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

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Abstract

In a 2009 field trial in NE Arkansas, effects of early and late season crop injury from tarnished plant bug (*Lygus lineolaris* (Palisot de Beauvois)) were evaluated across 5 different irrigation timing regimes. Irrigation treatments were: (1) early start followed by early termination, (2) early start followed by late termination, (3) late start followed by early termination, (4) late start followed by late termination, and (5) no irrigation. Early start irrigation was initiated pre-flower and late start was initiated at first flowers. Early irrigation termination was at cutout and late termination had two irrigations following cutout. The five different plant bug treatments consisted of bug induced damage during early squaring followed by either early termination timing (before cutout) or COTMAN termination timing (protecting until the final stage of crop susceptibility), plus an untreated check. The experiment was a split plot design arranged in a 5X5 factorial. Because plant bug numbers were low in early season, the field population was supplemented with manual applications of 3rd and 4th instar nymphs at levels of 1 to 2 bugs per plant during the first week of squaring.

Despite historically high levels of rainfall in the 2009 production season, there was a 2.5 week period in June with hot, dry weather where symptoms of water deficit stress was observed in treatments with delayed initiation or no irrigation. Early initiated treatments received 3 weekly irrigations prior to first flowers. In the pre-flower plant bug treatments, feeding injury from manual infestations resulted in square shed at levels of 20 to 25% (1st position main stem sympodia) measured the week of first flowers. In untreated or sprayed plots, less than 5% shed was observed. Just after the time of cutout, another hot, dry period was observed, and late irrigation treatments received 2 applications of water. At the same time, field population numbers of plant bugs increased, and they were either held below action thresholds with insecticide sprays, or they were allowed to feed.

Lint yield was significantly higher with an early irrigation start (1554 lb/ac) compared to no irrigation (1237 lb/ac) or delayed irrigation (1082 lb/ac).. The post-cutout irrigations increased the crop mean maturity date by 4 days. Plant bug related reductions in yield were observed under all irrigation regimes. Pre-flower manually applied bugs significantly reduced lint yield (1126 lb/ac) compared to treatments receiving season long insecticide applications (1599 lb/ac). With the late date of planting, time dependent compensation for early season square sheds was not achieved. Significant yield reductions (ca. 14%) were observed where the at-cutout infestation of plant bugs was not controlled. There were no significant irrigation*bug interactions.

Introduction

Insect control termination recommendations in Arkansas are based upon long standing and on-going COTMAN research conducted by University of Arkansas Division of Agriculture scientists. Work continues to address the 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, producers and their crop advisors can answer with confidence (Danforth and O'Leary 1998, Oosterhuis and Bourland, 2008). For each field or management zone, decision makers must first determine the flowering date of the last effective boll population, that last cohort of flowers that produce bolls that contribute to economic yield. This is called cutout. If a field reaches physiological cutout (average number of nodes above white flower=5 (NAWF=5)) (Bourland et al 1992) in late July or early August in Arkansas, then heat units (DD60s) are accumulated from the NAWF=5 date. Otherwise, DD60s are accumulated from a seasonal cutout date based on historical weather for that production region. Typically a boll needs 850 DD60s to mature with acceptable size and quality. The weather-restricted, seasonal cutout date is the calendar date on which there is a 50% probability that the crop will have the benefit of late season temperatures sufficient to develop a mature boll. Seasonal cutout dates range across the state from late July in the northernmost parts of the Midsouth out to late

August in the most southern areas. When that last effective boll population has accumulated 350 DD60s the crop has been shown to be safe from new infestations of the most significant boll feeding insect pests in Midsouth history: boll weevil, tobacco budworm and bollworm. The protection endpoint also has been validated for tarnished plant bug. In 2008, it was recommended in Arkansas that the endpoint should be cutout + 250 DD60s.

What about special cases? Uncertainty in late-season decision making can arise if NAWF values "hover" at 5 or dip below 5 earlier than expected. Crop advisors have questioned whether to extend the season for protection if there is renewed terminal growth around the time of cutout. Perhaps seasonal guides should be employed? This late-season decision making dilemma typically occurs after a period of pre-flower water deficit stress is followed by mid-season rains or late initiation of irrigation. Delays in physiological cutout also occur following pre-flower pest insect infestations such as those that result in excessive square shed. One consequence of crop delay is continued production of highly attractive squares in late season just in time for highest population densities of plant bugs. If there is time for late season crop recovery (time dependent compensation), should money be spent on providing protection from tarnished plant bugs for this "top crop" or should the cutout + 250 DD60s guide be followed? On the other hand, if low temperatures delay boll maturation, should control termination be made prior to 250 DD60s?

The aim of this Cotton Incorporated Arkansas State Support Committee sponsored study was to determine if the COTMAN guides should be revised to take into account crop growth anomalies following stress. Field trials in 2009 were established in both Lee County and in Mississippi County. Only Mississippi County results are summarized here.

Materials and Methods

The experiment was conducted in a commercial cotton field at Wildy Farms located in Northeast Arkansas near Leachville. The growing season is May through October, and the latest possible cutout date (that date with a 50% or 85% probability of attaining 850 DD60s from cutout) for this production area is 11 or 3 Aug, respectively (Zhang et al. 1994 and Danforth and O'Leary 1998). The cultivar Stoneville ST 5458 B2RF was planted 18 May 2009. Plant population density was ca. 3 to 4 plants/ft of row. Row spacing was 38 inches. The grower's practices for fertility, weed control, plant growth regulator application and defoliation were followed through the season; only irrigation and insecticide inputs were varied for the study. The sandy soil was a Routon-Dundee-Crevasse Complex.

Two factors were evaluated: irrigation timing (5 levels) and timing of plant bug induced injury (5 levels). The 5*5 split-plot factorial experiment was arranged in a randomized complete block design. There were 3 replications. Bug induced crop injury treatments were considered subplots within irrigation main plots. Irrigation treatments were: 1) early initiation followed by early termination (Early-Early), 2) early initiation followed by late termination (Early-Late), 3) late initiation and early termination (Late-Early), 4) late initiation and late termination (Late-Late) and 5) no supplemental irrigation (None). Timing details are listed in Table 1.

Table 1. Designations and timing (days after planting) of different irrigation and plant bug insecticide spray treatments at Wildy Farms, 2009, Leachville, AR.

Treatment Designation	Treatment timing (Days after planting)		
	Pre-flower	**Mid-season**	**Post-cutout**
Irrigation Timing[1]			
Early-Early	24 June, 1, 9 July (37, 44, 52)	Rains	None
Early-Late	24 June, 1, 9 July (37, 44, 52)	Rains	18, 29 Aug (92,103)
Late-Early	None	Rains	None
Late-Late	None	Rains	18, 29 Aug (92,103)
None	None	Rains	None
Bugs and Sprays[2]			
B-S-S	Bugs 19, 23 June (32, 36)	16 July (60)	Spray 12, 25 Aug (86, 99)
B-S-0	Bugs 19, 23 June (32, 36)	16 July (60)	None
S-S-S	Spray 6 July (49)	16 July (60)	Spray 12, 25 Aug (86, 99)
S-S-0	Spray 6 July (49)	16 July (60)	None
0-S-0	None	16 July (60)	None

[1]Early and late initiation was followed by either early or late termination timing. Furrow irrigation was not necessary in mid-season because of rains.
[2]Plant bug nymphs were released at levels of 1 to 3 bugs per plant at 32 and 36 DAP in bug ("B") designated treatments; plots received insecticide sprays ("S") or were untreated ("0"). The native, field population densities of bugs increased in mid Aug; they were allowed to feed ("0") or were controlled with insecticides ("S"). The mid-season spray was made across the entire experimental area.

The five levels of plant bug induced injury were accomplished by manipulating plant bug numbers by manually releasing bugs, ("B"), leaving plots untreated ("0") or applying insecticide sprays ("S"). All subplots received an insecticide spray at first flowers. Plant bug treatments were: 1) Plant bugs early (manually applied pre-flower) and plant bugs late (native population) (B-S-0); 2) Plant bugs early followed by late season insecticide sprays (B-S-S); 3) early sprays followed by late sprays (S-S-S); 4) early spray but no late spray (S-S-0); 5) no bugs or sprays applied early and no sprays late (0-S-0). Timing details and product selection are listed in Tables 1, 2. Plots were 75 ft long, 8 rows wide with 4 row buffers. Fifteen ft alleys separated plots. Using the grower's standard practices, furrow irrigation was applied to alternating row middles in appropriate treatment strips.

Table 2. Application timing and products for insecticide sprays in insect treatment sub-plots – Wildy Farms, 2009.

Application date[1]	Days after planting	Product (rate/acre)	Plant bug treatment
6-July	49	Centric (1.5 oz/ac)	S-S-S, S-S-0
16-July	60	Centric (1.5 oz/ac)	S-S-S, S-S-0, B-S-S, B-S-0, 0-S-0
11-Aug	83	Diamond (10 oz/ac)	S-S-S, B-S-S
19-Aug	91	Bidrin 8 (6 oz/ac)	S-S-S, B-S-S

[1] A back pack sprayer with 4-row hand held boom was used for the 6 and 14 July applications. The 16 July application was made by the cooperating producer. Late season sprays (11 and 19 Aug) were made with a high clearance tractor mounted sprayer with 8 row boom.

In the center portion of each plot, a 15 ft section on 2 adjacent rows was selected for all plant sampling, yield assessments and, where appropriate, for pre-flower plant bug releases to supplement native populations. Plant bug nymphs were released in the first week of squaring (Table 1). Third and fourth instar plant bug nymphs were applied at 1 to 3 bugs per plant. Confetti-sized strips of shredded white copy paper (0.5 cm wide and 10 to 20 cm long) on which the nymphs were resting were laid across the terminal leaves of plants to be infested. The paper strips lined the rearing containers, and the nymphs clinging to these ribbons crawled onto the plants. Bugs were released during the cool period of the morning just after dew had dried. Nymphs had been collected from weedy field borders near cotton fields in neighboring Craighead County 3 to 7 days prior to release. They had been held in the laboratory and provided ears of sweet corn for food.

Native plant bug field population numbers were monitored using drop cloth sampling in treatment plots outside the 2 row plant sampling area. Variation in average number of collected nymphs and adults per drop was analyzed using AOV separately for each date.

Plant monitoring with COTMAN was carried out weekly from the early squaring period through cutout. Two sets of five consecutive plants were monitored weekly using the standard Squaremap sampling procedure. This includes measurement of plant height, number of main stem sympodia, and presence or absence of first position squares and bolls. Care was taken to minimize handling sampled plants. In September, Squaremap sampling was modified to make only counts of squaring nodes on 10 consecutive plants.

On the seasonal cutout date of 11 Aug, (the date at which there is a 50% probability of accumulating 850 DD60s based on historical weather), cutout identification tags were placed on 10 consecutive plants within one row of the plant sample area. The plastic tags were hung at the uppermost main stem sympodial node that had produced a flower, therefore separating nodes with squares from nodes with bolls. Defoliant was applied 8 October, which was 602 DD60s after seasonal cutout. Final plant mapping was performed 10-12 October using COTMAP protocol (Bourland and Watson 1990). The ten plants with terminal tags were used for COTMAP sampling. Plants 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. Numbers of nodes above and below the cutout tag also were recorded. Total numbers of bolls per plant displaying boll rot symptoms including “dry lock” also were recorded.

Rains and cool weather delayed harvest in production fields across the region; harvest of the commercial field surrounding this experiment was made 20 October. For the experiment, weekly hand harvests in a single row, 10 ft long, in each plot sample area were made from appearance of first open bolls. Seven weeks of harvests were made, starting 7 September and extending through 20 October. Cumulative seedcotton yield was determined. These data also were used to calculate mean maturity date (Richmond and Ray 1966). Hand harvest of plants with cutout tags were on 21 October and 3 November. Bolls were picked above and below the cutout tag to determine percent of seed cotton produced from bolls that had flowered after 11 August. An additional seedcotton sample was made on 26 October for fiber quality assessments. Fifty consecutive bolls, hand-picked from adjacent whole plants in the plot sample row, were collected, 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). In addition to handpicked samples, rows 8 and 9 of each plot were machine harvested 3 November to obtain “grab” samples from each plot for fiber evaluations. Fiber quality assessments were made from these collections as well. All plant monitoring and yield and quality data were analyzed using AOV with mean separation using LSD.

Results

The wet spring in 2009 resulted in a delayed date of planting. June temperatures and rainfall were more normal and were conducive for water deficit stress, but July and early August were cool, cloudy and wet. The season closed with an early fall and more rain and cool temperatures. Comparisons of 2009 temperatures and rainfall accumulations to a 47 year average for the region indicate in June through October there were 442 fewer heat units and 15 inches of more rainfall (Table 3).

Table 3. Average monthly heat unit (DD60s) and precipitation accumulation, 1960-2007 for Northeast Arkansas[1] compared to 2009 on-farm measurements at Wildy Farms.

	Heat Units (DD60s)		Rain (inches)		2009 Deviation from Average	
Month	Average	2009	Average	2009	Heat Units	Rainfall
June	532	546	3.89	3.00	+14	-0.89
July	644	474	3.67	12.75	- 170	9.08
August	583	437	2.85	3.46	- 146	0.61
September	363	322	3.73	2.64	- 41	-1.09
October	127	28	3.30	10.10	- 99	6.80
				Total	- 442	15.00

[1]Source: NOAA National Climatic Data Center, daily surface data for Keiser, AR

COTMAN crop monitoring measures indicate initiation and development of squaring nodes was early relative to the days after planting, when compared to standard target development curve (Figs 1, 2). Plant bug treatments had no measured effect on squaring node development, and there were no bug*irrigation interactions in weekly measures of mean squaring nodes (Fig 1).

For irrigation main effects (Fig 2), significantly fewer total main-stem sympodia were observed at first flowers (57 days after planting (DAP)) on late-initiated and non-irrigated treatments compared to the early irrigated treatment (P=0.001, LSD=0.71). Mean no. of squaring nodes for the early irrigation was 8.0 compared to the COTMAN standard of 9.25 squaring nodes, but mean squaring nodes were 6.7 and 6.6 for late start and for non-irrigated treatments, respectively. For the COTMAN target development curve, the standard pre-flower pace of main stem sympodial development to achieve 9.25 squaring nodes by 60 DAP is approximately 0.37 nodes per day. For plants receiving early irrigation, pace of nodal development was 0.25 nodes per day compared to just 0.19 nodes per day for delayed and non-irrigated plants. Pre-flower water deficits were relieved with July rains. The expected steep decline in slope of the growth curves after flowers was not observed with plants that had been exposed to pre-flower stress. Because squaring node production did not subside (values “hovered” around 5), seasonal cutout rules were adopted for late season decision making. With cutout designation shifted to the latest possible cutout date (LPCD), calculations of heat unit accumulations for end-of-season management were delayed by 12 days compared to designating mean date of physiological cutout (Table 4).

Table 4. Termination timing for final plant bug insecticide applications and irrigation in relation to designation of cutout (flowering date of last effective boll population) – either from date of physiological cutout (NAWF=5) or from the seasonal cutout date.

Insecticide / Irrigation Treatment Timing	**Application Date**	**Accumulated DD60s from the cutout dates**		
		NAWF=5[1] 31-July	**LPCD[2] (85%) 2-Aug**	**LPCD (50%) 11-Aug**
Insecticide				
Diamond	12-Aug	193	166	15
Bidrin	25-Aug	383	356	205
Irrigation				
Irrigation	18-Aug	295	268	117
Irrigation	29-Aug	426	399	247

[1]Overall mean date for physiological cutout for all plots.
[2]Latest possible cutout date is date of seasonal cutout; it is calculated based on historical weather and is the calendar date for that site at which there is a 85% or 50% probability of attaining 850 DD60s.

COTMAN sampling typically is suspended just after cutout (as in Fig 2); however, in this study, squaring node counts were continued into late August and September in order to document how early season water deficits affected late season terminal growth. Plant response to irrigation and rainfall was evident when growth curves for irrigation main plot treatments were overlaid graphically with rainfall accumulations for the research site (Fig 3). On each of the final three sampling dates, significantly more sympodial nodes were observed in the delayed irrigation and non-irrigated treatments compared to plants that received irrigation early and were not exposed to pre-flower water deficit stress.

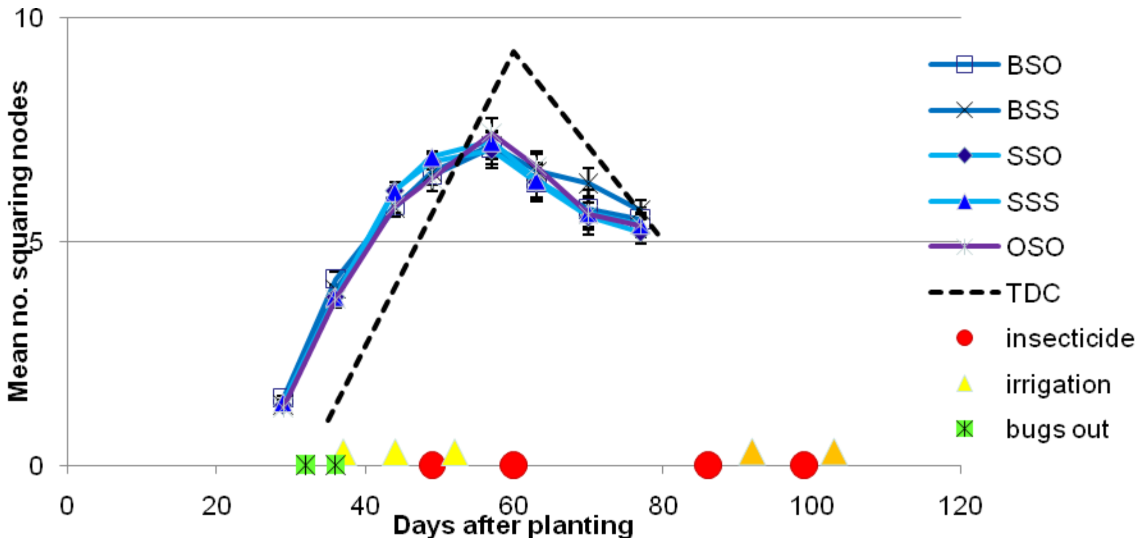

Figure 1. The COTMAN target development curve (TDC), shown as mean no. of squaring nodes (±SEM), can be used as a standard to compare the actual growth curves of plants in plant bug/insecticide timing subplots in the 2009 Wildy Farms trial. Dates for plant bug releases, insecticide sprays and irrigation are indicated by squares, circles, and triangles on the x-axis.

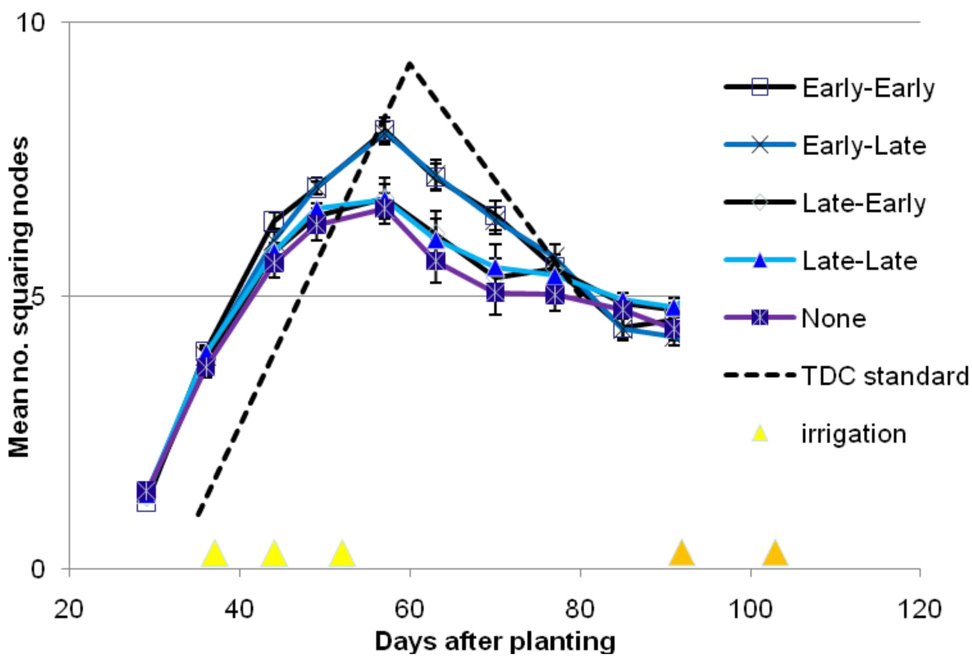

Figure 2. Mean no. of squaring nodes (±SEM) of plants in irrigation timing main plots in the 2009 Wildy Farms trial. Irrigation dates are indicated by yellow triangles on the x-axis for early (37, 44, 52 DAP) and late (92 and 103 DAP) irrigation.

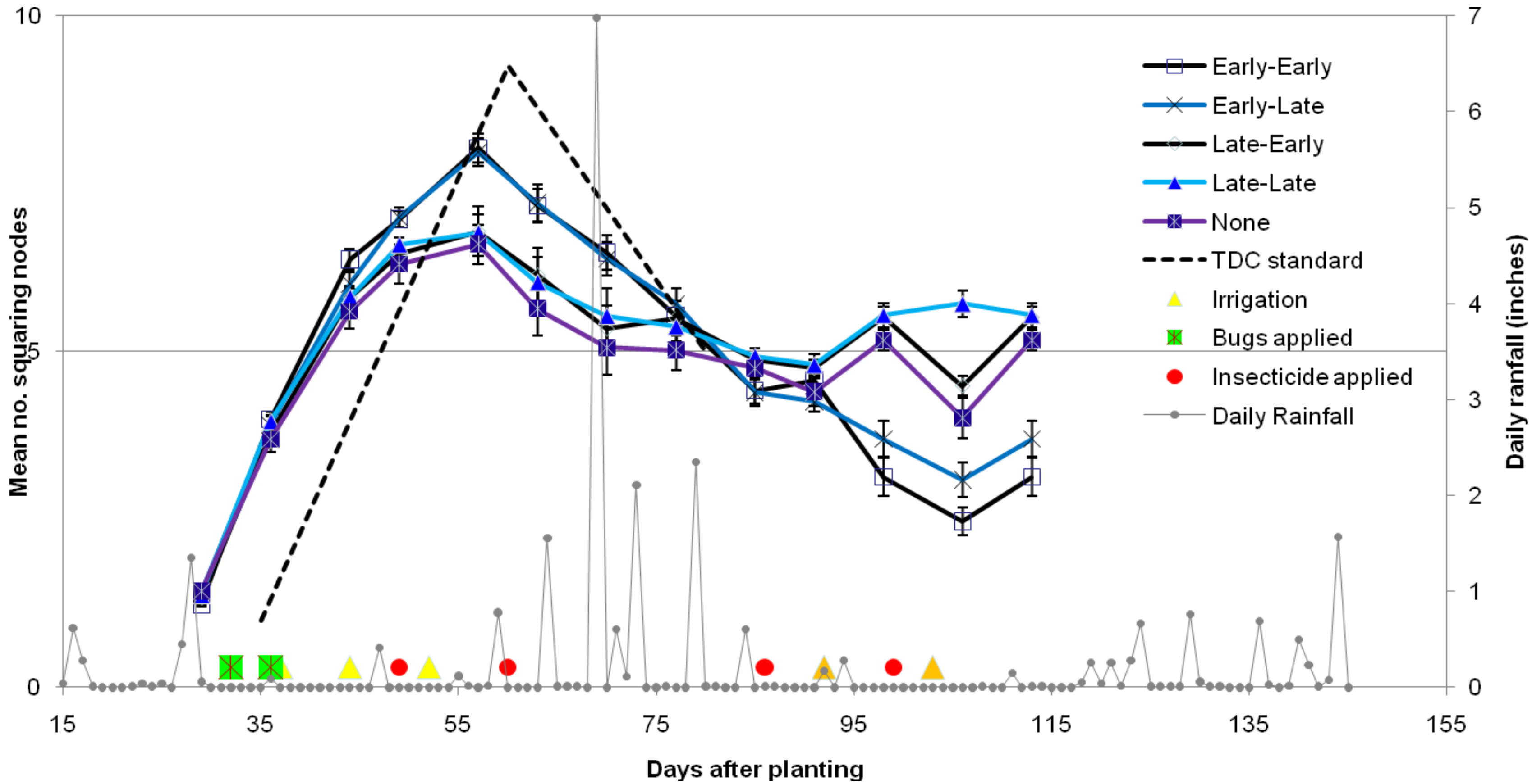

Figure 3. COTMAN growth curves for irrigation main effects are shown along with daily rainfall accumulations for 2009. Squaring node counts (no. of main stem sympodia that have not yet flowered) were continued for several weeks after cutout to measure differences in late season of terminal growth among irrigation regimes.

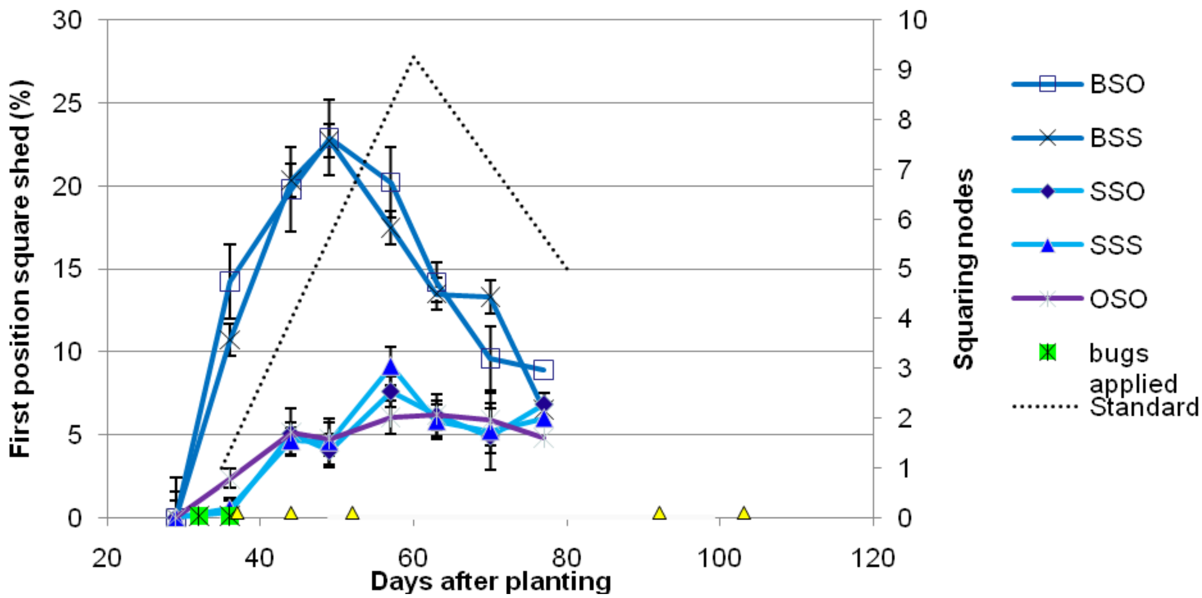

Figure 4. Mean % shed of 1st position squares (±SEM) for the five plant bug sub-plot effects. The COTMAN standard curve is also shown to provide reference for the crop seasonal development..

Where plant bug nymphs were released, significant increases in square shed were observed compared to sprayed and untreated plants in the three sample dates following release of nymphs and extending through 60 DAP (Fig 4) (P=05). Plant bug pre-flower feeding injury from manual infestations resulted in square shed at levels of 20 to 25% (1st position main stem sympodia) measured the week of first flowers. In untreated or sprayed plots, less than 5% shed was observed. No significant bug*irrigation interactions for square shed measures were observed from early squaring until physiological cutout.

Tarnished plant bug field population numbers were moderately low through most of the early season (Fig 5). Action levels for plant bugs were exceeded at first flowers in the commercial field surrounding the study (3 bugs/drop cloth sample), and the entire field received an insecticide application. Numbers increased again at the time of cutout, creating good conditions for validating the COTMAN insect control termination decision guide. At 85 DAP; mean no. nymphs per drop cloth sample ranged from 0 to 3.2 bugs. By 91 DAP, bug numbers ranged from 1 to 6, and by 105 DAP, bug numbers ranged from 0.9 to10 bugs/drop. Through this period, numbers were maintained at sub-threshold levels in sprayed plots. Plant bug numbers were not significantly affected by irrigation timing in 2009.

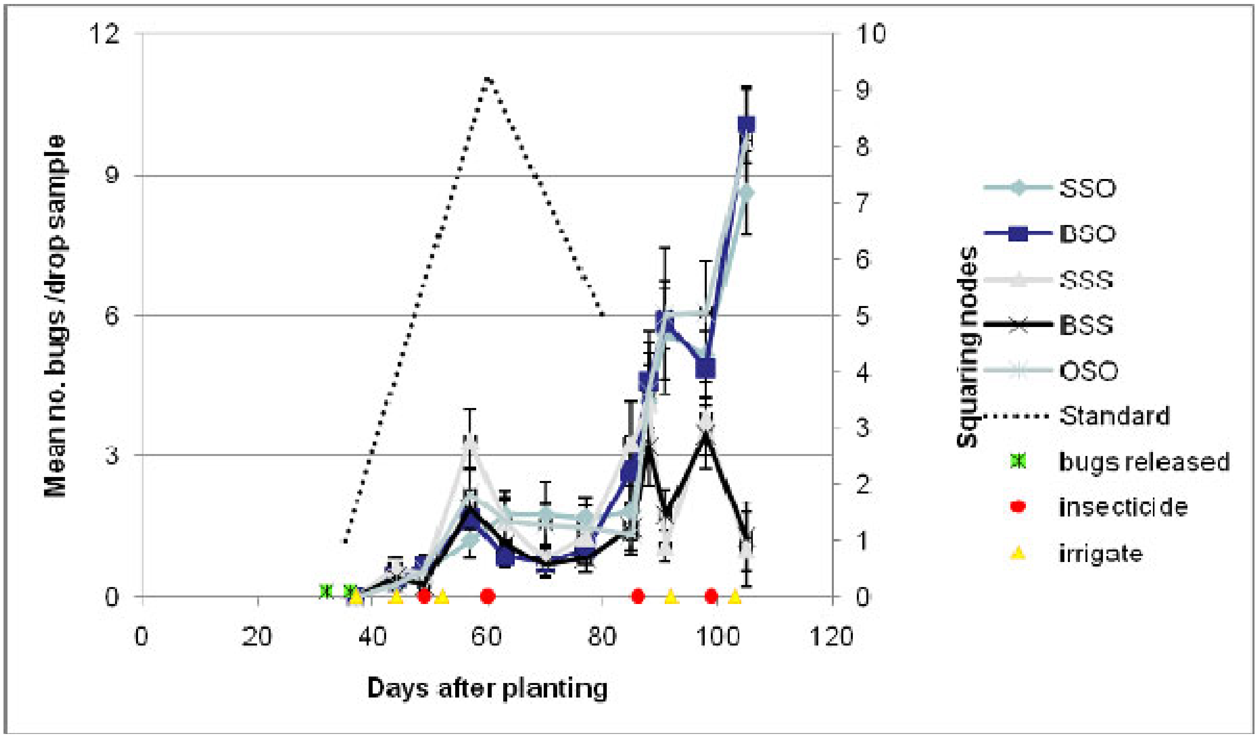

Figure 5. Mean no. tarnished plant bug adults and nymphs (±SEM) observed per drop cloth sampled by beating plants over a 2.5 ft black cloth positioned in rows outside the plant sample/bug release rows. Insecticide applications were effective in reducing numbers to sub-threshold levels in late season sprayed treatments.

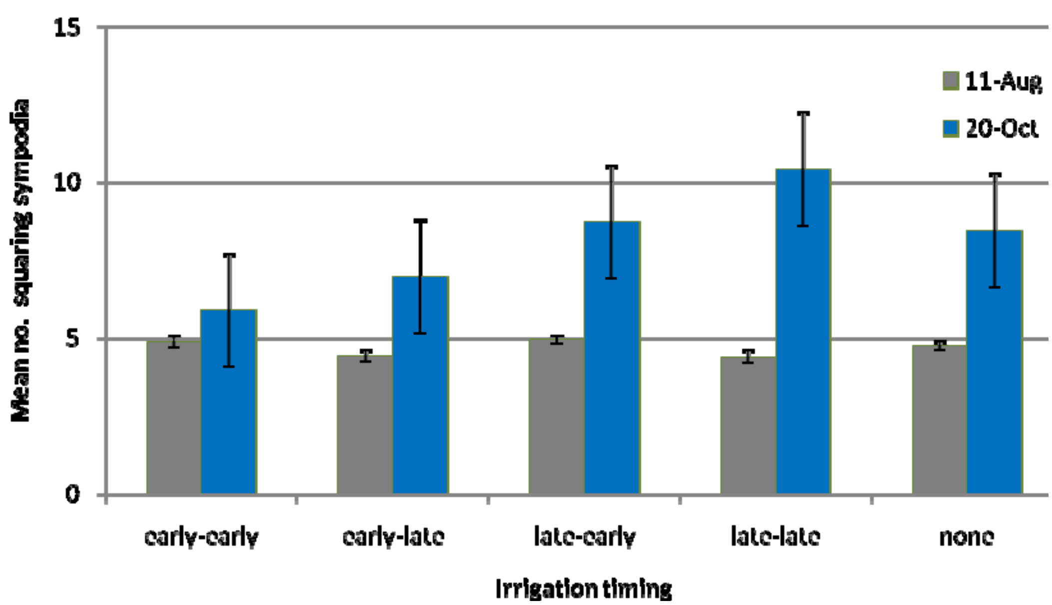

Figure 6. Mean no. of sympodial nodes above the cutout tag on 11 August (±SEM) and on 20 October (± LSD_{05}).

Results from cutout tag assessments (Fig 6) indicate significant effects of irrigation on number of main-stem sympodial nodes produced after cutout. Plants in late-late irrigation treatments had significantly higher numbers of main stem sympodial nodes above the cutout tag compared to the early-early and non-irrigated treatments (AOV; P=0.01).

Significant irrigation effects as well as plant bug treatment effects on final plant structure were measured in final, end-of-season plant mapping using COTMAP (Tables 5, 6). Late initiation and late termination resulted in greater production of sympodia and fewer sympodia with first position bolls. Early irrigation resulted in significantly higher retention of 1st position bolls (Table 5). For plant bug effects measured using COTMAP, higher mean numbers of monopodia per plant were observed where plant bugs were released during the early squaring period. First position boll retention was reduced with bug feeding early and late. Percent early boll retention was lowest where bugs were released and field populations were not controlled at cutout (Table 6). Plant bug treatments had no effect on counts of bolls with hard lock or boll rot.

Plant bug effects resulted in significant reductions in yield in 2009 under all irrigation regimes (Fig 7). There were no irrigation*bug interactions. Feeding injury from the pre-flower manually applied bugs significantly reduced lint yield compared to non-infested treatments. Significant yield reductions also were observed where the at-cutout infestation of field population of plant bugs was not controlled. Highest yield was observed where the bugs were not introduced pre-flower, and where the late season infestation was controlled using insecticides. The cutout infestation occurred prior to the final stage of susceptibility, the COTMAN insect control termination endpoint of cutout +250 DD60s.

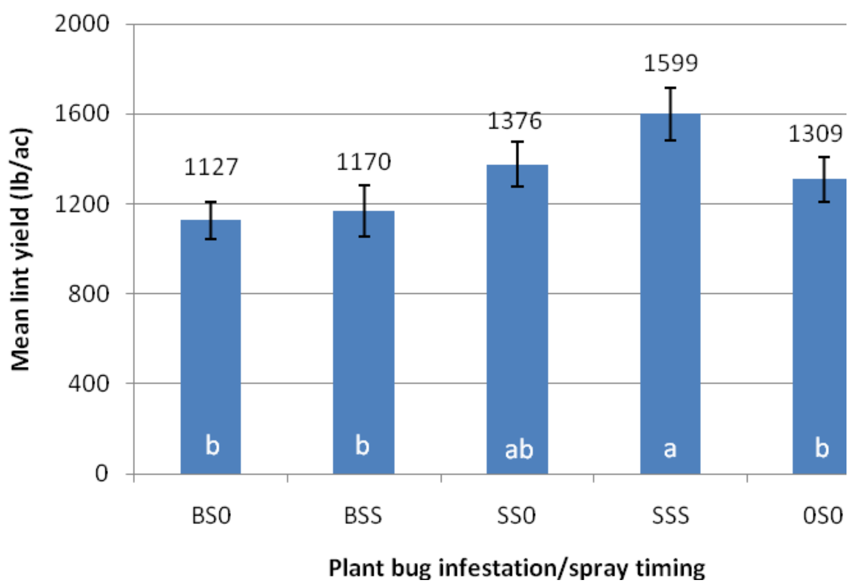

Figure 7. Mean lint (±SEM) for 5 different plant bug infestation and insecticide timing subplot effects ((AOV, *P*=0.01; LSD_{05}= 270).

Table 5. Results from final end-of-season plant mapping using COTMAP for irrigation timing treatment main plot effects – 2009 Leachville[1].

Category	Mean per plant for irrigation treatment					*P>F*	*LSD_{05}*
	Early – Early	Early – Late	Late - Early	Late - Late	None		
1st Sympodial Node	7.3	7.2	7.1	7.1	7.8	*0.48*	
No. Monopodia	2.0	1.9	2.0	1.7	2.1	*0.53*	
Highest Sympodia with 2 nodes	11.7	12.7	12.6	14.6	11.9	*0.09*	
Plant Height (inches)	36.0	36.5	36.3	38.6	34.2	*0.70*	
No. Effective Sympodia	9.3	10.2	9.1	10.5	8.6	*0.10*	
No. Sympodia	15.0	15.9	16.4	18.4	15.8	*0.05*	*1.92*
No. Sympodia with 1st Position Bolls	4.6	5.3	4.3	4.7	4.0	*0.05*	*0.82*
No. Sympodia with 2nd Position Bolls	0.9	1.1	1.1	1.0	0.9	*0.31*	
No. Sympodia with 1st & 2nd Bolls	1.1	1.1	1.0	1.1	1.2	*0.72*	
Total Bolls/Plant	9.2	10.1	8.8	9.3	8.7	*0.19*	
% Total Bolls in 1st Position	63.3	63.9	61.1	62.1	62.9	*0.68*	
% Total Bolls in 2nd Position	21.9	21.1	23.8	22.8	22.5	*0.17*	
% Total Bolls in Outer Position	4.6	3.6	5.1	5.9	5.3	*0.67*	
% Total Bolls on Monopodia	10.1	11.1	10.0	9.2	10.3	*0.95*	
% Total Bolls on Extra – Axillary	0.1	0.3	0.1	0.1	0.1	*0.50*	
% Boll Retention - 1st Position	38.8	40.5	32.6	32.1	32.9	*0.02*	*5.44*
% Boll Retention - 2nd Position	17.4	16.8	16.8	14.5	17.0	*0.18*	
% Early Boll Retention	40.3	43.3	39.8	39.4	40.8	*0.56*	
Total Nodes/Plant	21.2	22.1	22.5	24.2	22.6	*0.21*	
Internode Length (inches)	1.7	1.7	1.6	1.6	1.5	*0.37*	

[1] means of 10 plants per plot

Table 6. Results from final end-of-season plant mapping using COTMAP for plant bug treatment sub-plot effects – 2009 Leachville[1].

Category	Mean per plant for insecticide treatment					*P>F*	*LSD_{05}*
	B-S-S	B-S-O	S-S-S	S-S-0	0-S-0		
1st Sympodial Node	7.2	7.2	7.3	7.2	7.6	*0.75*	
No. Monopodia	2.1	2.0	1.8	2.0	1.8	*0.02*	*0.2*
Highest Sympodia with 2 nodes	13.0	13.3	12.5	12.7	12.2	*0.40*	
Plant Height (inches)	36.5	37.3	35.8	38.0	33.9	*0.51*	
No. Effective Sympodia	10.2	9.8	9.9	9.0	9.0	*0.23*	
No. Sympodia	16.4	16.8	15.9	16.3	15.6	*0.30*	
No. Sympodia with 1st Position Bolls	4.6	4.0	5.0	4.6	4.7	*0.01*	*0.5*
No. Sympodia with 2nd Position Bolls	1.2	1.2	1.0	0.8	0.9	*0.27*	
No. Sympodia with 1st & 2nd Bolls	1.0	0.8	1.5	1.1	1.2	*0.01*	*0.4*
Total Bolls/Plant	9.7	8.4	10.2	8.8	9.1	*0.09*	
% Total Bolls in 1st Position	58.9	58.2	64.5	66.0	65.6	*0.10*	
% Total Bolls in 2nd Position	21.5	22.2	24.2	22.0	22.2	*0.81*	
% Total Bolls in Outer Position	6.1	6.4	4.7	3.4	3.8	*0.07*	
% Total Bolls on Monopodia	13.3	13.1	7.5	8.5	8.4	*0.01*	*4.1*
% Total Bolls on Extra – Axillary	0.2	0.1	0.2	0.1	0.0	*0.64*	
% Boll Retention - 1st Position	34.3	28.1	40.8	35.5	38.0	*0.001*	*3.8*
% Boll Retention - 2nd Position	16.1	14.3	20.0	15.4	16.7	*0.08*	
% Early Boll Retention	34.2	28.9	48.1	45.9	46.5	*0.001*	*5.7*
Total Nodes/Plant	22.6	23.1	22.2	22.5	22.2	*0.82*	
Internode Length (inches)	1.6	1.6	1.6	1.7	1.6	*0.66*	

[1] means of 10 plants per plot

Irrigation timing significantly affected cotton yield (Fig 8). Early irrigation initiation resulted in a 20 to 30% increase compared to non-irrigated or delayed start. Late irrigation initiation resulted in no better yield than not irrigating. Providing 2 extra weeks of irrigation after cutout did not compensate for the early water deficit stress. The post cutout irrigations also resulted in crop delay increasing crop mean maturity date by 4 days (Fig 9).

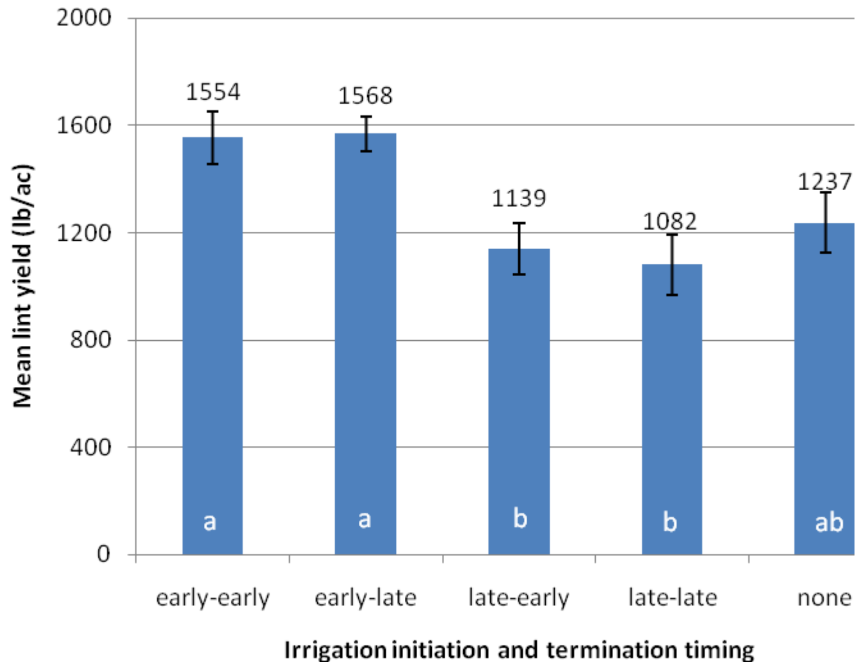

Figure 8. Mean lint (±SEM) for irrigation main plot effects ((AOV, P=0.02; LSD_{05}= 342) for 5 different irrigation timing treatments. There were no significant irrigation*bug interactions.

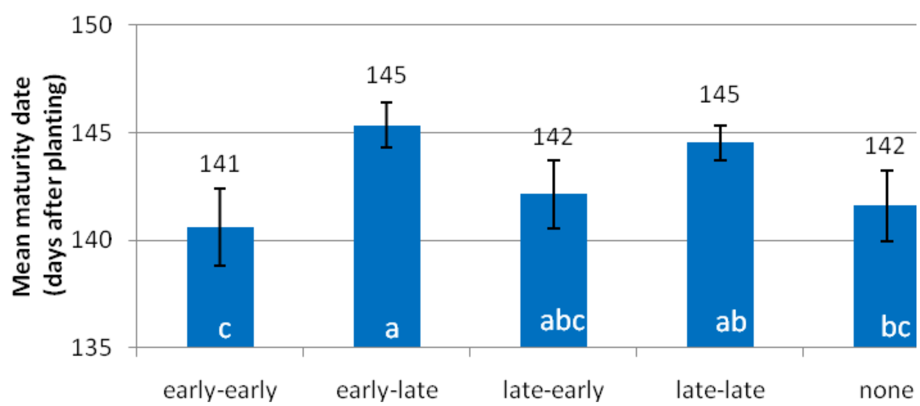

Figure 9. Mean maturity date (days after planting) for irrigation main plot effects based on 7 weeks of hand harvests (AOV, P=0.01).

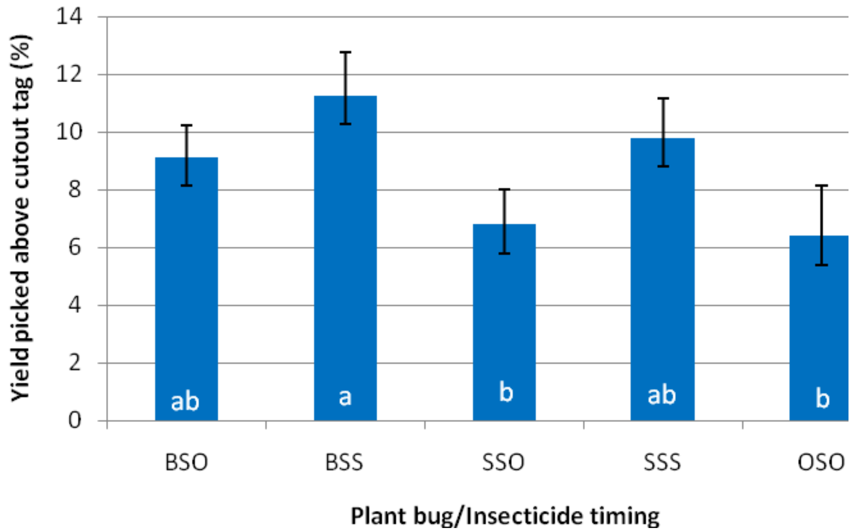

Figure 10. Seedcotton produced above the cutout tag - mean percent of yield associated with bolls harvested above the cutout tag for plant bug/insecticide timing subplots. Yield data from 10 tagged plants that were hand harvested on 21 October were analyzed using actual weights (AOV, P=0.05); percent of seed cotton weights are shown.

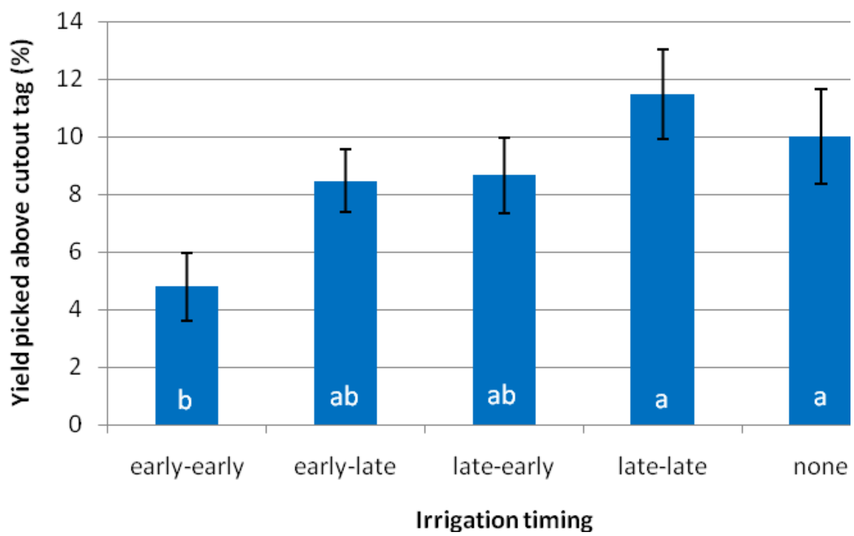

Figure 11. Seedcotton produced above the cutout tag was significantly affected by irrigation timing. Yield data from 10 tagged plants that were hand harvested on 21 October were analyzed using actual weights (AOV, P=0.01); percent of seedcotton weights produced above the tag are shown. There was no significant bug*irrigation interaction.

Harvestable bolls were produced on the upper main stem sympodia after the latest possible cutout date. Harvest data from plants with cutout tags indicate yield of upper canopy bolls above the cutout tag was significantly affected by both irrigation and plant bug/insecticide timing (Fig 10, 11). Late season sprays protected upper canopy bolls. Greater production of upper canopy bolls was observed where bugs reduced pre-flower square retention. Compensation is evident in these treatment effects with 8 to 10% of total yield associated with upper bolls (Fig 10). For irrigation main effects, upper canopy yields were highest following pre-flower stress and with late season irrigations (Fig 11).

Fiber quality and yield component analysis of samples is not yet complete.

Discussion

In this second year of a planned 3 year study, yields were significantly higher with an early irrigation start compared to delayed start or no irrigation. Providing extra weeks of irrigation after cutout did not compensate for the early water deficit stress. With late date of planting, compensation capacity of the crop to recover from early season manually applied bugs was not sufficient, and yields were reduced. Failure to protect late season bolls past the COTMAN endpoint cutout + 250 DD60s - the final stage of crop susceptibility - resulted in significant yield loss.

Multiple hand harvests were used in this experiment with final harvest extended until late October to allow for late season boll maturation of upper canopy bolls. Even with the delay, many of the immature upper canopy fruiting forms never opened. After application of defoliants, immature fruiting forms were shed, leaving empty positions and stripped terminals. These stripped terminals have the appearance of “buggy whips”. This was particularly apparent where pre-flower water stressed plants received late season irrigation (late-late). Under ideal environmental conditions, some of those additional squares set bolls, but timing of maturity for those late bolls typically is not compatible with modern production systems with once-over, machine harvest. Those late bolls are typically too late for a meaningful contribution to yield. Similar crop response to pre-flower water stress has been noted in previous work (Monge et al 2007, Teague et al 2000, 2001, 2005a,b, 2006)., and similar findings were observed in the first year of this study in 2008 in work in Lee County (Teague and Danforth 2009).

Figure 12. Results of pre-flower water deficit stress were still apparent in mid-October one week after application of harvest aid defoliate.

Failure of the crop to enter a definitive physiological cutout, when NAWF values “hover” at 5, leads to greater uncertainty in late season decision making. Production 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. Expensive insecticides are then required. Additional and sometimes unnecessary inputs of irrigation and fertilizer also can result as managers try to coax their crop into recovering from early stress. This drives up production costs even further. Other increased risks include delayed and more costly defoliation, reduced harvest efficiency, and variable fiber quality associated with weathering of the important lower canopy bolls. Simply put, costs rise but yields don’t. Avoiding this predicament by setting an early crop to avoid late season risks has long been a goal of IPM programs for Arkansas cotton. Proper irrigation timing is critical to managing for high and early yields and avoiding unnecessary production costs.

Conclusions

Producers should time irrigation applications to avoid pre-flower water deficits that can delay the crop and reduce yields. Late season, post cutout irrigation may not contribute to yield and can delay maturity. COTMAN growth curves are useful in monitoring effects on pre-flower crop development pace as well as late season crop maturity following pre-flower water deficits. Growth curves aid in interpreting causes of late season crop growth.

The COTMAN insect control termination guide is helpful in timing appropriate late season insecticide applications for crop protection. Producers save money by avoiding unnecessary applications, but they also protect yield by knowing when the crop remains susceptible and making necessary sprays to protect still vulnerable bolls. The cutout + 250 DD60 endpoint for boll protection appears valid for plant bug control termination. Adjustments in defining the cutout date - when to start heat unit accumulation - may be required when a crop has suffered pre-flower stress. If the crop exhibits indeterminate physiological cutout, seasonal cutout guides should be employed, and heat unit accumulations started at that date.

Acknowledgements

This project was supported with funding from Cotton Incorporated through the Arkansas State Support Committee. We appreciate their continued support for refinement and validation of COTMAN. We extend our thanks to David and Justin Wildy and the excellent staff at Wildy Farms for their assistance and cooperation. Special thanks to UA Program Technician, Kamella Neeley, and student workers, Katie Olive, Michelle Johnson, and Rachel Henderson for their assistance.

References

Bourland, F.M., and C.E. Watson, Jr. 1990. COTMAP, a technique evaluating structure and yield of cotton. Crop Sci. 39:224-226.

Bourland, F.M., D.M. Oosterhuis, and N.P. Tugwell. 1992. The concept for monitoring the growth and development of cotton plants using main-stem node counts. J. Prod. Agric. 5:532-538.

Bourland, F.M. R. Benson, E. Vories, N.P. Tugwell, D.M Danforth. 2000. Measuring maturity of cotton using nodes above white flower. J. Cotton Sci. 5:1-8

Bourland, F.M., A.B. Beach, J.M. Hornbeck, and A.J. Hood. 2008a. Arkansas cotton variety test 2007. Ark Agric. Exp. Station Research Series 556.

Bourland, F.M., D.M. Oosterhuis, N.P. Tugwell, M.J. Cochran and D.M. Danforth. 2008b. Interpretation of crop growth patterns generated by COTMAN. *in :* D.M. Oosterhuis and F.M. Bourland (ed). COTMAN Crop Management System. U. of Ark Agric. Exp. Sta., Fayetteville, AR.

Danforth, D.M., and P.F. O'Leary (ed.) 1998. COTMAN expert system 5.0. User's Manual. U. of Ark Agric. Exp. Sta., Fayetteville, AR.

Monge, J.J., T.G. Teague, M.J. Cochran, D.M. Danforth, 2007. Economic impacts of termination timing for irrigation and plant bug control. Proc. Beltwide Cotton Conf., National Cotton Council, Memphis, TN, pp. 1396-1405.

Oosterhuis, D.M., and F.M. Bourland (eds). 2008. COTMAN Crop Management System University of Arkansas Agricultural Experiment Station, Fayetteville, AR.

Richmond, T.R., and L.L. Ray. 1966. Product-quantity measures of earliness of crop maturity in cotton. Crop Sci. 6:235–239.

Teague, T.G., S. Coy, and D.M. Danforth. 2005. Interactions of Water Deficit Stress and Tarnished Plant Bug Induced Injury in Midsouth Cotton. Proc. Beltwide Cotton Conf., National Cotton Council, Memphis, TN, pp. 1275-1289.

Teague, T.G., D.M. Danforth. 2005. Final irrigation timing and late season crop susceptibility to tarnished plant bug (*Lygus lineolaris* Palisot de Beauvois)- using COTMAN to make crop termination decisions. Proc. Beltwide Cotton Conf., National Cotton Council, Memphis, TN, pp.1743-1753.

Teague, T.G., J. Lund, and D.M. Danforth. 2006. Final irrigation timing and late season crop susceptibility to tarnished plant bug (*Lygus lineolaris* (Palisot de Beauvois)) - using COTMAN to make crop termination decisions – Year 2. Proc. Beltwide Cotton Conf., National Cotton Council, Memphis, TN, pp. 1059-1072.

Teague, T.G., J. Smith, D.M. Danforth and P.F. O'Leary. 2008. Manually applied infestations of tarnished plant bug nymphs in late season cotton to identify the final stage of crop susceptibility. Proc. Beltwide Cotton Conf., National Cotton Council, Memphis, TN, pp. 1239-1250.

Teague, T.G., and D.M. Danforth. 2009. Irrigation timing and tarnished plant bug management – Implications for late season susceptibility to tarnished plant bug and crop termination decisions. S. Boyd, M. Huffman, D. A. Richter, B. Robertson (eds.). Proc. Beltwide Cotton Conf. , National Cotton Council, Memphis, TN. pp. 787-801.

Zhang, J.P., M.J. Cochran, N.P. Tugwell, F. M. Bourland, D. M. Oosterhuis, and D.M. Danforth. 1994. Using long-term weather patterns for targeting cotton harvest completion. Proc. Beltwide Cotton Conf., National Cotton Council, Memphis, TN, pp.1284-1285.