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ARTHROPOD MANAGEMENT AND APPLIED ECOLOGY

Influence of Within-season Densities of Heliothines and Tarnished Plant Bugs on Variability in End-of-season Cotton Yield Mapping

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ABSTRACT

Nineteen different experiments were compiled to examine temporal trends in fruit retention among various insect related treatments based on end-of-season yield mapping of cotton, *Gossypium hirsutum* L., plants. Fourteen of these data sets were used to examine the effect of varying densities of bollworm, *Helicoverpa zea* (Boddie), tobacco budworm, *Heliothis virescens* (F.) (heliothines) and tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), on survival and seed cotton weight of particular fruit cohorts at harvest. Regression equations using only sample dates where insects were present described end-of-season fruit loss better than equations using all insect sample dates. More fruit loss occurred when populations of heliothines were observed on cotton varieties not expressing an insecticidal protein from *Bacillus thuringiensis* Berliner (*Bt*) than *Bt* varieties. Populations of heliothines observed on non-*Bt* cotton at six different stages of plant development (based on total mainstem nodes) were related to decreased survival of fruit within some fruiting cohorts. Heliothine eggs and larvae on *Bt* cotton were related to reduced fruit survival when infestations were present on plants with four and three different total mainstem nodes, respectively. Based on these regression analyses, most damage caused by observed populations of heliothine larvae and plant bugs occurred to cotton squares ranging from 3 to 15 d old at the time of infestation. Collectively, these data indicate that important insect injury can be followed through the growing season and recorded on end-of-season yield maps. The dynamic nature of the impact and the probable role of plant compensation further support continued development of dynamic insect thresholds.

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Plant responses to insect feeding are fundamental to developing economic injury levels, which are a major component of integrated pest management (Pedigo 1989). Stern et al. (1959) described the objective of integrated pest management as "treating pest populations when densities reach a level that would result in economic loss if not treated." Processes such as plant compensation may complicate estimates of injury levels by allowing some damage by frugivores to occur to immature fruit without reducing final yield (Hamner 1941, Adkisson et al. 1964, Graham et al. 1972, Brook et al. 1992, Lei 2002, Hebert et al. 2006). The ability of a plant to compensate for insect injury may be influenced by the time of injury within the growing season and a wide range of environmental growing conditions (Eaton 1931, Sadras et al. 1997, Holman and Oosterhuis 1999).

Research has shown that each fruiting position on a cotton, *Gossypium hirsutum* L., plant does not contribute equally to yield (Jenkins and McCarty 1995, Stewart et al. 2001). Although there is some recognition of a crop's varying sensitivity to insect injury, including recent definitions of when to terminate insecticide sprays late in the season (Cochran et al. 1998), most guidelines that provide estimates of treatable insect densities are static across the growing season (Studebaker 2007). The value of fruit available for insect feeding and the probability that fruit may be destroyed are dynamic. Cotton plants with adequate fruit retention early in the growing season may produce late-season fruit that are less valuable to final yield. An increased economic injury level should be present for insects feeding on these plants, especially if the insects prefer to feed on the younger, less valuable fruit. Similarly, plants with early-season fruit loss may produce late-season fruit that contributes a larger percentage to final yield, which would cause the economic injury level of a particular insect to decrease later in the season. Thus, knowing when the compensation ability is no longer a consideration is important in developing dynamic thresholds. Compensation complicates our ability to understand the impact of insect damage at different times of the season (Wilson 1985, Jones et al. 1996). Jenkins and McCarty (1995) described a method to measure the contribution of each fruiting site of the cotton plant using end-of-season maps. Coupling end-of-season plant mapping to within-season insect scouting and within-season plant mapping information allows an examination of relationships between insect densities and ultimate value of fruit loss within particular cohorts of fruit.

The tobacco budworm, *Heliothis virescens* (F.), bollworm, *Helicoverpa zea* (Boddie), (collectively referred to as heliothines in this paper) and the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) are three of the most important insect pests of cotton in the southern United States. All three feed directly on fruiting structures. Most of the fruit damage caused by heliothine larvae is to younger developing cotton squares, although large larvae may feed on older fruiting structures (Quaintance and Brues 1905, Kincade et al. 1967, Nicholson 1975). Likewise, the tarnished plant bug prefers to feed on smaller squares when available, but may also inflict damage to various-sized bolls (Pack and Tugwell 1976). End-of-season plant maps of fruit survival and estimates of the numbers of insects present at a particular stage of plant development (based on within-season plant mapping) may provide evidence of the preferred feeding sites and actual damage caused at various densities of these herbivores.

The main objective of this study was to determine the impact of varying densities of three economically important insect pests of cotton on surviving fruit and seed cotton weight within defined fruiting cohorts based on end-of-season yield map estimates. These impacts were determined at 13 different stages of crop development based on total mainstem nodes. Additionally, the impact of insect densities at various stages of mainstem nodal development on total fruit survival and seed cotton weight at harvest was examined.

MATERIALS AND METHODS

Studies were conducted from 2002 through 2005 in Arkansas to examine variability in end-of-season yield mapping of cotton plants. Three existing data sets for experiments conducted in Mississippi during 1996 through 1997 (Hand 1997, Parker et al. 1999) were also included as they served as a conceptual foundation for the Arkansas studies. In total, end-of-season yield mapping was done on samples from 19 experiments with 94 total treatments (815 total samples). A sample consisted of an average of 14 plants across all experiments with between one to four samples taken from an individual plot or commercial field. Plant mapping of surviving and missing fruiting forms (1,506 total samples) and numbers of insects present were also recorded at periodic intervals within the growing season, but the timing and number of sample dates varied widely from experiment to experiment. The total number of insect samples examined at times when cotton plants had eight to 20 total mainstem nodes were 1,426 heliothine egg samples, 1,480 heliothine larvae samples, and 1,400 samples for plant bugs. The different treatments and experiments included both *Bt* transgenic and non-*Bt* plants in sprayed and unsprayed environments.

Within-season plant mapping. Once fruit development began, and periodically thereafter, a set of plants within each plot or grower field was examined for plant development. The sample of plants examined on a particular date ranged from five to 40 plants within a plot or grower field. Usually, 10 plants were mapped in small plot studies, while a total of 40 plants (four samples sites of 10 plants) were mapped in commercial fields. Depending upon the study, the number of within-season plant mapping dates ranged from two to nine. Both within-season plant mapping and periodic sampling of insects were obtained in 14 of the 19 data sets. Data recorded on particular plant mapping dates included total number of mainstem nodes, missing or present first position or first through third position fruit on mainstem sympodial branches, development stage of fruit (i.e., square, flower, boll) on each sympodium, and plant height. Mainstem nodes were numbered from bottom to top with the cotyledon node equal to zero and the node of the first true leaf as one. Total number of mainstem nodes was the only within-season plant mapping estimate used in this study.

Insect sampling. Insect information was typically recorded for major insect pest species across most of the experiments, but only data obtained for numbers of heliothines and plant bugs (the majority of insect samples recorded) were included in this study. The number of insect sample dates for a particular plot ranged from one to 16, with a mean of 4.7 ± 0.2. Methods used to obtain insect samples varied among experiments and included visual observations (10 – 100 plants per plot), drop-cloth (2 -20 samples of five row feet per plot), and sweep-net samples (25 – 100 sweeps per plot). All heliothine egg estimates were obtained via visual observations. Heliothine larvae estimates were obtained via visual observations and drop-cloth samples. Plant bug estimates were obtained via drop-cloth and sweep-net samples. Plant bugs recorded in sweep-net samples were converted to number per row meter based on the conversion of stink bugs captured in sweep net samples in soybean (Studebaker 2007). Resulting numbers of insects recorded by visual observations, drop-cloth and sweep-net samples were converted to number per plant for each experimental plot or commercial field assuming a density of 9.84 plants per row meter in all plots.

All insect samples were indexed by date of sample. To standardize insect sampling across all experiments, within-season plant mapping information was used to estimate the total number of mainstem nodes per plant for a plot or grower field on each sampling date. In data sets in which an insect sample occurred between within-season plant mapping intervals, linear interpolation was used to estimate the number of mainstem nodes per plant for this date. In data sets in which multiple insect samples occurred between within-season plant mapping dates, or insect samples occurred after the last plant mapping date, linear regression was used to obtain estimates of total mainstem nodes per plant on these insect sample dates (Proc Reg, SAS Institute 2001).

End-of-season yield mapping. When plants within a treatment were assumed to be mature for harvest, samples of plants were cut near the soil surface, loosely tied with nylon string, and transported to indoor facilities where end-of-season yield mapping was conducted. The number of plants removed from a plot or grower field ranged from a 1 m sample of ~ 10 plants up to 12.2 m (four samples of 3.05 m). If multiple samples were obtained from a plot or field, they were combined for a single descriptor for that particular plot or field. Over all experiments, 11,460 plants were examined. Plants were categorized as typical or as non-typical for those which a dominant mainstem could not be determined. Non-typical plants (~2% of all plants examined) were grouped separately from the typical plants. Vegetative or monopodial branches were removed from the typical plants. The number of bolls and weight of non-typical and monopodial branches were recorded separately for each sample. The remaining seed cotton (i.e., that from mainstem sympodia of typical plants) was separated based upon mainstem node and horizontal position of the fruit as described by Jenkins and McCarty (1995). For data sets obtained from Mississippi, a wooden box with four rows representing four horizontal positions on a sympodial branch and up to 27 columns for main stem nodes was used for end-of-season "box-mapping" of samples. The cotyledon node was assigned a value of zero and the subsequent fruit from sympodial branches was placed in the proper node-position cell of the box. For each boll placed in a cell, a pinto bean was placed into a small cup within the box cell to maintain a count of the number of bolls present in each cell. The seed cotton was weighed for each fruiting position, and the number of bolls and weight for the collective sample on a particular mainstem node-position fruiting site were recorded. Number of bolls and collective weight were converted to a per plant basis to standardize the number of plants that were mapped. For experiments conducted in Arkansas, plastic (one-liter) flower pots were used in place of the large wooden box. Pots were arranged in the same manner as the box with each pot representing one mainstem fruiting branch node-position. A pinto bean was placed in a small cup within each flower pot to maintain a count of the number of bolls at each node-position. This appeared to be a logistical improvement as these pots can be stacked and transported from site to site easier than the large wooden box.

Grouping of fruit cohorts. For end-of-season yield maps, similar age-class fruit were grouped into cohorts based on a 2.0 fruiting ratio of vertical to horizontal fruit development, which is a typical fruiting sequence of cotton (Jenkins and McCarty 1995). This means that plants develop fruit typically every 3 d on a new mainstem sympodial branch (first position fruit) going vertically up the plant and new fruit every 6 d on an existing branch (second position and higher fruit). Cohorts were labeled according to the node of first position fruit within the group. For example, mainstem node 12 horizontal position one fruit were grouped with node 10 second position, node eight third position and node six fourth position fruits (labeled C12). Figure 1 presents an example of cohort grouping for mainstem nodes 5 -12. This cohort grouping was used to examine the accumulation of surviving fruit and seed cotton weight for each treatment within studies based on end-of-season fruit survival estimates. Relationships between insect samples recorded when plants had a particular number of total mainstem nodes and seed cotton weight within these cohorts were also examined.

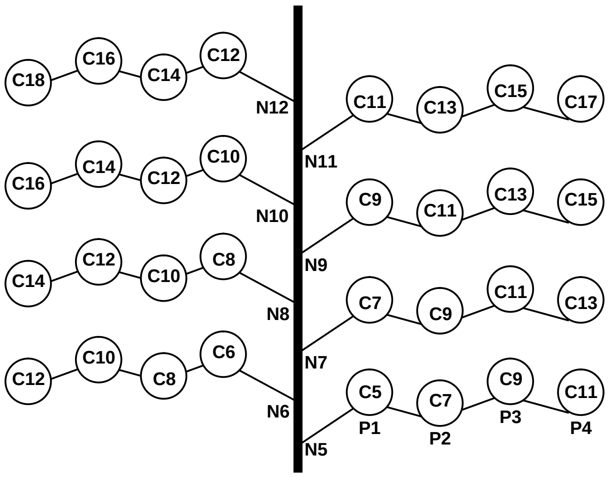

Figure 1. Cotton plant depicting fruiting pattern for mainstem nodes five through 12. Fruit cohorts are named by the first-position fruit on a particular mainstem node and assumes a 2.0 vertical (fruit developing on mainstem node above a particular node) to horizontal (fruit developing on the next position on the same mainstem node) fruiting interval. Numbers following the letter "N" depict the number of the mainstem node. Numbers following the letter "P" depict the fruiting position on a mainstem node. Numbers following the letter "C" depict fruit within a particular fruiting cohort.

Insect effect on surviving fruit and weight within cohorts. For each total mainstem node of plant development, a simple regression (Proc Reg, SAS Institute 2001) was used to estimate effects of potential larvae developing from heliothine eggs, heliothine larvae, and plant bugs (both nymphs and adults) per plant on surviving fruit and seedcotton weight within a cohort based on end-of-season yield map data. The regression estimates were generated for insect samples recorded when plants had a particular number of total mainstem nodes and a corresponding fruit cohort identified by the first position fruit at the uppermost node at the time of the insect sample. For example, the average number of insects present per plant when plants had 12 total mainstem nodes was regressed on the surviving fruit and seed cotton weight at mainstem node 12 position one and similar age fruit grouped within this cohort as described in the previous section. Insect densities per plant recorded when plants were sampled at a particular total mainstem node of development were also regressed with cohorts of surviving fruit (based upon the node of the first position fruit) and seed cotton weight up to ± five, plus five, and minus five nodes from the uppermost mainstem node at the time of the insect sample. For example, insect densities recorded when plants had 12 mainstem nodes were regressed on surviving fruit and seed cotton weight for the following fruit cohorts:

Exact node	C12
± 1	C11-C13
± 2	C10-C14
± 3	C9-C15
± 4	C8-C16
± 5	C7-C17
+ 1	C13
+ 2	C13-C14
+ 3	C13-C15
+ 4	C13-C16
+ 5	C13-C17
- 1	C11
- 2	C10-C11
- 3	C9-C11
- 4	C8-C11
- 5	C7-C11

Additionally, insect densities per plant recorded when plants were sampled at a particular total mainstem node of development were regressed on total surviving fruit and seedcotton weight per plant. Simple regressions were initially estimated using information from all insect sample dates using insect density as an independent variable and surviving fruit and seed cotton weight as dependent variables. Regressions were then estimated using sample dates when either heliothines or tarnished plant bugs were present. For heliothine eggs and larvae, separate regressions were generated for *Bt* and non-*Bt* cotton.

For each total mainstem node of plant development in which there was at least one significant regression ($P < 0.05$) between a cohort of fruit and an insect variable, the r^2 values were examined. Regression equations with the highest r^2 (i.e., those zones of fruit in which insect densities explained the most variability in survival and seedcotton weight) were chosen for inclusion in this paper. All regression equations are included in Allen (2007).

RESULTS

End-of-season yield mapping. Overall, boll survival and seed cotton weight contribution of first position fruiting positions were greater than second through fourth position fruits on a per plant basis (Fig. 2). Fruit on mainstem nodes eight to 10 had the greatest survival and weight contribution per plant. When examining the average seed cotton weight for surviving fruit at each node/position combination, first position fruit were the heaviest (3.98 g ± 0.08, n = 21 nodes), and followed by second position (3.77 g ± 0.06, n = 19 nodes), third position (3.65 g ± 0.06, n = 17 nodes) and fourth position (3.54 g ± 0.08, n = 13 nodes) fruits.

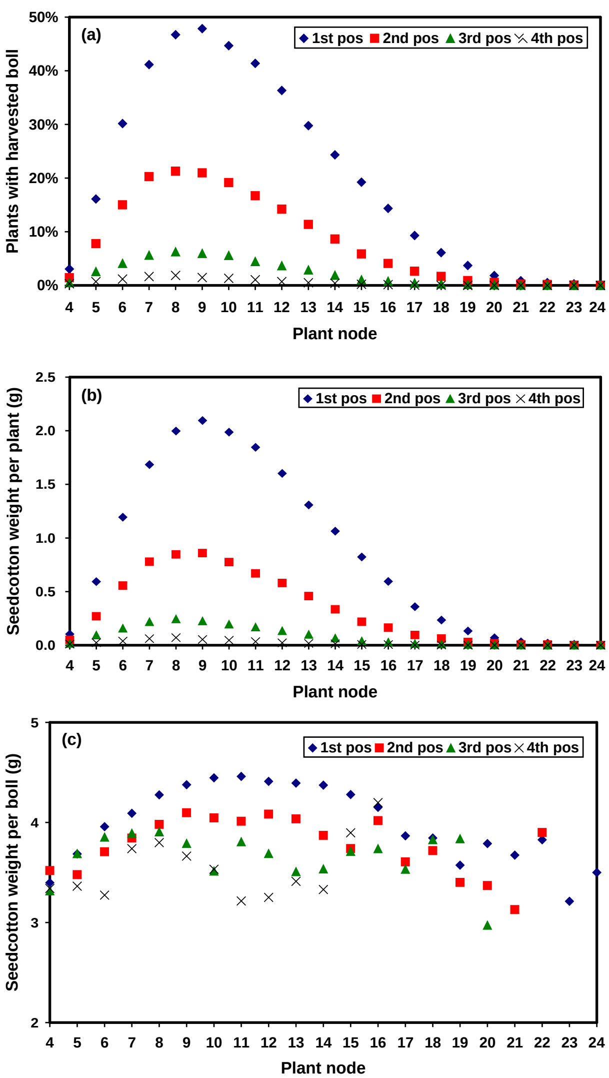

Figure 2. (a) Percentage of plants with harvested bolls at different mainstem nodes, resulting (b) mean weight per plant at different node/position combinations, and (c) mean seedcotton weight per harvested boll across all samples.

Heliothine eggs: effect on fruit survival and seedcotton weight. Most eggs were observed in *Bt* and non-*Bt* cotton plots when plants had approximately 14 to 19 total mainstem nodes (Table 1). When eggs were observed on *Bt* plants with 10 and 12 total mainstem nodes, the best fitting regression equation (based on highest r^2 value) was for reduced survival of fruit to occur within fruit cohorts C11 – C15 and C13 – C17, respectively, which suggests damage by hatching larvae to the terminal region of the plant (Table 2). When eggs were observed on plants with 11 and 18 total mainstem nodes, fruit loss was best explained for fruit cohorts C7 – C10 and C14 – C17, respectively, which suggests that larvae from eggs damaged fruit up to 12 d of age. The negative effect of potential larvae from eggs on seed cotton weight occurred when eggs were present on plants having 10 to 12 mainstem nodes. The best-fitting regression equations occurred within almost the exact same fruit cohorts as those for fruit loss. The only significant regression equation for eggs and total surviving bolls or seed cotton weight occurred when plants had 11 mainstem nodes, where larvae from these eggs negatively impacted older fruit present on the plant (up to 12 d old).

On non-*Bt* cotton plants, the potential larvae developing from observed eggs had a significant negative impact on surviving fruit when infestations occurred on plants having six different total mainstem nodes (Table 3). Larvae developing from eggs on plants with eight and 15 total mainstem nodes explained missing fruit best for cohorts including first position fruits within ± two nodes from the uppermost node at the time of infestation. Larvae from eggs present on plants with nine and 10 total mainstem nodes explained fruit loss best five and two cohorts above the uppermost node of the plant at the time of infestation, respectively, suggesting that damage was to fruit that had not been initiated at the time of egg observation. When plants had 13 total mainstem nodes, the highest r^2 was for C14 fruit, while a higher r^2 was observed when plants had 18 total mainstem nodes for total surviving bolls (i.e., all fruit). Significant effects of heliothine larvae from egg populations on seed cotton weight loss were observed for plants with the same number of total mainstem nodes as fruit loss except for eggs present when plants had 18 total mainstem nodes (Table 3). The effect of larvae developing from observed eggs on weight loss was greatest within almost the same cohorts for each respective node. Larvae from eggs present on plants with nine and ten total mainstem nodes also had a negative impact on total surviving bolls and total seed cotton weight per plant.

Table 1. Mean number of heliothine eggs per sample at various total mainstem nodes of cotton plant development across collective data sets.

Node	Samples in *Bt* cotton			Samples in Non-*Bt* cotton		
	Total samples[x]	Samples with eggs present		Total samples[x]	Samples with eggs present	
		n[y]	Mean ± SE[z]		n[y]	Mean ± SE[z]
8	30	4	0.011 ± 0.003	63	11	0.045 ± 0.018
9	63	13	0.095 ± 0.033	34	9	0.123 ± 0.038
10	70	18	0.103 ± 0.043	36	11	0.040 ± 0.010
11	78	10	0.081 ± 0.033	46	6	0.032 ± 0.012
12	94	14	0.047 ± 0.008	67	18	0.094 ± 0.028
13	103	35	0.114 ± 0.029	40	14	0.072 ± 0.016
14	71	32	0.118 ± 0.027	56	17	0.130 ± 0.039
15	85	41	0.216 ± 0.046	42	21	0.160 ± 0.037
16	81	34	0.279 ± 0.064	45	21	0.221 ± 0.070
17	78	24	0.153 ± 0.032	34	16	0.222 ± 0.050
18	74	29	0.142 ± 0.025	24	14	0.103 ± 0.037
19	48	18	0.100 ± 0.024	32	11	0.175 ± 0.056
20	23	8	0.031 ± 0.013	9	7	0.054 ± 0.019

[x] Total samples recorded in either *Bt* or non-*Bt* cotton types at mainstem node of plant development (including samples with no eggs).

[y] Number of samples when eggs were present in either *Bt* or non-*Bt* cotton types.

[z] Mean ± SE of eggs per plant for samples in which eggs were detected in either *Bt* or non-*Bt* cotton types.

Table 2. Significant regressions ($P < 0.05$) with greatest r^2 values for heliothine eggs present at different total mainstem nodes of *Bt* cotton development and end-of-season boll numbers and seedcotton weight per plant for particular cohorts of fruit.

Node	n	Fruit cohort with greatest r^2								All bolls per plant			Total weight per plant[v]		
		Bolls per cohort				Weight per cohort[v]									
		Cohort[w]	Int[x]	slope	r^2	Cohort[w]	Int[x]	slope	r^2	Int[z]	slope	r^2	Int[x]	slope	r^2
8	4	*[y]	*	*	*	*	*	*	*	*	*	*	*	*	*
9	13	NS[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
10	18	C11-C15	2.7	-3.9	0.27	C11-C15	10.5	-16.2	0.25	NS	NS	NS	NS	NS	NS
11	10	C7-C10	3.6	-9.5	0.83	C6-C10	17.2	-47.8	0.84	7.6	-19.1 ± 6.6	0.51	32.3	-86.9	0.51
12	14	C13-C17	3.0	-36.7	0.45	C13-C17	12.0	-153.4	0.44	NS	NS	NS	NS	NS	NS
13	35	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
14	32	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
15	41	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
16	34	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
17	24	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
18	29	C14-C17	2.4	-3.0	0.19	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
19	18	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
20	8	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[v] Seedcotton weight (g).

[w] Fruit examined included a range of total fruiting positions up to ± five cohorts (cohorts named by the node of the first position fruit) from the uppermost mainstem node at the time that an insect sample was recorded.

[x] Estimated intercept coefficient.

[y] Data eliminated because samples size was less than five comparisons.

[z] Regression equations were not significant ($P < 0.05$) for a particular mainstem node.

Table 3. Significant regressions (P < 0.05) with greatest r^2 values for heliothine eggs present at different total mainstem nodes of non-*Bt* cotton development and end-of-season boll numbers and seedcotton weight per plant for particular cohorts of fruit.

Node	n	Fruit cohort with greatest r^2								All bolls per plant			Total weight per plant[w]		
		Bolls per cohort				Weight per cohort[w]									
		Cohort[x]	Int[y]	slope	r^2	Cohort[x]	Int[y]	slope	r^2	Int[y]	slope	r^2	Int[y]	slope	r^2
8	11	C6-C10	3.8	-18.8	0.54	C7-C9	10.3	-56.3	0.54	NS[z]	NS	NS	NS	NS	NS
9	9	C10-C14	4.0	-13.0	0.77	C10-C14	17.5	-59.9	0.80	8.0	-21.1	0.63	34.60	-91.7	0.61
10	11	C11-C12	1.7	-16.4	0.59	C11-C12	7.4	-79.4	0.57	7.7	-51.9	0.39	32.27	-228.3	0.39
11	6	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
12	18	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
13	14	C14	0.7	-3.2	0.37	C14-C18	7.5	-35.1	0.29	NS	NS	NS	NS	NS	NS
14	17	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
15	21	C14-C16	1.5	-1.9	0.23	C14-C16	5.8	-7.1	0.19	NS	NS	NS	NS	NS	NS
16	21	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
17	16	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
18	14	NS	NS	NS	NS	NS	NS	NS	NS	9.0	-9.3	0.38	NS	NS	NS
19	11	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
20	7	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[w] Seedcotton weight (g).

[x] Fruit examined included a range of total fruiting positions up to ± five cohorts (cohorts named by the node of the first position fruit) from the uppermost mainstem node at the time that an insect sample was recorded.

[y] Estimated intercept coefficient.

[z] Regression equations were not significant (P < 0.05) for a particular mainstem node.

Heliothine larvae: effect on fruit survival and seedcotton weight. The greatest number of heliothine larvae observed on *Bt* cotton plants occurred when plants possessed 18 mainstem nodes (Table 4), while the greatest number of larvae observed on non-*Bt* cotton occurred when plants had 17 mainstem nodes. Heliothine larvae were observed in only 15.4% of samples on *Bt* cotton while they were observed on 36.7% of the samples on non-*Bt* cotton.

Heliothine larvae present on *Bt* cotton at three different total mainstem nodes of plant development had a negative impact on surviving fruit and weight within particular fruiting cohorts (Table 5). Heliothine larvae present when plants had 13 mainstem nodes explained fruit loss and seedcotton weight loss best within cohorts C8 to C18. Larvae present on plants with 17 mainstem nodes explained fruit and weight loss on fruit cohorts C12 - C16, while larvae present on plants with 18 mainstem nodes explained fruit and weight loss best for the fruit cohort C19. Larvae present when plants had 13 and 17 mainstem nodes resulted in a significant negative impact on both total fruit and weight on a per plant basis.

All significant negative impacts for heliothine larvae present on non-*Bt* cotton and fruit survival and seed cotton weight occurred for populations observed when plants had 14 to 19 mainstem nodes (Table 6). These impacts were for cohorts of fruit that were developing at the time of infestation (plants with 14 mainstem nodes), total bolls per plant (plants with 18 mainstem nodes), or cohorts of fruit ~ 3 – 15 d old at the time of infestation (plants with 15-17 and 19 mainstem nodes). Larvae present when plants had 18 and 19 mainstem nodes had a significant negative effect on total fruit and seed cotton weight loss per plant.

Plant bugs: effect on and fruit survival and seedcotton weight. Generally, the number of plant bugs observed on insect sample dates increased as cotton plants developed more mainstem nodes, with peak plant bug numbers observed on plants possessing 19 mainstem nodes (0.18 ± 0.04 plant bugs per plant) (Table 7). Plant bugs present on plants with eight different mainstem nodes of development had a negative impact on fruit survival within particular cohorts of fruit, and all but one of these (infestations when plants had 12 mainstem nodes) had a negative impact within comparable cohorts on seed cotton weight loss (Table 8). Survival of fruit cohorts for infestations on six of these eight mainstem nodes of plant development was best explained for fruit up to ~ 15 d old at the time of infestation. Similarly, plant bugs present at four different mainstem nodes of plant development explained seed cotton weight loss best for fruit cohorts including fruit up to ~ 15 d old at the time of infestation. This indicates that plant bugs were feeding, or actually causing loss of harvestable fruit already established on the plant at the time of infestation. Plant bug populations negatively impacted total harvested bolls per plant at four different mainstem nodes of plant development and total seed cotton weight per plant when infestations occurred on plants with nine and 17 total mainstem nodes. Estimated impacts of plant bugs on fruit survival and seed cotton weight decreased as the number of mainstem nodes on plants increased.

DISCUSSION

End-of-season yield mapping of cotton plants provides information about fruit survival, but provides no evidence of the causes of fruit loss. It is simply a 'picture' taken at the end of the season that reveals the location of surviving fruit and the contributions of fruit from these fruiting locations to final yield. Within-season plant mapping provides some information as to the timing of fruit loss at various nodes and positions if conducted regularly during the growing season, but again does not discern the cause or causes of missing fruit or measure the probability of fruit loss prior to season-end harvest. Fruit loss can be caused by numerous factors including weather, field conditions, disease, fruit presence or absence at other locations of the plant, or damage caused by insects (Sadras et al. 1997).

One of the obstacles in using end-of-season mapping to examine the impact of insect densities is to properly relate the insect information with the cohort of fruit that most likely received damage. It has been noted that most of the fruit damage caused by heliothines is to cotton squares (Quaintance and Brues 1905, Kincade et al. 1967, Nicholson 1975), although developing larvae generally feed on increasingly larger fruiting forms. The tarnished plant bug also prefers to feed on squares less than three mm (or only a few days old) (Pack and Tugwell 1976). In this study, the numbers of insects present when plants were at an estimated stage of mainstem

Table 4. Mean number of heliothine larvae per sample at various total mainstem nodes of cotton plant development across collective data sets.

Node	Samples in *Bt* cotton			Samples in Non-*Bt* cotton		
	Total samples [x]	Samples with larvae present		Total samples [x]	Samples with larvae present	
		n [y]	Mean ± SE [z]		n [y]	Mean ± SE [z]
8	32	0	0.000 ± 0.000	64	4	0.013 ± 0.004
9	63	0	0.000 ± 0.000	34	3	0.054 ± 0.019
10	71	4	0.011 ± 0.003	36	6	0.008 ± 0.002
11	83	3	0.007 ± 0.002	46	7	0.019 ± 0.006
12	95	3	0.032 ± 0.024	67	15	0.042 ± 0.007
13	102	7	0.054 ± 0.027	40	14	0.035 ± 0.008
14	72	15	0.066 ± 0.026	58	21	0.082 ± 0.017
15	88	25	0.049 ± 0.011	46	27	0.101 ± 0.017
16	87	25	0.065 ± 0.012	46	35	0.118 ± 0.016
17	81	21	0.106 ± 0.028	35	24	0.169 ± 0.031
18	79	21	0.121 ± 0.027	26	21	0.115 ± 0.021
19	56	15	0.086 ± 0.037	33	17	0.122 ± 0.027
20	31	6	0.009 ± 0.001	9	4	0.054 ± 0.017

[x] **Total samples recorded in either *Bt* or non-*Bt* cotton types at mainstem node of plant development (including samples with no larvae).**

[y] **Number of samples when larvae were present in either *Bt* or non-*Bt* cotton types.**

[z] **Mean ± SE of larvae per plant for samples in which larvae were detected in either *Bt* or non-*Bt* cotton types.**

node development was related to the youngest fruiting cohorts that would have been available for feeding. These fruiting cohorts were based on a 2.0 vertical to horizontal fruiting pattern. To compensate for a possible different vertical to horizontal fruiting interval and to examine insect effects on different age classes of fruit, the impact of fruit survival and seed cotton weight up to ± five fruiting cohorts from the uppermost node when the insect sample was recorded was examined.

Because numerous factors influence end-of-season survival of fruit, relationships between insect densities and end-of-season fruit survival were examined using only samples when at least one of the particular insect variables was detected. Heliothines or tarnished plant bugs were observed in less than 50% of the individual samples. Heliothine eggs were observed in 31% and 33% of the samples in *Bt* and non-*Bt* cotton, respectively. Heliothine larvae were observed in only 15% of samples in *Bt* cotton, while larvae were observed 37% of the time in non-*Bt* cotton samples. Plant bugs were recorded in 48% of all samples and were the most common of the targeted insects observed.

Heliothine eggs, heliothine larvae and plant bugs shared temporal distributions within the data sets used in this paper. Only a single insect variable was used in regression equations to examine fruit and seed cotton weight loss within particular cohorts of fruit. Damage or seed cotton weight loss caused to cohorts of fruit by these insects almost certainly overlapped. The goal of the analysis was to determine if losses within particular cohorts of fruit based on end-of-season plant maps could be attributed to trends in particular insect densities. The numerous significant regression equations with negative slope coefficients indicate that this was accomplished.

The number of plant bugs present when plants had eight different total mainstem nodes of development resulted in negative impacts on surviving fruit. Fruit loss caused by plant bugs was best explained for fruiting forms ~ 3 to 15 d old at the time of infestation, corresponding to small to medium sized squares.

Table 5. Significant regressions (P < 0.05) with greatest r^2 values for heliothine larvae present at different total mainstem nodes of *Bt* cotton development and end-of-season boll numbers and seedcotton weight per plant for particular cohorts of fruit.

Node	n	Fruit cohort with greatest r^2								All bolls per plant			Total weight per plant[v]		
		Bolls per cohort				Weight per cohort[v]									
		Cohort[w]	Int[x]	slope	r^2	Cohort[w]	Int[x]	slope	r^2	Int[x]	slope	r^2	Int[x]	slope	r^2
8	0	*[y]	*	*	*	*	*	*	*	*	*	*	*	*	*
9	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	3	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12	3	*	*	*	*	*	*	*	*	*	*	*	*	*	*
13	7	C8-C18	6.0	-20.5	0.69	C8-C18	25.0	-111.6	0.71	7.4	-21.6	0.65	30.8	-127.2	0.70
14	15	NS[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
15	25	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
16	25	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
17	21	C12-C16	3.2	-6.4	0.49	C12-C16	13.0	-27.1	0.41	8.8	-7.7	0.31	37.8	-31.0	0.19
18	21	C19	0.1	-0.3	0.35	C18	0.5	-1.7	0.27	8.9	-8.5	0.33	NS	NS	NS
19	15	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
20	6	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[v] Seedcotton weight (g).

[w] Fruit examined included a range of total fruiting positions up to ± five cohorts (cohorts named by the node of the first position fruit) from the uppermost mainstem node at the time that an insect sample was recorded.

[x] Estimated intercept coefficient.

[y] Data eliminated because samples size was less than five comparisons.

[z] Regression equations were not significant (P < 0.05) for a particular mainstem node.

Similarly fruit loss caused by heliothine larvae on non-*Bt* cotton was best explained for fruiting forms ~ 3 to 15 d old or fruiting forms just being developed. Since these data include sprayed fields, there is a possibility that pest populations in some experiments were treated with insecticides soon after they were detected. This may cause an underestimation of the true impact of insect feeding. Likewise, some samples occurred soon after an insecticide application which would cause an overestimation in the damage caused by insect feeding (i.e., existing damage related to fewer insects than actually caused the damage).

Overall, plant bugs impacted surviving fruit within a wider defined zone of plant development than did heliothines. The effect of plant bugs on the loss of both total numbers of bolls and total seed cotton weight per plant decreased through the season. This indicates that economic thresholds for tarnished plant bugs should increase later in the growing season. Detectable impacts of heliothines occurred more often on non-*Bt* cotton than on *Bt* cotton. The clearest trend for insect induced damage and fruit cohorts was for plant bugs and heliothine larvae (on non-*Bt* cotton) to eliminate squares ~ 3 to 15 d old. Understanding the age of fruit that is most likely to be damaged by an insect population is important for making management decisions, especially when to terminate insecticide sprays late in the growing season. If an insect population prefers to feed on younger fruit which are not likely to be harvested, then insecticide applications may be terminated earlier than if the insects preferentially feed on older fruit. The actual magnitude of insect damage (slope coefficient) is influenced by the management practices within particular treatments. This study included a very large database with field observations from different locations and insect-treated environments. Utilization of end-of-season yield mapping to understand the impact of temporal patterns of insect injury on harvestable fruit and yield should be more accurate for experiments where crop development and insect information are collectively recorded. These results indicate development of dynamic thresholds would be appropriate and are needed.

Table 6. Significant regressions (P < 0.05) with greatest r^2 values for heliothine larvae present at different total mainstem nodes of non-*Bt* cotton development and end-of-season boll numbers and seedcotton weight per plant for particular cohorts of fruit.

Node	n	Fruit cohort with greatest r^2								All bolls per plant			Total weight per plant[v]		
		Bolls per cohort				Weight per cohort[v]									
		Cohort[w]	Int[x]	slope	r^2	Cohort[w]	Int[x]	slope	r^2	Int[x]	slope	r^2	int[c]	slope	r^2
8	4	*[y]	*	*	*	*	*	*	*	*	*	*	*	*	*
9	3	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10	6	NS[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
11	7	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
12	15	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
13	14	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
14	21	C14	0.4	-1.7	0.30	C14	1.6	-6.9	0.28	NS	NS	NS	NS	NS	NS
15	27	C14	0.6	-2.0	0.33	C13-C14	4.7	-14.4	0.28	NS	NS	NS	NS	NS	NS
16	35	C14-C15	0.8	-1.9	0.17	C12-C15	8.2	-15.5	0.17	NS	NS	NS	NS	NS	NS
17	24	C14-C16	1.1	-2.2	0.27	C14-C16	4.6	-9.0	0.28	NS	NS	NS	NS	NS	NS
18	21	C15-C21	1.4	-4.8	0.36	C18	0.5	-1.8	0.23	8.6	-17.6	0.39	34.5	-58.0	0.31
19	17	C14-C18	2.2	-6.7	0.61	C16-C18	3.9	-10.2	0.38	8.5	-15.6	0.45	34.7	-53.8	0.36
20	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*

[v] Seedcotton weight (g).

[w] Fruit examined included a range of total fruiting positions up to ± five cohorts (cohorts named by the node of the first position fruit) from the uppermost mainstem node at the time that an insect sample was recorded.

[x] Estimated intercept coefficient.

[y] Data eliminated because samples size was less than five comparisons.

[z] Regression equations were not significant (P < 0.05) for a particular mainstem node.

Table 7. Mean number of plant bugs per sample at various total mainstem nodes of cotton plant development across collective data sets.

Node	Samples in all cotton types		
	Total samples[x]	Samples with plant bugs present	
		n[y]	Mean ± SE[z]
8	92	9	0.023 ± 0.010
9	98	36	0.027 ± 0.007
10	149	80	0.075 ± 0.010
11	140	57	0.059 ± 0.010
12	179	67	0.049 ± 0.006
13	126	45	0.038 ± 0.006
14	110	47	0.054 ± 0.012
15	105	51	0.081 ± 0.015
16	102	75	0.128 ± 0.020
17	87	65	0.173 ± 0.024
18	96	61	0.145 ± 0.026
19	79	58	0.180 ± 0.043
20	37	25	0.051 ± 0.010

[x] Total samples recorded in all cotton types at mainstem node of plant development (including samples with no plant bugs)

[y] Number of samples when plant bugs were present in all cotton types

[z] Mean ± SE of plant bugs per plant for samples in which plant bugs were detected in all cotton types

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Table 8. Significant regressions (P < 0.05) with greatest r^2 values for plant bugs present on all cotton types at different total mainstem nodes of cotton development and end-of-season boll numbers and seedcotton weight per plant for particular cohorts of fruit.

Node	n	Fruit cohort with greatest r^2								All bolls per plant			Total weight per plant[w]		
		Bolls per cohort				Weight per cohort[w]									
		Cohort[x]	Int[y]	slope	r^2	Cohort[x]	Int[y]	slope	r^2	Int[y]	slope	r^2	int[c]	slope	r^2
8	9	NS[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
9	36	C10-C14	3.4	-15.2	0.16	C10-C14	14.2	-69.6	0.19	7.2	-27.0	0.14	29.1	-117.2	0.15
10	80	C5-C9	2.2	-5.8	0.19	C5-C9	9.2	-22.1	0.14	NS	NS	NS	NS	NS	NS
11	57	C6-C10	2.8	-7.7	0.16	C8-C10	8.6	-21.3	0.14	NS	NS	NS	NS	NS	NS
12	67	C7-C11	3.3	-9.3	0.09	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
13	45	C8-C12	4.1	-14.1	0.14	C8-C12	17.0	-50.0	0.09	8.4	-21.3	0.13	NS	NS	NS
14	47	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
15	51	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
16	75	C13-C19	2.8	-3.8	0.23	C13-C19	11.0	-13.2	0.16	7.8	-4.8	0.13	NS	NS	NS
17	65	C12-C16	3.4	-2.8	0.18	C12-C16	13.5	-12.2	0.18	8.2	-3.8	0.13	33.8	-19.9	0.17
18	61	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
19	58	C14-C18	2.1	-1.5	0.12	C14-C18	8.6	-5.4	0.09	NS	NS	NS	NS	NS	NS
20	25	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[w] Seedcotton weight (g).

[x] Fruit examined included a range of total fruiting positions up to ± five cohorts (cohorts named by the node of the first position fruit) from the uppermost mainstem node at the time that an insect sample was recorded.

[y] Estimated intercept coefficient.

[z] Regression equations were not significant (P < 0.05) for a particular mainstem node.

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