes, even with the "promise" of a late season "top crop" where the crop was delayed by pre-flower water deficit stress. Irrigation should be timed to avoid pre-flower stress to achieve early and high yields. Decision makers should employ the COTMAN insect control termination guides and avoid the temptation to make unnecessary and costly late season insecticide applications.

Introduction

Work continues in Arkansas to address these questions: When is a cotton crop safe from new infestations of insect pests? When is scouting no longer necessary? Using the COTMAN™ crop monitoring system (Danforth and O'Leary 1998, Oosterhuis and Bourland, 2008), producers and their crop advisors can answer those questions with confidence. First, they must determine the flowering date of the last effective boll population, that last cohort of flowers that produce bolls that contribute to economic yield. In the once-over, mechanically harvested systems of the Midsouth, this is defined as when the number of main-stem nodes above white flower (NAWF) in the field averages 5. The crop has reached physiological cutout (Bourland et al 1992). When that boll population has accumulated 350 DD60s (heat units) the crop has been shown to be safe from new infestations of the most significant boll feeding insect pests in Midsouth history: boll weevil (*Anthonomus grandis* Boheman), tobacco budworm (*Heliothis virescens* (Fab.)) and bollworm (*Helicoverpa zea* (Boddie)) (reviews by O'Leary et al 1996, Cochran et al 1999, Danforth et al 2004). This protection endpoint also has been validated for tarnished plant bug (Teague et al 2007), and in 2008, it was recommended in Arkansas that the endpoint should be modified to time control termination at physiological cutout + 250 DD60s (Teague et al 2008).

What about special cases? Crop advisors have questioned the appropriateness of extending the time for protection should the crop initiate new terminal growth after cutout. Questions generally arise when NAWF values have dipped below 5 earlier than "expected" because of water deficit stress. If there is time for late season crop recovery, should money be spent on providing protection from tarnished plant bugs for this new "top crop" or should the NAWF=5+250 HU guide be followed? Plants that have undergone pre-flower water deficit stress typically have a low numbers of sympodial nodes at first flower. Consequently, there is lower boll loading stress during the first weeks after flowering. As water stress is relieved with rains or late irrigation, terminal growth resumes. This is easily measured using NAWF counts (Bourland et al 2000). As early set bolls continue to mature, plant terminals resume growing, adding new sympodial nodes and squares. The crop NAWF values do not decline as rapidly after flower as expected and MAY actually increase. The crop is delayed. From a crop protection perspective, these late season squares are particularly attractive to tarnished plant bugs. High numbers of adults from surrounding fields may move into (or remain in) the "re-growth" or "late" crop. Oviposition and an explosion of nymphs follow. If crop protection decisions are made solely on bug numbers, then the obvious recommendation from crop advisors is to apply costly insecticides to protect those upper canopy fruiting forms. If, however, the crop status is considered, decisions are made based on maturity of the last effective boll population. When the COTMAN guide indicates that the crop is past the final stage of crop susceptibility, then the recommendation would be to "stand pat" – no insecticide application – regardless of numbers of plant bugs.

The aim of this 2008 study was to determine if COTMAN decision guides for insect control termination should be adjusted in cases where early season stress results in delayed maturity. Should the COTMAN guides be revised to take into account possible late season re-growth following stress?

Materials and Methods

The experiment was conducted at the University of Arkansas Lon Mann Cotton Research Station in Lee County, near Marianna. In this Mississippi Delta production area, the growing season is May through October. The flowering date of latest possible cutout dates – those dates with a 50% or 85% probability of attaining 850 DD60s from cutout are 14 August and 8 August , respectively (Zhang et al. 1994, Oosterhuis and Bourland 2008).

Cultivar Stoneville 5599 RBG was seeded on 7 May at a seeding rate of 3 to 4 Cruiser treated seeds/ft in rows spaced 38 inches apart. Poor weather conditions resulted in an inadequate stand, and the experiment was replanted on 20 May. The soil was a Calloway silt loam. The experiment was designed as a 3* 5 factorial with irrigation timing (3 factors) and tarnished plant bug control timing (5 factors), arranged in a split plot with irrigation as main plots. Specific treatment application dates are listed in Tables 1&2. Plots were 60 ft long, and 8 rows wide. Fifteen ft alleys separated plots. There were 3 replications.

Standard UA Experiment Station production practices were used for fertility, weed control and tillage across the experiment. Mepiquat chloride was applied to all test plots on 9 July (8oz/ac and 22 July (10 oz/ac); the final application was made in irrigated main plots only.

Table 1. Timing of different irrigation and plant bug insecticide spray treatments at the UA Lon Mann Research Station, Marianna, 2008.

		Treatment timing					
Treatment	**Designation**	**Pre-Flower**	**Mid-season**	**Late season[1]**	**days after planting**		
Irrigation	**Delayed Start**	None	Irrigated	Rain		58, 64	
	Early Start	Irrigated	Irrigated	Rain	28, 37, 44	58, 64	
	None	None	None	Rain			
Insecticide	**0-S-S**	None	Spray	Spray		49, 69	83, 91
Sprays (S) or	**0-S-0**	None	Spray	None		49, 69	
No sprays (0)	**S-S-S**	Spray	Spray	Spray	32, 39	49, 69	83, 91
	S-S-0	Spray	Spray	None	32, 39	49, 69	
	0-0-0	None	None	None			

[1] Date of planting was 20 May. Late season sprays were made after physiological cutout. Furrow irrigation timing was based on the University of Arkansas Irrigation Scheduler and initiated at 1.5 inch deficit.

Table 2. Application timing and products for insecticide sprays in insect treatment sub-plots – Marianna, 2008.

Application date[1]	**Days after planting**	**Product (rate/acre)**	**Insecticide spray treatment**

21-June	32	Centric (1.5 oz/ac)	S-S-S, S-S-0
28-June	39	Centric (1.5 oz/ac)	S-S-S, S-S-0
8-July	49	Centric + Diamond (1.5 oz + 10 oz/ac)	S-S-S, S-S-0, 0-S-S, 0-S-0
28-July	69	Acephate 90S (0.6 lb/ac)	S-S-S, S-S-0, 0-S-S, 0-S-0
11-Aug	83	Acephate + Tombstone (0.7 lb + 2.1 oz)/ac	S-S-S, 0-S-S
19-Aug	91	Acephate + Diamond (0.7 lb + 6.5 oz)/ac	S-S-S, 0-S-S

[1]Insecticides were applied with JD high clearance sprayer and 8 row boom.

Numbers of tarnished plant bugs were monitored weekly using drop cloth samples taken across 2 adjacent rows (1.5 ft samples per row) in a section of rows 3 and 4 of each plot. Variation in average number of collected nymph and adults per 3 ft was analyzed using AOV separately for each date.

Plants across treatment plots were monitored from the early squaring period through defoliation using the COTMAN system. Two sets of five consecutive plants in a separate section of sample rows 3 and 4 were monitored weekly using the Squaremap sampling procedure which includes measurement of plant height, number of main stem sympodia, and presence or absence of first position squares and bolls. Care was taken to touch the plants as little as possible to avoid sampler induced thigmonastic plant responses. After 1st flowers, Squaremap sampling of consecutive plants was continued to monitor changes in square and boll retention, and squaring node levels. On 10 and 15 September, the COTMAN Scoutmap sampling protocol was used to assess boll retention and injury symptoms. Sampling procedures were similar to Squaremap with mean no. of squaring nodes and post-flower nodes (main stem sympodia below squaring nodes), first position squares and boll retention monitored as well as external signs of bug feeding injury on fruiting forms. Also, numbers of 1st position bolls with either hard lock or other boll rot symptoms were recorded. Plants in rows 5 and 6 were examined, and care was taken to minimize handling sampled plants.

Defoliant and boll opener were applied 18 September. Final plant mapping was performed 24-26 September using COTMAP protocol (Bourland and Watson 1990). Ten plants in rows 5 and 6 of each 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 main-stem sympodia with 2 nodal positions and number of bolls on sympodia located on secondary axillary positions were also noted. Plant height was measured as distance from soil to apex.

Fifty consecutive bolls, hand-picked from adjacent whole plants in row 5, were collected on 1 Oct for fiber quality assessments. These samples were ginned on a laboratory gin and submitted to the Fiber and Biopolymer Research Institute at Texas Tech University for HVI fiber quality determinations. Additional yield component calculations were made using methods employed in the University of Arkansas variety testing program (Bourland et al. 2008). Rows 5 and 6 of each plot were machine harvested 3 October for yield. All plant monitoring and yield and quality data were analyzed using AOV with mean separation using LSD.

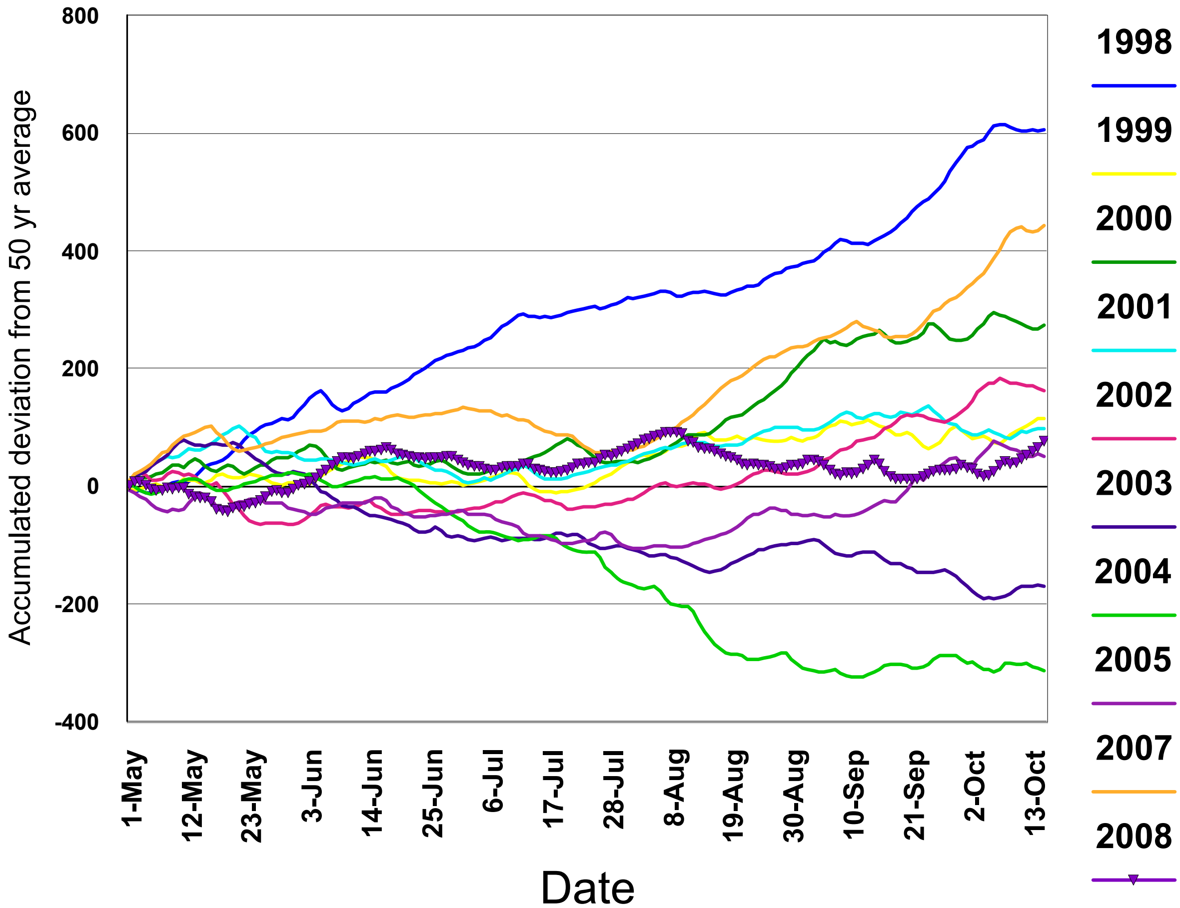

Figure 1. When compared to the 50 year average DD60 accumulation (presented as the standard (zero)), the graph of cumulative deviations show that the 2008 temperatures in Marianna were slightly cooler in spring and in late August.

Results

The 2008 crop season featured a cool, wet spring followed by warm, moderately dry June, and hot July. (Fig. 1). Because of the late date of re-planting, initiation and development of squaring nodes were early compared to the standard COTMAN target development curve (Fig 2). Plant bug treatments had no effect on squaring node development season long, and there were no bug*irrigation interactions (P>0.25). There were significant irrigation effects. For the early start irrigation plants, the rate of nodal development through 1st flowers paralleled the COTMAN standard curve. By first flowers, squaring node production for the early start irrigation was lower than the COTMAN standard with mean no. of nodes = 7.7 compared to the COTMAN standard of 9.25 squaring nodes. Growth curves for non-irrigated and delayed irrigation main plots were comparable pre-flower and clearly show the effects of pre-flower stresses on crop structure. Significantly fewer total main-stem sympodia were observed by first flowers (56 days after planting (DAP)) for these non-irrigated plants compared to the early irrigated treatment (P=0.001, LSD=0.71). Mean squaring nodes were 5.9 and 6.0 for late start and for non-irrigated plants, respectively. The pre-flower pace of nodal development among irrigation treatments was slowed for non-irrigated and delayed irrigation treatments compared to the early start. For the COTMAN target curve, the expected standard pace is approximately 0.4 nodes/day. For main plots with early irrigation, mean pace of nodal development was 0.22 nodes per day compared to 0.15 and 0.16 nodes per day for delayed irrigation and non-irrigated, respectively.

Growth curves reflecting the 3 irrigation treatment effects clearly separated post flower (Fig 2). Delayed irrigation resulted in more sustained terminal growth after first flowers compared to early start and non-irrigated treatments. The rate of NAWF decline among irrigation treatments depicts the differences in terminal growth in July. Late irrigation initiation delayed crop maturity as measured by days to physiological cutout (Table 3). Non-irrigated treatments reached physiological cutout 6 days earlier than plants receiving early irrigation, and delayed irrigated treatments reached cutout 5 days after that the early irrigated plants(Fig 2). Plant bug insecticide timing did not affect crop maturity as measured by days to physiological cutout.

Table 3. Irrigation timing effects on no. of days to physiological cutout (NAWF = 5), and subsequent effects on timing for final plant bug insecticide applications.

Irrigation timing	Date of physiological cutout	Mean no. days to physiological cutout[1]	Crop status at time of early insect control termination[2]	Crop status at time of late insect control termination
Delayed Start	5 Aug	77 a	NAWF=5.7	NAWF=5 + 258 DD60s
Early Start	31 July	72 b	NAWF=5.1	NAWF=5 + 380 DD60s
None	25 July	66 c	NAWF=5 + 96 DD60s	NAWF=5 + 527 DD60s

[1] Irrigation significantly affected mean days to physiological cutout (Pr>F = 0.001; LSD=2.75 days).
[2] Early insect control termination occurred with final sprays on 28 July and late termination application occurred with final sprays on 19 August.

Terminal growth was suspended shortly after flower in plants not receiving irrigation – cutout occurred early, but August rains resulted in re-growth in those "dryland" plots. The timing of post-cutout re-growth among all irrigation treatments is apparent in growth curves overlaid graphically with rainfall accumulations for the Marianna station (Fig 3). Resurgence of terminal growth was documented by continuing to take COTMAN data post-cutout. Re-growth in early start irrigation plots also was observed, but was less conspicuous. Mepiquat chloride applications affected re-growth potential among treatment plots, and production of late season "spikes" or "buggy whips" were apparent but probably less obvious than they would have been without application of plant growth regulators.

Tarnished bug numbers were very low through most of the season (Fig 4). Pre-flower bugs and bug induced sheds were similar among all insecticide timing treatments (Figs 4, 5). No significant differences (P<0.05) in total shed levels (% square or square + bolls) among bug or irrigation treatments were observed prior to cutout. There were no significant bug*irrigation interactions observed during any sample period prior to cutout. With low insect numbers, square retention levels never decreased below 90%. Action levels for plant bugs were not exceeded during the pre-flower period (3 bugs/drop cloth sample), and plant based indicators (% shed) showed the crop injury levels were not sufficient to warrant insecticide applications.

Bug numbers increased dramatically around the time of cutout in unsprayed treatments. At 69 days after planting, mean no. nymphs per drop cloth sample ranged from 0 to 2.7 bugs. By 78 DAP bug numbers ranged from 0 to 8.3, and by 95 DAP, bug numbers ranged from 0 to 32 bugs/drop. Total bug numbers dropped to < 1 bug per drop by 103 DAP as the insects completed development to adult and moved out of the field. Throughout this period, numbers were maintained at low, sub-threshold levels in sprayed plots.

Severity of bug infestation was related to irrigation timing. The most dramatic increase in bug numbers occurred in delayed irrigation main plots. Plants in this irrigation treatment had highest numbers of squares in the field at the time of the late season surge of plant bugs. Square availability is reflected by higher NAWF compared to early start irrigation and non irrigated plots in late July. Immigrating adults deposited eggs in plants with late season squares, the nymphs survived where no insecticides were applied, and the dramatic surge in plant bug nymphs resulted (Fig 4). Final insecticide termination sprays were made on 19 August or 28 July depending on the insecticide timing treatment. When timing was related to crop maturity status, these termination dates correspond with cutout + 258 DD60s for delayed irrigation start, cutout+380 DD60s for early irrigation start and cutout +527 DD60s for non-irrigated. Timing of early insect termination corresponded with NAWF= 5.7 for delayed irrigation start, NAWF=5.1 for early start and cutout + 96 DD60s for non-irrigated.

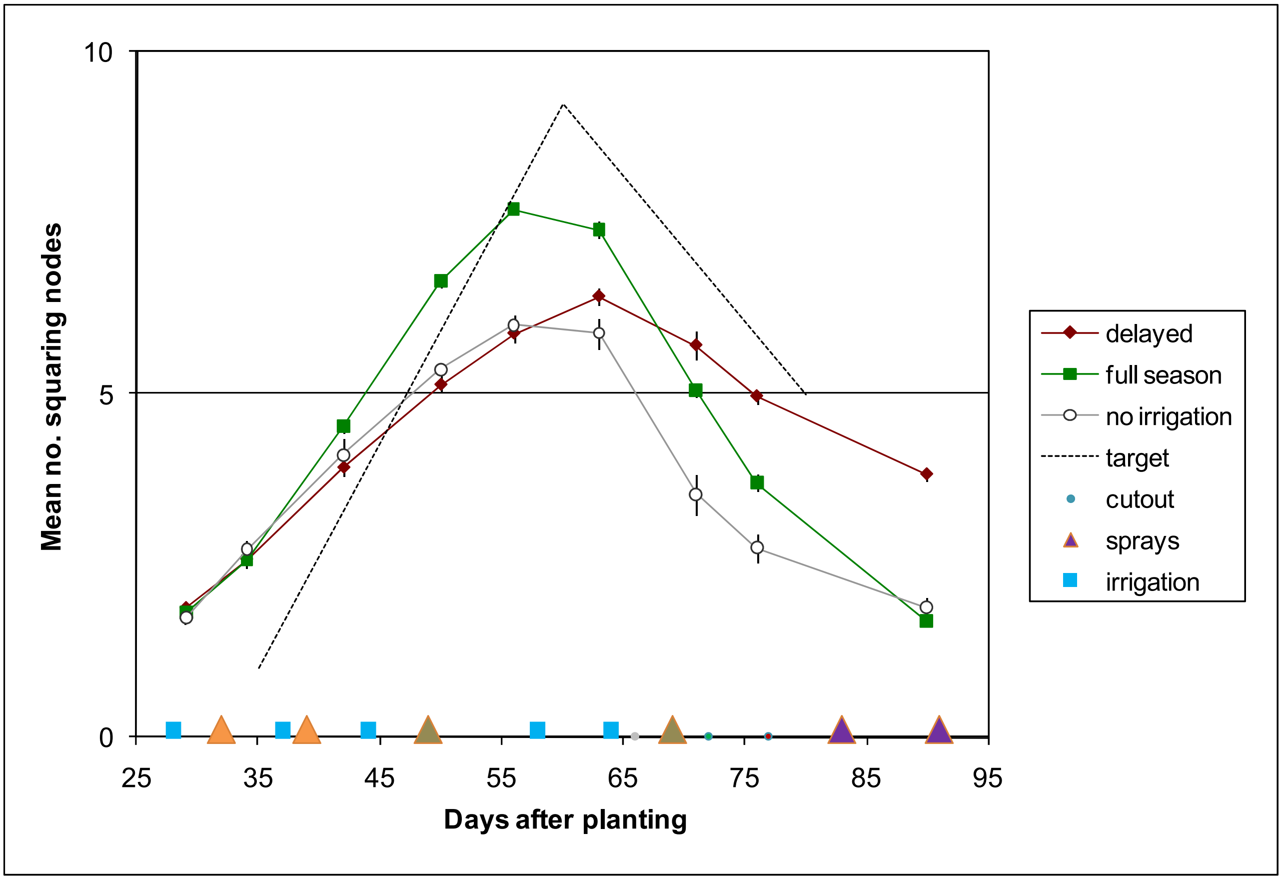

Figure 2. The COTMAN target development curve, shown as mean no. of squaring nodes (±SEM), can be used as a standard to compare the actual growth curves of plants in irrigation timing main plots in the 2008 Marianna trial. Insecticide spray dates are indicated as triangles on the x-axis in days after planting (dap) for early (32, 39 dap), mid (49, 69) and late (83, 91) application dates. Squaring node counts (no. of main stem sympodia that have not yet flowered) were made with Squaremap sampling conducted through the 3rd week of flower followed by NAWF monitoring. Mean cutout date (NAWF=5) was significantly earlier for main plots that did not receive irrigation compared to irrigated treatments, and cutout date for delayed irrigation was significantly later than full season irrigation (p=0.001; LSD=2.5days).

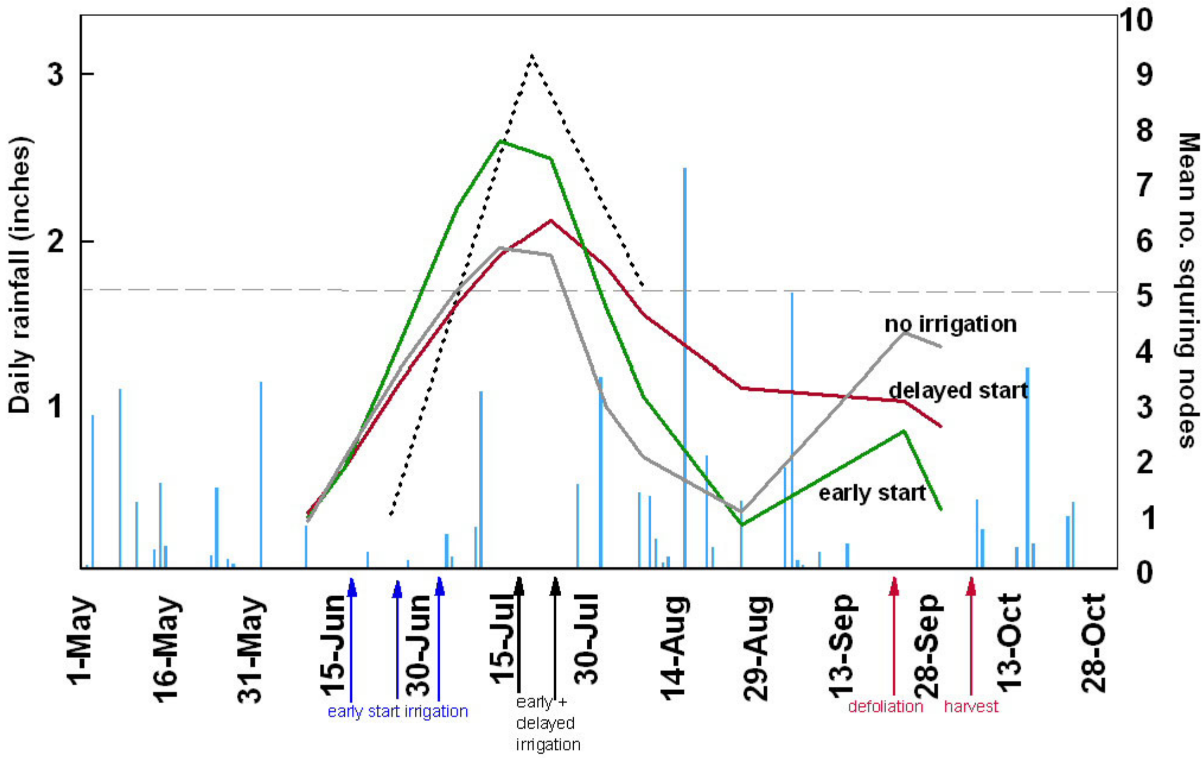

Figure 3. Daily rainfall accumulations with dates of irrigation for the 2008 Marianna trial indicated below the x-axis. Early irrigation commenced 28, 37, 44 DAP on 17, 25, June and 3 July. All irrigated treatments received irrigation on 17 and 23 July, 58 and 64 DAP. Also shown on the rainfall chart is the COTMAN standard curve and actual growth curves for irrigation main effects. . Squaring node measures (no. of main stem sympodia that have not yet flowered) were made with Squaremap, NAWF and Scoutmap sampling. Squaring node production continued post cutout following August rains. Revival of terminal growth was marked in non-irrigated main plot treatments. At defoliation, heat unit accumulations from NAWF=5 for non-irrigated, early start and delayed start irrigation main plots were 984, 837 and 715 DD60s, respectively.

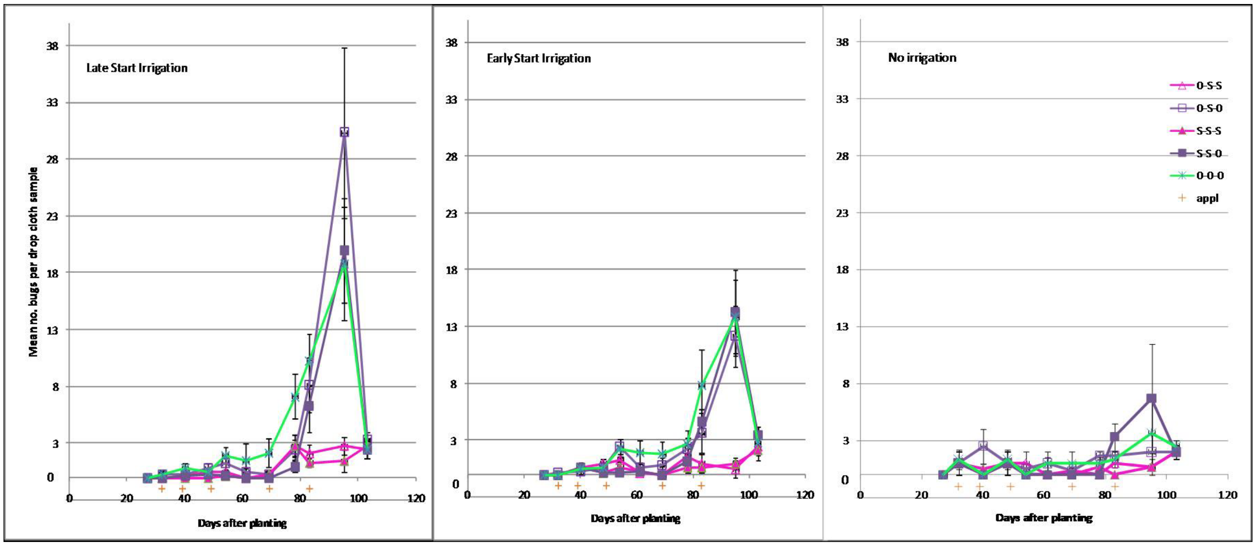

Figure 4. Mean no. tarnished plant bug adults and nymphs (±SEM) observed per drop cloth (3 ft of row) sampled by beating plants over a 3 ft black cloth positioned between rows 3 and 4 in each 8 row plot. The irrigation treatment is noted in the upper left corner. Significantly higher numbers of nymphs were observed 70 DAP associated with delayed irrigated treatment (above, left) compared to early start (center) and non-irrigated treatments (right) (p=0.001) for plots not receiving the final 2 insecticide sprays (post cutout timing). Insecticide applications were effective in reducing numbers to sub-threshold levels in late season sprayed treatments and means never exceeded 3 bugs per drop season-long.

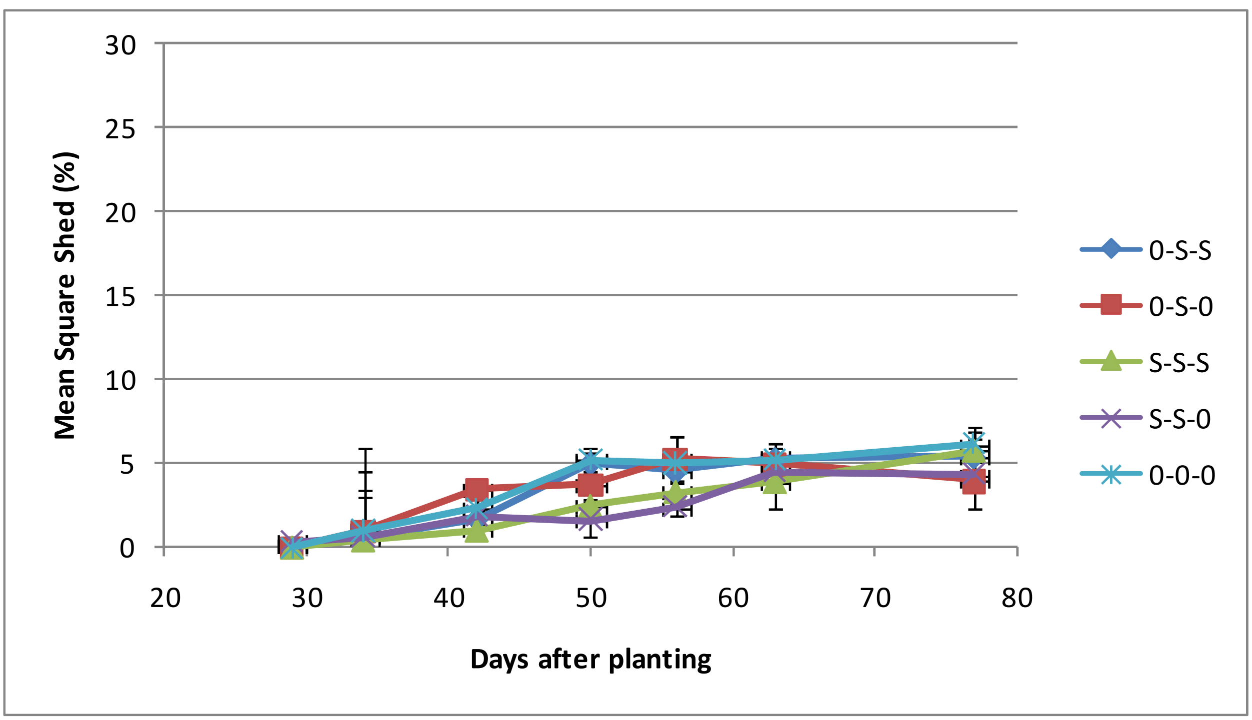

Figure 5. Mean % shed of 1st position squares (±SEM) for the five plant bug insecticide timing sub-plot effects. No significant bug or bug*irrigation interactions were observed from early squaring until physiological cutout.

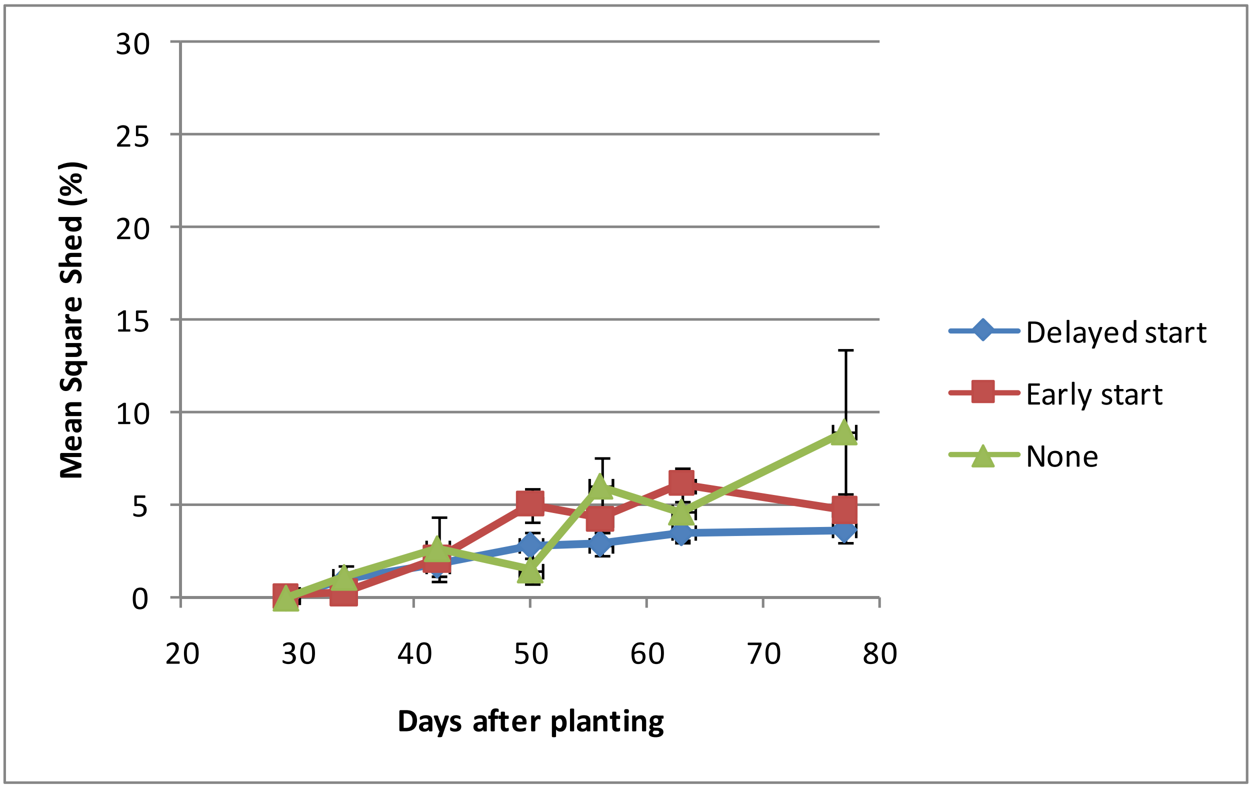

Figure 6. Mean % shed of 1st position squares (±SEM) for the 3 irrigation timing main plots. No significant irrigation or bug*irrigation were observed through the period of COTMAN Squaremap sampling.

Results from Scoutmap samples made just prior to defoliation indicate significant effects of irrigation on number of main-stem sympodial nodes and fruit retention (Table 4). Plants in delayed irrigation treatments had significantly higher numbers of boll nodes compared to the early initiation and non-irrigated treatments; highest shed levels also were recorded for the delayed start irrigation. There was no significant insecticide spray effect on bug related external injury to bolls; however, reduced levels of external boll injury were associated with delayed irrigation. Retention of bolls was highest in the spray treatment receiving early, mid and late season (S-S-S) insecticide applications and highest shed levels were observed in the untreated control (0-0-0). Plant bug spray treatments had no effect on counts of bolls with hard lock or boll rot.

Table 4. Results from COTMAN Scoutmap[1] monitoring taken on 15 September just prior to application of harvest aid defoliants and boll openers showing effects of irrigation timing and insecticide sprays for plant bug on number and condition of first position main stem sympodia and fruiting forms – Marianna 2008.

Treatment Timing	Sympodial nodes (no.)	Boll Nodes[2] (no.)	Shed Bolls[3] (%)	Shed fruiting forms[4] (%)	Bolls with external TPB injury[5] (%)	Bolls with hard lock or rot[6] (%)
Irrigation						
Delayed start	15.3	11.0	46.9	58.2	12.0	3.7
Early start	12.7	9.4	38.3	49.9	21.2	2.4
None	13.3	7.5	41.8	53.1	24.0	2.7
Plant Bug Sprays						
0-S-S	9.3	13.3	41.6	50.1	20.7	2.8
0-S-0	9.1	13.8	42.7	55.0	19.4	3.5

S-S-S	9.6	13.9	36.8	48.1	20.9	4.0
S-S-0	9.4	13.7	40.6	55.5	16.2	3.0
0-0-0	9.2	14.1	49.3	60.0	17.8	1.4
P>F						
irrigation (I)	*0.01*	*0.02*	*0.16*	*0.03*	*0.01*	*0.11*
spray (S)	*0.42*	*0.91*	*0.03*	*0.01*	*0.79*	*0.19*
*I*S*	*0.63*	*0.68*	*0.28*	*0.78*	*0.82*	*0.29*
LSD_{05}						
irrigation (I)	*1.0*	*1.7*		*4.3*	*6.2*	
spray (S)			*7.8*	*7.1*		

[1] standard Scoutmap procedure modified to count squaring nodes rather than NAWF; means represent results of sampling 10 plants per plot, 5 consecutive plants in 2 adjacent rows.
[2] mean of main-stem sympodial branches on which first-position square had flowered.
[3] mean of main-stem boll nodes with missing first-position fruiting form.
[4] mean of main-stem sympodial nodes with missing first position squares or bolls.
[5] mean of first position bolls with external injury from apparent bug feeding - internal injury not determined.
[6] mean of first position bolls with external boll rot symptoms or open bolls with hard lock.

Results from end-of-season plant mapping using COTMAP sampling indicate significant effects of irrigation and insecticide on final plant structure (Tables 5, 6). Early irrigation resulted in more monopodia per plant compared to late irrigation initiation and non-irrigated, but fewest main-stem sympodia(Table 5). Late season terminal growth in delayed irrigation and non irrigated plants contributed to this total sympodial node count. Values for highest sympodia with 2 nodes were significantly higher for plants grown with delayed start for irrigation; this treatment also resulted in more plants with 2nd position bolls compared to early start and non-irrigated treatments (Table 5). These values indicate an end-of-season plant structure with potential for compensation for effects of early season stress. Irrigated plants were taller than non-irrigated plants. Internode length was lowest for non-irrigated plants and highest for plants in early start irrigation.

For Insecticide effects measured using COTMAP, higher mean numbers of effective sympodia per plant were observed where insecticides were used season long (S-S-S) (Table 6). Fewer total sympodia per plant were observed where early insecticides (S-S-S and S-S-0) were applied, and 1st position fruit retention was highest in these treatments. Fewer total bolls per plant were observed where insecticides were terminated early.

Table 5. Results from final end-of-season plant mapping using COTMAP for irrigation timing main plot effects- 2008 Marianna [1].

Category	**Mean per plant for irrigation timing treatment**				
	Early start	**Delayed start**	**None**	***P>F***	***LSD_{05}***
1st Sympodial Node	5.8	5.7	5.5	*0.21*	
No. Monopodia	2.2	1.6	1.4	*0.04*	*0.61*
Highest Sympodia with 2 nodes	9.1	10.8	9.4	*0.04*	*0.89*
Plant Height (inches)	31.3	30.6	24.2	*0.005*	*2.62*
No. Effective Sympodia	7.5	7.8	6.5	*0.46*	
No. Sympodia	12.5	15.4	14.2	*0.01*	*1.22*
No. Sympodia with 1st Position Bolls	4.0	3.8	3.8	*0.68*	
No. Sympodia with 2nd Position Bolls	0.6	0.9	0.5	*0.03*	*0.21*
No. Sympodia with 1st & 2nd Bolls	1.7	1.6	1.3	*0.55*	
Total Bolls/Plant	9.7	10.1	8.0	*0.32*	
% Total Bolls in 1st Position	58.1	55.0	63.7	*0.08*	
% Total Bolls in 2nd Position	23.3	24.6	21.7	*0.53*	
% Total Bolls in Outer Position	2.5	6.5	2.2	*0.10*	

% Total Bolls on Monopodia	15.8	12.9	10.6	*0.06*	
% Total Bolls on Extra – Axillary	0.3	1.0	1.9	*0.36*	
% Boll Retention - 1st Position	44.9	35.9	36.1	*0.19*	
% Boll Retention - 2nd Position	24.9	23.7	19.3	*0.50*	
% Early Boll Retention	58.0	55.1	52.1	*0.63*	
Total Nodes/Plant	17.3	20.1	18.7	*0.04*	*1.66*
Internode Length (inches)	1.8	1.5	1.3	*0.001*	*0.07*

[1] means of 10 plants per plot

Table 6. Results from final end-of-season plant mapping using COTMAP for insecticide timing sub-plot effects – 2008 Marianna[1].

	Mean per plant for insecticide treatment						
Category	**0-S-0**	**0-S-0**	**S-S-S**	**S-S-0**	**0-0-0**	***P>F***	***LSD_{05}***
1st Sympodial Node	5.7	5.6	5.6	5.7	5.8	*0.23*	
No. Monopodia	1.6	1.9	1.8	1.8	1.8	*0.64*	
Highest Sympodia with 2 nodes	9.6	10.0	9.6	9.4	10.4	*0.12*	
Plant Height (inches)	28.3	29.7	29.4	28.1	30.1	*0.25*	
No. Effective Sympodia	7.7	7.3	8.0	6.5	7.2	*0.01*	*1.81*
No. Sympodia	13.9	14.1	13.6	13.6	14.9	*0.03*	*0.82*
No. Sympodia with 1st Position Bolls	4.1	3.7	4.2	3.8	3.5	*0.05*	*0.48*
No. Sympodia with 2nd Position Bolls	0.9	0.6	0.6	0.5	0.9	*0.002*	*0.21*
No. Sympodia with 1st & 2nd Bolls	1.7	1.7	1.8	1.3	1.3	*0.03*	*0.36*
Total Bolls/Plant	10.0	9.7	10.1	8.5	8.7	*0.01*	*1.07*
% Total Bolls in 1st Position	59.4	56.0	59.5	61.4	56.2	*0.25*	
% Total Bolls in 2nd Position	24.9	23.2	23.7	20.6	24.3	*0.21*	
% Total Bolls in Outer Position	4.0	4.9	4.1	2.0	4.3	*0.32*	
% Total Bolls on Monopodia	11.2	13.5	11.9	15.4	14.6	*0.47*	
% Total Bolls on Extra – Axillary	0.4	2.4	0.8	0.6	0.6	*0.32*	
% Boll Retention - 1st Position	42.0	38.9	44.0	38.5	32.7	*0.001*	*4.01*
% Boll Retention - 2nd Position	25.9	23.1	25.1	19.7	21.0	*0.05*	*4.47*
% Early Boll Retention	56.8	56.2	58.9	54.8	50.1	*0.02*	*5.01*
Total Nodes/Plant	18.6	18.7	18.2	18.4	19.6	*0.02*	*0.84*
Internode Length (inches)	1.5	1.6	1.6	1.6	1.6	*0.29*	

[1] means of 10 plants per plot

Irrigation timing significantly affected cotton yield (Table 7, Fig 7). Early initiation of irrigation resulted in higher seed cotton and lint yields compared to either delayed or non-irrigated which were similar. The late start to irrigation initiation resulted in no better yield than not irrigating; natural rainfall was sufficient to produce comparable yields in less time. Despite high late season plant bug numbers in unsprayed treatments and good insecticidal control in sprayed treatments, plant bugs had no effect on yield in 2008 (Table 7). Yields in unsprayed, untreated controls were no different than yield from cotton receiving 2 to 6 applications of insecticide. There were no irrigation*bug interactions. Results of yield component calculations of fibers per seed and fiber density indicate that these values were not affected by treatments. There were no significant treatment effects on lint quality parameters as determined by HVI analysis (Table 8).

Table 7. Means for seed cotton and lint yields along with yield component information for plant bug control and irrigation interaction study, Marianna 2008.

Treatment Timing	**% Lint**	**Weight per Boll (g)**	**Seed cotton per acre (lbs)[1]**	**Lint Yield per acre (lbs)**	**Seed per acre ($* 10^6$)**	**Fibers per seed**	**Fiber density**
Irrigation							

Delayed start	44.4	4.3	2468	1096	6.5	18623	32.6
Early start	43.7	4.3	2980	1301	7.6	18087	31.3
None	46.0	4.6	2435	1123	6.0	18950	31.3
Plant Bug							
0-S-S	44.4	4.3	2620	1162	6.9	18414	32.9
0-S-0	45.2	4.2	2792	1257	7.3	19213	33.1
S-S-S	43.8	4.4	2650	1161	6.9	18156	31.8
S-S-0	45.3	4.6	2708	1222	6.7	18594	31.3
0-0-0	43.5	4.2	2561	1113	6.3	17993	30.0
P>F							
irrigation (I)	*0.44*	*0.65*	*0.01*	*0.05*	*0.02*	*0.51*	*0.67*
spray (S)	*0.20*	*0.15*	*0.73*	*0.27*	*0.67*	*0.22*	*0.06*
*I*S*	*0.91*	*0.84*	*0.93*	*0.98*	*0.89*	*0.16*	*0.56*

[1]Yields calculated from machine harvest made using 2-row JD research picker in 2 center rows of each "trimmed" plot (ca. 40ft). Yield component calculations were based on fiber data from 50 boll samples and calculations based on UA variety testing protocols (Bourland et al 2008a).

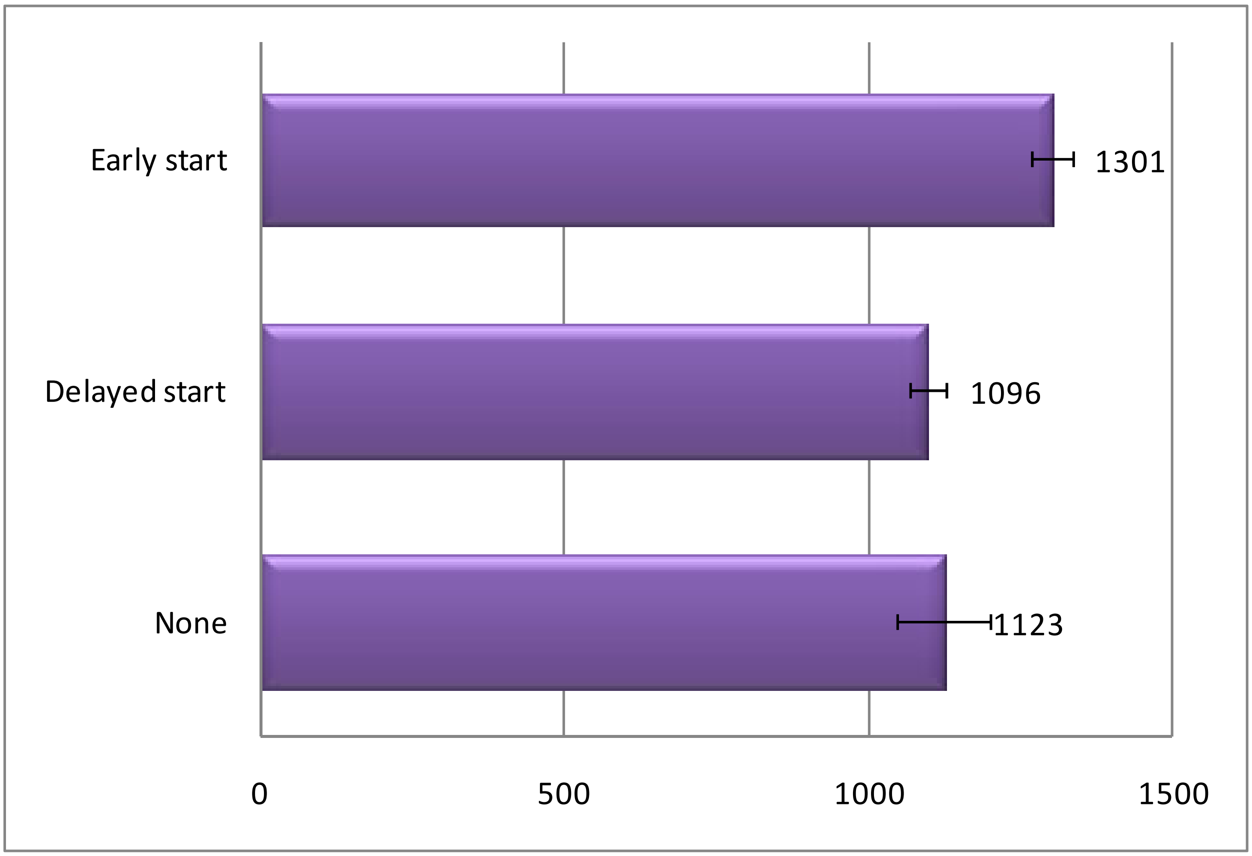

Figure 7. Mean lint yields (±SEM) for irrigation main plot effects ((AOV, *P*=0.05; LSD_{05}=191) for 3 different irrigation timing treatments. There were no significant plant bug or plant bug*irrigation interactions affecting yield.

Table 8. Means for HVI classing data[1] and yield component information from 50 boll hand-picked samples collected in plots from consecutive plants for plant bug * irrigation interaction study, Marianna 2008.

Treatment

Timing	Micronaire	Length	Uniformity	Strength	Elongation	Rd	+b	Leaf
Irrigation								
Delayed start	4.4	1.15	83.2	30.7	8.26	75.8	8.6	1.8
Early start	4.6	1.14	83.7	30.4	8.38	76.2	8.5	1.8
None	4.9	1.13	83.5	30.9	8.21	74.7	8.4	2.3
Plant Bug								
0-S-S	4.4	1.15	83.7	30.7	8.39	76.4	8.4	1.9
0-S-0	4.4	1.14	83.0	30.8	8.32	75.8	8.5	1.8
S-S-S	4.6	1.14	83.3	30.0	8.33	76.0	8.4	1.9
S-S-0	4.8	1.14	83.7	30.9	8.19	75.9	8.7	1.8
0-0-0	4.7	1.14	83.6	30.9	8.25	74.8	8.6	2.1
P>F								
irrigation (I)	*0.20*	*0.06*	*0.39*	*0.28*	*0.57*	*0.27*	*0.73*	*0.25*
spray (S)	*0.14*	*0.64*	*0.19*	*0.13*	*0.34*	*0.09*	*0.17*	*0.89*
*I*S*	*0.64*	*0.58*	*0.60*	*0.37*	*0.15*	*0.57*	*0.25*	*0.06*

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

Discussion

Rainfall patterns and plant bug population dynamics in 2008 at the Marianna site were nearly ideal for a field evaluation of the COTMAN insect control termination rule in plants with different growth patterns resulting from exposure to different irrigation management and water stress. With limited rainfall during the squaring period, there was pre-flower water deficit stress plants in non-irrigated and delayed irrigation initiation treatments. Early cutout was noted in non-irrigated treatments. Crop delay resulted where irrigation was held until first flowers. Bug numbers were low until the time of cutout when there was a late season surge of nymphs. Plant bugs were controlled in sprayed plots, but numbers were up to 10 times higher than the recommended Midsouth action threshold in unsprayed plots. Waiting until first flowers to initiate irrigation resulted in a crop growth pattern late season that was highly attractive to bugs. To the casual observer, it appeared that plant bug infestations after cutout would result in yield loss, but that was not the case. Even with very good chemical control of late season plant bugs, insecticides had no positive effect on yield. There was no benefit to extending sprays after cutout.

Irrigation initiation during early squaring reduced pre-flower water stress compared to delayed initiation or no irrigation; early irrigation increased yield. Crop monitoring allowed measurement of irrigation timing effects and provided a simple way to document crop delay that occurred when irrigation initiation was late. Similar crop response to pre-flower water stress has been noted in previous work in the Midsouth (Andrews et al 2002, Barrentine et al. 2001, Monge et al 2007, Teague et al 2000, 2001, 2005a,b, 2006).

The COTMAN growth curves provide a simple depiction of changes in crop development and maturity through the season. Interpretation of COTMAN growth curves was recently reviewed by Bourland et al (2008b). In the current study, growth curves clearly showed effects of preflower stress as well as late season crop delay. Under good growing conditions, when plants are not subjected to pre-flower stress, the pace of main stem sympodial development and crop growth are not slowed or interrupted until after first flowers. At that point, developing bolls became the dominant physiological sink, and metabolic stress increases as boll filling progresses. Terminal growth continues, but at a reduced pace until the crop reaches cutout at NAWF=5. If, on the other hand, delayed irrigation initiation results in water deficit stress, fewer total sympodia are produced by first flowers. With fewer fruiting forms, there is reduced metabolic stress from boll loading during the effective flowering period. Growth of the plant terminal does not slow as it would if there were greater numbers of developing bolls. Small boll shed also may increase as the plants recover from water stress, further reducing metabolic stress. Terminal growth continues, and cutout is delayed.

Under ideal environmental conditions, some of those additional squares may set bolls, but timing of maturity for those late bolls may not be compatible with modern production systems with once-over, machine harvest. The crop's attempt to compensate for pre-flower stress typically comes too late for a meaningful contribution to yield.

Risks associated with waiting on those upper canopy bolls include delayed and more costly defoliation, reduced harvest efficiency, and variable fiber quality associated with weathering.

Management decisions that result in crop delay ultimately translate into availability of highly attractive squares in late season just in time for highest population densities of bugs. Avoiding this predicament by setting an early crop to avoid late season pests has long been a goal of IPM programs for Arkansas cotton. Proper irrigation timing is critical to managing for high and early yields.

Conclusions

Pre-Flower Irrigation Timing. Producers should time irrigation applications to avoid pre-flower water deficits that can delay the crop and reduce yields. It has been said that COTMAN provides crop advisors the technology to furnish growers real-time data showing that their crop is doing well, even without protective sprays. COTMAN crop monitoring data also can reveal the stresses associated with pre-flower water deficits. With this, advisors and growers can see that the crop is not doing well even with protective sprays. Irrigation should be timed to avoid pre-flower stress to achieve early and high yields.

Insect Control Termination. Despite apparent production of new top crop bolls in late season, extending insecticide applications to protect late growth after cutout did not increase lint yield. There was no lint yield or fiber quality penalty associated with injury by plant bug infestations occurring after cutout. These results support the COTMAN decision guide: terminate insect control for new infestations of plant bug at NAWF=5+250 DD60s.

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