LATE-SEASON TARNISHED PLANT BUG INFESTATIONS – WHEN IS THE CROP SAFE?

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RESEARCH PROBLEM

Economic thresholds (Stern et al., 1959) are used extensively in cotton production for determining when to initiate insecticide applications. Despite their importance in pest management, at some point in the season the crop is no longer susceptible to insects, and thresholds become irrelevant. The crop is beyond its final stage of susceptibility, and subsequent insecticide applications are uneconomical (Pedigo et al., 1986).

The question of when a cotton crop is "safe" from late-season insect pests has been the focus of intense research during the last 20 years (Bernhardt et al., 1986; Bagwell and Tugwell, 1992; Bourland et al., 1992; Zhang et al., 1994; Cochran et al., 1996; O'Leary et al., 1996; Benedict et al., 1997; Torrey et al., 1997; Harris et al., 1997; Cochran et al., 1999). Those previous studies dealt with terminating crop protection for heliothine caterpillars and boll weevils. There has been little research to define termination rules for tarnished plant bug (TPB), a key pest in mid-South cotton.

BACKGROUND

Research efforts have yielded a simple crop monitoring procedure and crop termination rule that allows a decision maker to define the final stage of crop susceptibility for a particular pest. After that point, the decision maker can ignore future infestations of those pests. The process is easily performed using the COTMAN™ system (Danforth and O'Leary, 1998).

To determine the final stage of crop susceptibility in cotton for a specific fruit-feeding insect pest, one must know which fruiting forms are the last to contribute to economic yield – the last effective boll population – and then know when those fruit are reasonably safe. Crop monitoring allows identification of the flowering date of the

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last effective boll population. This is considered cutout. Physiological cutout (Oosterhuis et al., 1996) takes place as the crop approaches carrying capacity, that point at which terminal growth has slowed and eventually stops because of boll loading (Hearn and Constable, 1984). By monitoring changes in the number of nodes above white flower (NAWF), the decision maker can measure late-season terminal growth and gauge physiological stress brought on by boll loading. With normal crop development, the last effective boll population occurs when the mean NAWF of a field reaches 5 (Wells, 1991; Bourland, 1992). Should physiological cutout be delayed significantly and NAWF=5 not reached prior to the latest possible cutout date, then the last effective boll population is defined based on a seasonal cutout date (Oosterhuis et al., 1996). In the COTMAN system, the latest possible cutout date is calculated based on the probability of accumulating 850 heat units (DD60s) from the date of flowering of the last effective boll population. Seasonal cutout dates are calculated based on local historical weather data from the crop production area.

If cutout date defines the last bolls to be protected, the next question is when are those bolls sufficiently mature that they are safe from insect attack. Research by Bagwell (1992) indicated that at about 350 DD60s after anthesis, injury to a boll by bollworm (*Helicoverpa zea*) and boll weevil (*Anthonomus grandis*) is dramatically reduced. Kim (1998) made measurements of different-aged bolls and found significant increases in resistance of the boll wall to penetration at about 350 DD60s. With these results in hand, researchers hypothesized that infestations occurring after cutout + 350 would not lead to economic loss. This hypothesis was tested in small-plot research trials and then in large-plot, on-farm validation studies. In three years of research across several states and involving 20 small-plot trials, a yield penalty was never observed for terminating insect control after 350 DD60s beyond NAWF=5. Four years of large-plot grower trials compared yields using the COTMAN termination rule to yields using the growers' normal economic thresholds for initiating insecticide applications. In each of the 33 trials, the grower thresholds resulted in additional insecticide applications beyond 350 DD60s, at an additional cost ranging from $7 to $70 per acre. In 32 of 33 trials, insecticide termination at 350 DD60s improved farm profits. Overall, less than two pounds of lint difference on average was observed between termination at 350 DD60s and the grower full-season treatment. An average of $19.62 per acre was spent on insect control with no return to yield (Cochran et al., 1999).

Late-season injury resulting from plant bug feeding on bolls includes damage to lint and seed. Pack and Tugwell (1976) observed as high as a 10% yield reduction from damaged bolls in studies in northeast Arkansas; however, during the time of that research, there were no efficient tools to monitor crop development, and timing of the infestation with regard to crop maturity was not easily quantifiable.

In studies conducted in Mississippi, Horn et al. (1999) examined the incidence and severity of plant bug feeding punctures. In no-choice cage studies, adult bugs were confined on bolls of different ages for 48 hrs. They determined that bolls which had accumulated 250 DD60s were relatively safe from tarnished plant bug injury. The authors proposed a conservative recommendation of establishing 300 DD60s after cutout as the point at which to terminate insecticides (i.e. insecticide sprays to control future infestations of plant bugs would be unnecessary). Similar no-choice cage tests were conducted in Louisiana, where Russell et al. (1999) evaluated retention of bolls after 72 hrs exposure to 2 TPB adults. They found that TPB did not sufficiently penetrate the boll wall to result in boll abscission if the boll had accumulated >300 DD60s.

The objectives of this study were: 1) to conduct field studies to validate decision rules for defining the final stage of cotton crop susceptibility to tarnished plant bug; and 2) to use standardized procedures to assess plant responses to late-season injury by TPB and to protective sprays in a high yielding production system in the absence of boll weevil, heliothine larvae, and defoliating caterpillar pests.

RESEARCH DESCRIPTION

The experiment was conducted at Wildy Farms, a commercial farm in northeast Arkansas near Manila. 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 9 August or 31 July, respectively (Zhang et al., 1994; Danforth and O'Leary, 1998).

The cultivar, Stoneville 4892 (a transgenic *Bt* variety with tolerance to the herbicide glyphosate), was seeded on 2 May 2001. Temik 15G (aldicarb) was applied in furrow at planting at 5 lb formulation per acre. The soil was a Routon-Dundee-Crevasse Complex (sand). Sprinkler irrigation was initiated beginning 7 May, and continued at weekly intervals until 21 Aug. Rainfall in May, June, July, August, September, and October was 5.27, 1.33, 2.04, 1.30, 2.67, and 5.82 inches, respectively. Foliar applications of Orthene 90S (acephate) (0.33 lb formulation/acre) were made to control infestations of mirid pests, cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter), and TPB on 1 and 27 June and 12 July. Applications were made when mirid counts in drop cloth samples and/or percent square shed approached grower thresholds (1 bug/3ft or pre-flower first-position square shed not to exceed 10%). Defoliants were applied on 19 September (12oz Folex and 4oz Finish/acre) and 25 Sept (4oz Finish + 32 oz Super Boll/acre).

Infestation Treatment

TPB nymphs were released at different times and levels after cutout to compare injury and lint yield of infested plants to plants protected by insecticide. There were 5 infestation treatments: 1) Bug 3, release of TPB nymphs 3 times at weekly intervals beginning August 10, the day after the latest possible cutout date; 2) Bug 2, release of TPB nymphs 2 times weekly, beginning 8 days after the latest possible cutout date; 3) Bug 1, a single release of TPB nymphs made 15 days after the latest possible cutout date; 4) no releases, just the naturally occurring TPB infestation, and 5) protected with insecticide sprays.

In Bug 3, Bug 2, and Bug 1 treatments, 3 to 5 TPB nymphs (3rd instar) were released on every plant on the appropriate date. Plant stand density was approximately 3.5 plants/ft. Nymphs were allowed to walk onto plants from shredded strips of white copy paper. These 0.5-cm wide and 10- to 20-cm long strips are used to line the bottom of rearing boxes, and the bugs rest on them after feeding. Rearing boxes were carried to the field, and a single paper strip was pulled from the box with TPB nymphs clinging to the paper. Excess bugs were brushed off and the paper strips laid across leaves on the top of the plant. Bugs were released during the cool periods of the morning after dew had dried. For the sprayed treatment, Centric 40 WG (thiamethoxam), was applied at 3 ounces/acre using a back-pack sprayer. Plot rows as well as the 2 rows adjacent to the plot were sprayed at 6-day intervals. Details on timing treatments in relation to DD60 accumulation after physiological cutout and the seasonal cutout date are outlined in Table 1.

Each treatment was replicated 3 times. Plots were 2 rows wide, 15 ft long. Plots were separated through the field by 85 ft buffer areas. Tarnished plant bugs were obtained from a colony maintained on artificial diet at the USDA-ARS Biological Control and Mass Rearing Research Unit at Mississippi State, MS (Cohen et al., 2000).

Crop Monitoring and TPB Counts

Plants were monitored from the early squaring period through cutout using the COTMAN system. Five consecutive plants in 2 treatment rows were monitored weekly. Prior to first flowers, sampling included measurement of plant height, number of squaring nodes (nodes on which 1st position squares had not yet flowered), and sheds of first-position squares. After first flowers, nodes above white flower were monitored. Beginning on the date of seasonal cutout (9 Aug) the SCOUTMAP component of COTMAN was used to monitor square and boll retention and injury (Tugwell et al., 1999). In this sampling scheme, total squares, small bolls, and large bolls on 10 plants were monitored for retention, and external symptoms of TPB feeding. Total squares were all first-position squares. Small bolls were first-position bolls located on the first 3 sympodial nodes below the white flower (or last squaring node if no flower was present), and large bolls were all first-position bolls located 4 nodes below the last squaring node.

Natural infestations of TPB were monitored outside the treatment plots. Plant bug population density was estimated on 16 and 24 Aug using 10 sweeps of the terminal areas of plants with an 18-inch net. Twelve samples were made through the entire field. Within plots, on these same dates, 10 white flowers in each plot were examined in the late morning just after flowers were open. Any signs of injury were noted, and counts of total numbers of plant bugs/flower were made. For yield determinations, plots were hand harvested 27 Sept, 2 Oct, and 9 Oct. These data, along with other plant and insect monitoring data, were analyzed using ANOVA with mean separation using LSD.

RESULTS

TPB Population Densities

Natural infestations of tarnished plant bugs were surprisingly high during mid-August though September in northeast Arkansas. TPB numbers were considered at treatment level (exceeded economic thresholds) throughout the area, and consequently it was common for growers who were not using plant monitoring for crop termination decisions to apply from 2 to 5 insecticide applications for TPB during late August and early September (Keith Martin, personal communication). At our study site, means of 10.7 and 15.3 bugs per 10 sweeps from plant terminals were recorded on 16 and 24 Aug, respectively, in sweep net sampling taken adjacent to the experiment. Other non-mirid pest species were at inconsequential levels; boll weevil and heliothine numbers were *extremely* low in the production area in the 2001 season and were not a factor in the end-of-season decision making.

Crop Monitoring

Mean number of squaring nodes for each treatment is plotted as nodes above first square and nodes above white flower in COTMAN growth curves in Fig 1. When compared to the COTMAN target development curve, it was apparent that the crop was somewhat late in square initiation, but the rate of squaring node accumulation indicated no significant pre-flower stress after squaring commenced. NAWF values indicated that boll loading appeared to be slightly delayed; however, the crop reached physiological cutout (NAWF=5) prior the latest possible cutout date (9 Aug). Days to cutout among all plots ranged from 89 to 97 days after planting (30 July to 8 Aug). Mean date of physiological cutout for all plots was 3 Aug.

SCOUTMAP data taken following cutout indicated plants had fewer than 4 squaring nodes (NAWF<4) and had between 10 and 11 total sympodial nodes with bolls on 16 Aug. There were no differences in square or boll sheds between treatments exposed to natural infestations of TPB and released bug and sprayed plots although numerically, percent square shed was lowest in sprayed treatments (Table 2). By 23 Aug, these trends continued, but by 30 Aug there were few squares remaining in any treatment. Small boll shed numerically was lower in sprayed plots compared to treatments with released and/or natural bugs. Sheds of all first-position fruiting forms ranged between 43 and 56% by 23 Aug.

Significant differences between infested and the sprayed treatments in TPB injury symptoms were observed for small bolls for the first 2 sample dates and for total fruiting forms for the second sample dates (Table 3). By 30 Aug the trend for lower levels of small boll injury in sprayed plots was still present; however, there were no significant differences. In white flower inspections, numbers of flowers with injury symptoms and counts of TPB/flower indicated significantly higher levels of TPB activity in unsprayed plots compare to those protected with insecticide (Table 4). By the time of the 23 Aug sample, Bug 3 treatments had received 2 applications of nymphs, and in those plots 100% of all flowers were infested by a bug and were found to have injury symptoms. Casual inspection of plots in late August produced the impression that severe boll injury from TPB feeding had occurred in unsprayed plots, especially in those receiving 2 and 3 applications of bugs. Significant economic damage appeared inevitable to at least one of the senior authors.

Yield

From the mean date of physiological cutout (3 Aug) until the first application of defoliants on 16 Sept, daily temperatures were such that 822 DD60s were recorded. From 9 Aug, the seasonal cutout date, to 16 Sept, total DD60 accumulation was 697. Most plots were over 80% open at the time of defoliation, and all plots had at least 60% open bolls. Yield data indicated no differences between treatments for any harvest date (Table 5).

DISCUSSION

In the Bugs 3 infestation treatment, plant bug feeding was continuous from 150 DD60s following physiological cutout until open bolls were present. All infestation treatments had significantly higher levels of small boll injury, but no differences in yield between sprayed and any TPB infestation level were measured. The crop apparently had passed its final stage of susceptibility to TPB, and protection of those fruiting forms was unnecessary.

In previous boll susceptibility studies with TPB, boll weevil, and bollworm, insects were tested in no-choice environments (Bagwell, 1992; Horn et al., 1999; Russell et al., 1999) and caged on bolls of different ages. Under field conditions, an insect's ovipositional and feeding site preferences are important factors that affect the potential for damage to economically significant boll populations. This is especially true for TPB, a persnickety herbivore that when feeding in cotton, prefers succulent squares to large bolls (Tugwell et al., 1976).

As a cotton crop approaches carrying capacity and is at physiological cutout, the late-season bolls usually are small and low in fiber quality (Bourland et al., 1992). Protection of those upper canopy fruiting forms with late-season insecticide applications is expensive. If those bolls are lost, photosynthates produced by upper canopy source leaves may be translocated to alternate sites such as economically important bolls lower in the canopy. This could act to compensate for loss of yield from the upper bolls. Results from ^{14}C labeling studies by Oosterhuis et al. (2000) indicated that removal of late-season squares after physiological cutout + 350 DD60s improved carbon partitioning to lower developing bolls. When they tested this hypothesis in field trials, they observed that there were no statistical differences in yields following removal of fruiting forms in the upper canopy; however, in 2 of 3 years, yields were highest numerically where squares had been removed following physiological cutout. In studies by Fife et al. (2000) in Louisiana, removal of upper canopy squares after cutout did not result in increased yields; however, there were no yield reductions.

The elimination of late-season insecticide applications when bolls are no longer susceptible to damage by fruit-feeding insects has been shown to save producers money without adversely impacting yields (Cochran et al., 1999). The lack of yield penalty in literally dozens of validation studies, for the cutout + 350 DD60 control termination rule, seems to correspond to Hearn and Room's (1979) characterization of time-independent response of cotton to loss of fruiting forms: 1) *instantaneous tolerance* – when the damage occurs to fruiting forms that would have shed physiologically anyway; or 2) *instantaneous compensation* – when resources that would have been directed to damaged bolls are directed to the remaining undamaged bolls making them bigger. Pest management specialists and cotton professionals must work to increase recognition among growers and other decision makers that such tolerance and compensation factors do exist in late-season cotton systems, and that recommendations to adopt insect control termination rules are economically and environmentally sound advice.

PRACTICAL APPLICATION

Despite significant, high tarnished plant bug numbers and associated feeding injury, no yield penalty was observed following TPB infestations initiated at 150, 296, or 375 DD60s after physiological cutout. Results from this one season of research indicate that insect control termination rules that have been in use for heliothine caterpillars and boll weevils (cutout +350 DD60s) are more than sufficient for late-season tarnished plant bug management.

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Table 1. Timing of TPB introductions and time of initiating and terminating insecticide sprays in relation to calendar date and stage of crop development.

Infestation treatments	Date of application	DD60s accrued after physiological cutout[z]	DD60s accrued after seasonal cutout date[y,x]
Applied bugs 3	10, 17, 24 Aug	156	19
Applied bugs 2	17, 24 Aug	296	137
Applied bugs 1	24 Aug	375	272
Natural infestation only			
Sprayed[w]	10, 16, 22, 28 Aug	488	356

[z] DD60 accumulation began when a treatment mean reached NAWF=5.
[y] Latest possible cutout date of 9 Aug based on historical probability (50%) for accruing heat units (DD60s) needed for boll maturation.
[x] Daily DD60s = (daily high temperature (°F) +daily low temperatue)/2 – 60.
[w] Centric (3 oz/acre) sprayed on each date with final spray at 488 DD60s after physiological cutout/ or 356 DD60s after the seasonal cutout date.

Table 2. Mean number of nodes above white flower (NAWF), number of sympodial nodes with bolls, total sympodial nodes, percent total square shed, percent small boll shed, percent large boll shed, percent total boll shed, and total percent shed fruiting forms (all first position) observed in plant monitoring observations made following infestation treatments.

Sample date	Infestation treatment	NAWF	No. sympodial nodes with bolls	Total square shed	Small boll shed	Large boll shed	Total boll shed	Total fruiting form shed
				(%)				
16 Aug	Bugs 3	3.4	10.9	45.1	48.9	39.8	42.3	40.2
	Bugs 2	3.3	11.1	28.0	33.3	43.4	40.7	35.3
	Bugs 1	3.3	11.5	16.0	22.2	40.6	35.8	29.4
	Natural	3.5	11.2	20.8	35.7	49.6	45.8	37.3
	Sprayed	3.9	10.7	13.8	31.1	44.4	40.6	31.3
	P > F	*0.79*	*0.88*	*0.24*	*0.15*	*0.41*	*0.42*	*0.16*
23 Aug	Bugs 3	2.5	10.5	76.3	48.9	37.5	40.8	44.9
	Bugs 2	2.5	12.5	71.0	40.0	33.6	35.1	38.7
	Bugs 1	2.3	11.9	60.0	60.0	35.8	41.9	41.9
	Natural	2.2	12.5	60.6	44.4	43.4	43.6	43.2
	Sprayed	2.5	11.9	16.2	31.1	44.0	40.8	34.2
	P > F	*0.97*	*0.16*	*0.07*	*0.15*	*0.47*	*0.18*	*0.21*
30 Aug	Bugs 3	2.0	13.4	100.0	71.1	49.4	54.2	56.5
	Bugs 2	1.7	13.6	100.0	71.1	41.5	48.0	50.6
	Bugs 1	1.9	13.8	100.0	62.2	39.5	44.4	48.0
	Natural	2.1	13.7	96.9	77.8	43.8	51.2	54.0
	Sprayed	2.3	12.6	91.2	44.4	36.8	38.6	43.7
	P > F	*0.84*	*0.32*	*0.46*	*0.40*	*0.74*	*0.37*	*0.34*

Table 3. Mean percent injured first position small squares, total first position squares, first position small, large, and total bolls, and total first position fruiting forms with symptoms of tarnished plant bug feeding injury observed during 3 sample dates for each infestation treatment.

Sample date	Infestation treatment	Total squares	Small bolls[z]	Large bolls	Total bolls	Total fruit. forms[z]
		----------	----------	(%)	----------	----------
16 Aug	Bugs 3	23.5	24.4 a	8.5	12.9	14.4
	Bugs 2	8.0	13.3 ab	3.3	6.0	6.0
	Bugs 1	8.0	13.3 ab	2.3	5.2	5.5
	Natural	11.3	8.9 ab	4.1	5.4	6.4
	Sprayed	6.9	0.0 b	3.5	2.5	3.4
	P > F	*0.36*	*0.05*	*0.38*	*0.34*	*0.15*
23 Aug	Bugs 3	52.6	35.6 a	16.1	21.7	25.7 a
	Bugs 2	52.6	44.4 a	12.6	20.2	24.1 a
	Bugs 1	31.4	11.1 b	7.6	8.4	11.4 bc
	Natural	42.4	33.3 a	7.0	13.3	16.5 ab
	Sprayed	18.9	0.0 c	5.2	3.9	6.2 c
	P > F	*0.17*	*0.002*	*0.10*	*0.08*	*0.009*
30 Aug	Bugs 3	100.0	26.7	23.1	23.9	34.2
	Bugs 2	100.0	20.0	17.6	18.1	26.5
	Bugs 1	71.4	28.9	12.4	15.9	21.2
	Natural	75.0	15.6	14.4	14.6	21.4
	Sprayed	26.5	8.9	6.3	6.9	9.4
	P > F	*0.15*	*0.45*	*0.18*	*0.2*	*0.1*

[z] Means within a column for a sample date followed by different letters are significantly different (LSD 0.05).

Table 4. White flowers with feeding injury symptoms and number of tarnished plant bugs observed in 10 flowers on 2 sample dates following infestation treatments.

Sample date	Infestation treatment	Flowers with anther injury[z]	No. bugs in 10 flowers
16 Aug	Bugs 3	70.0	3.0
	Bugs 2	43.3	2.0
	Bugs 1	40.0	0.7
	Natural	40.0	1.7
	Sprayed	3.3	0.0
	P > F	*0.01*	*0.09*
23 Aug	Bugs 3	100.0	10.0
	Bugs 2	83.3	5.9
	Bugs 1	83.3	3.7
	Natural	70.0	7.0
	Sprayed	16.7	0.3
	P > F	*0.005*	*<0.001*

[z] Symptoms likely were associated with bug feeding although spotted cucumber beetles (*Diabrotica* spp.) were present in some flowers and could have contributed to injury.

Table 5. Mean cumulative lint yield for each infestation treatment for each date of harvest.

	Cumulative lint[z] yield per harvest date		
Infestation treatment	27 Sept	2 Oct	9 Oct
Bugs 3	601	970	1186
Bugs 2	516	872	1243
Bugs 1	496	841	1211
Natural	516	837	1253
Protected	391	819	1219
P>F	*0.84*	*0.94*	*0.89*

[z] Lint yields based on 0.33% gin turnout.

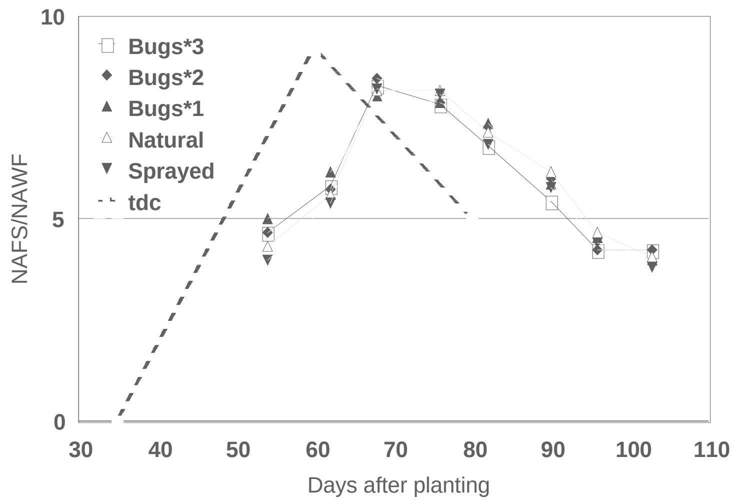

Fig. 1. Growth curves for plants in each treatment; data represent changes in nodes above first square/nodes above white flower through cutout. The latest possible cutout date, 9 Aug, was 99 days after planting.