EVALUATING INSECT MANAGEMENT STRATEGIES USING YIELD MAPPING

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Abstract

Field plots were artificially infested with neonate tobacco budworm larvae at 6 different densities on 6 different weeks during 1997. The plots were subsequently monitored for larval survival. When all bolls had opened at the end of the season, the weight of fruit produced by individual locations on the plant was recorded, and same age fruit was grouped as cohorts. Low survival of artificial infestations limited the interpretation of the data. However, the data did indicate that if larvae do have time to establish, the end of season plant mapping could be used to evaluate the effect on individual cohorts.

Introduction

Management decisions regarding insect pests of cotton often rely on published pest thresholds to determine treatment densities. Changes in technology, pest species, and varieties may necessitate refinement of current thresholds. The use of transgenic insecticidal plants and the increased pest status of stinkbugs demonstrate some recent issues requiring modification of threshold recommendations. Additionally, an earlier transition from vegetative to reproductive stage has been reported for modern cotton cultivars as compared to obsolete cultivars (Wells & Meredith 1984a, b).

Studies reporting the number of fruit damaged per insect per day offer valuable information in identifying critical insect densities that warrant control. However, the complexity of identifying which cotton bolls will survive and be harvested limits the exactness of thresholds based on feeding potential of pests. Plant compensation may allow damage to occur to immature fruit without reducing the final yield. Conversely, protecting fruit from insect damage does not ensure the harvest of the fruit. Factors such as pathogens, nutrients, or other physical stresses may cause the fruit to abscise (Mauney & Henneberry 1984). As much as 25 to 50% of all squares may abscise before blooming (Hall 1958).

Expenditures intended for protection of immature fruit that will not be harvested represents losses in profit. A recent example of non-justified expenditures was identified for insecticide control measures applied after the cotton crop had exceeded 350 to 450 degree days beyond five nodes above the first position white flower (Bourland, et al. 1992). Methods to evaluate insect management decisions need to ensure expenditures are justified. Compensation and physiological losses should be incorporated into the evaluation of insect management decisions. Jenkins and McCarty (1995) described varietal yield differences using "end of season plant maps". This method provides a measurement of the contribution of each fruiting site of the cotton plant. Subsequent grouping of the data allowed examination of the relative contribution of individual nodes and individual positions. The present study utilized the "end of season plant map" or yield mapping method to examine insect management strategies. Our purpose was to determine if yield mapping could be used to identify differences in pest densities.

Materials and Methods

Plots (8 rows X 32 feet) of DES 119 were planted at normal plant densities (3 to 4 plants per foot of row) at the Mississippi Agricultural and Forestry Experiment Station Plant Science Research Farm, Miss. State, MS during 1997. Four replicates of each plot were planted on May 15. Treatments included 6 different densities of *Heliothis virescens* F. larvae infested on 6 different weeks. For each of the 6 infestation weeks, four plots were used, each representing one replicate. Rows within the plot were randomly assigned a density of *H. virescens* larvae (0, 1, 3, 10, 30, or 100% plants with larvae). Eggs were obtained from adult *H. virescens* reared by the USDA Crop Science Research Laboratory at Mississippi State, MS. Eggs obtained from the USDA laboratory were held until hatching in environmental chambers. Infestations were made using the Davis Inoculator (Davis et al. 1989) to place 5 neonate larvae in the terminal of a percentage of the cotton plants depending on the intended density of plants with larvae. Once infested, plots remained untreated for approximately 14 days to allow the completion of the larval cycle. Before and after the two-week infestation period, plots were scouted collectively and protected based on natural infestations exceeding recommended thresholds for Mississippi. Therefore, all plots were protected similarly except during the 2-wk infestation designated for a particular treatment. Thus, any influence of natural infestation would still occur during the 2-wk period of interest. Terminals and squares were scouted at various days after placing the larvae in the terminals to record established densities.

When all bolls had opened, a 10-foot section of row was removed from the field to measure the fruiting pattern of the yield. Non-typical plants were grouped separately from the typical plants. The number of atypical plants, bolls from

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1128-1132 (1999)
National Cotton Council, Memphis TN

atypical plants, and weight (gm) of seed cotton from atypical plants was recorded. Vegetative branches were removed from the typical plants and the number of bolls and weight of bolls was recorded. The remaining seed cotton on reproductive branches was separated based on the main stem node and vertical position of the fruit as described by Jenkins and McCarty (1995). A wooden box was constructed with 4-rows representing 4-vertical positions on a reproductive branch and necessary columns representing the number of main stem nodes. Each cell within the box represented an individual node-position location on a cotton plant. Assigning a value of zero to the cotyledonary node, the location of each boll was identified and placed in the respective box. For each boll placed in a cell, a pinto bean was also placed in the cell to maintain a count of the number of bolls. After all plants for a given week and given insect density had been processed, the number of bolls (beans) was recorded for the individual node-position fruiting site. The seed cotton was removed and weight was recorded for each fruiting site (cell). Additionally, the total number of plants (atypical and typical) for the 10-foot section of row was recorded. Weight data were converted to a per plant average to equalize the number of plants mapped.

Using the typical sequence of cotton fruiting in MS (3 days between vertical fruit and 6 days between horizontal fruit [Jenkins and McCarty 1995]), the fruit expected to be initiated on the same day was grouped (fruit cohort). For example, if C represents a cohort of fruit being initiated and *i* indicates the number of days past first fruit, then the first fruit is represented by C_0. The next fruit would set 3 days later (C_3). Assuming the earliest first fruit at node 4, we can begin the sequence of fruit initiation.

C_0 = node 4 position 1 (4.1)
$C_3 = 5.1$
$C_6 = 4.2+6.1$
$C_9 = 5.2+7.1$
$C_{12} = 4.3+6.2+8.1$

Similarly, we can calculate the accumulation of the fruit, AC_i, by adding the successive fruit cohorts (C_i) such as

$AC_0 = C_0$
$AC_3 = C_0 + C_3$
$AC_6 = C_0 + C_3 + C_6$
$AC_9 = C_0 + C_3 + C_6 + C_9$

By using these calculations, we can examine the yield response of plants over time.

Data were analyzed by analysis of variance with the means separated by Fisher's Protected Least Significant Difference test. Data were examined as a factorial analysis (6 weeks X 6 densities X 4 replicates) with interaction tests. Additional analysis examined density effects within each infestation week due to interactions between week and density.

Results and Discussion

The artificial infestation of larvae resulted in an 80% and 66% establishment 1-day post infestation for the June 18 and June 26 infestation dates respectively (Table 1 and 2). Unfortunately, larval survival was reduced for later observation dates. Larvae infested on July 8, 10, 15, and 25 had low survival (Tables 3, 4, 5, and 6, respectively). Few significant differences were detected between initial infestation densities for any infestation date. However, the numerical differences provide an index for comparing differences in the harvested cohorts of fruit. Additionally, the scouting data provide information relevant to the natural infestations. Natural infestations were believed to have occurred when the percent of plants with larvae had increased on a scouting date as compared to the previous date. Since these plots were in very close proximity to each other, it is assumed that natural infestations occurred for all plots at the same time, regardless of artificial infestation date.

Results from the end-of-season plant mapping indicated significant differences in the weight of seed cotton from atypical plants for the 10-row-feet sample on the June 18 and June 25 infestation dates (Table 7). The data indicate that the larvae were established long enough to cause terminal damage resulting in atypical growth. The difference in atypical weight of seed cotton per 10 row feet is due to different number of atypical plants. No significant differences were detected between infestation densities with regards to mean weight per atypical plant, mean weight per plant for vegetative branch yield, or mean total harvested weight.

Few significant (p#0.05) differences were detected between densities with regards to cohort weight per plant (Table 8). For the June 18 infestation date, differences were detected between densities for the second cohort of fruit (C_3) and the 11th cohort of fruit (C_{30}). Based on average number of nodes, the June 18 infestation date coincided with the initiation of the C_6 cohort. Although the C_6 cohort was not significantly different between densities (p=0.15), it is conceivable that the larvae moved down the plant and damaged the C_3 cohort. The C_3 cohort measurements were very small and only indicated that the non-infested plot maintained early fruit that no insect infestation density maintained. The difference that was observed for the C_{30} cohort showed more weight was produced in the 3% density than in any other infestation density. Additionally, the 30% density produced more weight per plant at the C_{30} cohort than the 100% infestation density, with all remaining infestation densities as intermediates. It is interesting to note that the insect count data suggest a natural infestation coincided with the initiation of the C_{33} cohort (p=0.11) which may have caused the loss in weight at the C_{30} cohort as a result of larger larvae moving down the plant from their initial site of egg hatch.

The July 8 infestation date was calculated to have coincided with the initiation of the C_{24} cohort. The only difference detected between densities was the C_{27} cohort. Data show more weight produced in the 100% density than in the 0% or 30% density. This may be due to compensation, but no significant loss was measured at C_{24}.

The July 10 infestation date was calculated to have coincided with the initiation of the C_{27} cohort. Differences in weight of seed cotton harvested between densities were found for the C_{27} and C_{45} cohorts. The C_{39} cohort was not significant at the p#0.05 level, but was very close and should be noted (p=0.06). The data for the C_{27} cohort showed more weight produced in the 100% density as compared to the 0% density; for the C_{45} cohort, the 30% density produced more weight than the 0% density. Again, these data may indicate a compensation effect.

The July 25 infestation date was calculated to have coincided with the C_{39} cohort. Significant differences between densities were detected for the C_{33} and C_{39} cohorts. The C_{33} cohort showed more weight produced in the 30% density than the 0% density. The C_{39} cohort indicated more fruit produced in the 100% density as compared to the 0% density. The larval data 4-days post infestation shows numerically more larvae in the 0% density as compared to the 100% density during this time.

Adding cohorts in the sequence of their production provides a graphical representation of the harvested fruit in a time sequence (Figures 1-6). The only density effect detected for accumulated cohorts (AC) was for the June 18 infestation date at AC_3. However, this difference is the same as C_3 due to no previous fruit. Differences detected for an individual cohort (C) coincided with the same subscript for the accumulated cohorts (AC). Therefore, the divergence in fruiting behavior can be observed. The relevance of observing these differences can be demonstrated by noting that the larval data suggest natural infestations coincided with AC_{12}, AC_{33}, AC_{45}, and AC_{51}. In most figures, a disturbance in the slope of the curves can be observed at the natural infestation cohorts or the preceding cohorts. Unfortunately, sufficient insect data were not maintained in these studies for the duration of the fruiting season and the artificial infestations had low survival. Although these data suggest infestation effects on individual cohorts can be detected with the end of season plant mapping, additional data would increase the applicable interpretation of the data. It appears obvious that subsequent natural infestations may not be uniformly distributed in these small plots and may confuse single artificial infestation effects. The yield mapping method may provide more information if insect data and average node data were maintained for the growing season. Additionally, the method may be improved by using degree-days for cohort groups rather than days or by actually calculating by node counts the precise number of days per node on a continuous basis. Noting stress periods and periods of fruit shed may offer additional refinement of interpreting fruiting effects. Such improvements may provide valuable refinement to insect management evaluation.

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Table 1. Mean (Std. Dev.) percentage of plants with larvae for different initial infestation densities that were infested on June 18 and monitored 1, 8, and 12 days post infestation

	% Plants with Larvae		
Initial Infestation Density	1 Day [a]	8 Days	12 Days
0	0.0	0.0 (0.0)a	2.5 (0.5)a
1	0.8	2.5 (5.0)a	0.0 (0.0)a
3	2.4	5.0 (5.8)a	0.0 (0.0)a
10	8.0	12.5 (18.9)a	0.0 (0.0)a
30	24.0	5.0 (5.8)a	0.0 (0.0)a
100	80.0	20.0 (14.1)a	0.0 (0.0)a

[a] Percentage based on percent of infested plants with larvae multiplied by the initial infestation density.

Table 2. Mean (Std. Dev.) percentage of plants with larvae for different initial infestation densities that were infested on June 26 and monitored 1, 5, and 14 days post infestation

	% Plants with Larvae		
Initial Infestation Density	1 Day [a]	5 Days	14 Days
0	0.0	2.5 (0.5)a	0.0 (0.0)a
1	0.7	0.0 (0.0)a	0.0 (0.0)a
3	2.0	0.0 (0.0)a	0.0 (0.0)a
10	6.6	0.0 (0.0)a	0.0 (0.0)a
30	19.8	2.5 (0.5)a	2.5 (0.5)a
100	66.0	5.0 (5.8)a	0.0 (0.0)a

[a] Percentage based on percent of infested plants with larvae multiplied by the initial infestation density.

Table 3a. Mean (Std. Dev.) percentage of plants with larvae for different initial infestation densities that were infested on July 8 and monitored 2, 8, and 15 days post infestation

	2 Days		8 Days		15 Days	
Initial Infestation Density	% Plants with Larvae		% Plants with Larvae		% Plants with Larvae	
0	0.0 (0.0)	a	0.0 (0.0)	a	0.0 (0.0)	a
1	0.0 (0.0)	a	7.5 (15.0)	a	0.0 (0.0)	a
3	0.0 (0.0)	a	5.0 (10.0)	a	0.0 (0.0)	a
10	0.0 (0.0)	a	5.0 (10.0)	a	0.0 (0.0)	a
30	0.0 (0.0)	a	5.0 (10.0)	a	0.0 (0.0)	a
100	0.0 (0.0)	a	2.5 (10.0)	a	2.5 (5.0)	a

Table 3b. Mean (Std) percentage of plants with damaged terminals for different initial infestation densities that were infested on July 8 and monitored 2, 8, and 15days post infestation

	2 Days		8 Days		15 Days	
Initial Infestation Density	% Plants with Damaged Terminals		% Plants with Damaged Terminals		% Plants with Damaged Terminals	
0	0.0 (0.0)	a	0.0 (0.0)	a	2.5 (5.0)	a
1	0.0 (0.0)	a	10.0 (11.5)	a	2.5 (5.0)	a
3	7.5 (9.6)	a	10.0 (14.1)	a	10.0 (11.5)	a
10	7.5 (9.6)	a	2.5 (5.0)	a	7.5 (9.6)	a
30	10.0 (8.2)	a	2.5 (5.0)	a	2.5 (5.0)	a
100	15.0 (3.0)	a	20.0 (18.3)	a	7.5 (9.6)	a

Table 4a. Mean (Std. Dev.) percentage of plants with larvae for different initial infestation densities that were infested on July 10 and monitored 6, 13, and 19 days post infestation

	6 Days		13 Days		19 Days	
Initial Infestation Density	% Plants with Larvae		% Plants with Larvae		% Plants with Larvae	
0	0.0 (0.0)	a	0.0 (0.0)	a	10.0 (8.2)	a
30	0.0 (0.0)	a	0.0 (0.0)	a	7.5 (9.6)	a
100	0.0 (0.0)	a	0.0 (0.0)	a	12.5 (12.6)	a

Table 4b. Mean (Std. Dev.) percentage of plants with damaged terminals for different initial infestation densities that were infested on July 10 and monitored 6, 13, and 19 days post infestation

	6 Days		13 Days		19 Days	
Initial Infestation Density	% Plants with Damaged Terminals		% Plants with Damaged Terminals		% Plants with Damaged Terminals	
0	5.0 (10.0)	a	2.5 (5.0)	a	0.0 (0.0)	a
30	0.0 (0.0)	a	0.0 (0.0)	a	10.0 (8.2)	a
100	2.5 (5.0)	a	5.0 (10.0)	a	2.5 (5.0)	a

Table 5a. Mean (Std. Dev.) percentage of plants with larvae for different initial infestation densities that were infested on July 15 and monitored 8, 14, and 19 days post infestation

	8 Days		14 Days		19 Days	
Initial Infestation Density	% Plants with Larvae		% Plants with Larvae		% Plants with Larvae	
0	0.0 (0.0)	a	0.0 (0.0)	b	5.0 (5.8)	a
30	0.0 (0.0)	a	15.0 (10.0)	a	7.5 (9.6)	a
100	0.0 (0.0)	a	7.5 (9.6)	ab	0.0 (0.0)	a

Table 5b. Mean (Std. Dev.) percentage of plants with damaged terminals for different initial infestation densities that were infested on July 15 and monitored 8, 14, and 19 days post infestation

	8 Days		14 Days		19 Days	
Initial Infestation Density	% Plants with Damaged Terminals		% Plants with Damaged Terminals		% Plants with Damaged Terminals	
0	7.5 (9.6)	a	15.0 (5.8)	a	2.5 (5.0)	a
30	10.0 (11.5)	a	12.5 (5.0)	a	17.5 (9.6)	a
100	5.0 (10.0)	a	0.0 (0.0)	b	5.0 (10.0)	a

Table 6a. Mean (Std. Dev.) percentage of plants with larvae for different initial infestation densities that were infested on July 25 and monitored 4 and 9 days post infestation

	4 Days		9 Days	
Initial Infestation Density	% Plants with Larvae		% Plants with Larvae	
0	7.5 (15.0)	a	5.0 (10.0)	a
30	17.5 (22.2)	a	5.0 (5.8)	a
100	5.0 (5.8)	a	7.5 (5.0)	a

Table 6b. Mean (Std. Dev.) percentage of plants with damaged terminals for different initial infestation densities that were infested on July 25 and monitored 4 and 9 days post infestation

	4 Days		9 Days	
Initial Infestation Density	% Plants with Damaged Terminals		% Plants with Damaged Terminals	
0	2.5 (5.0)	a	12.5 (5.0)	a
30	2.5 (5.0)	a	15.0 (10.0)	a
100	10.0 (8.2)	a	12.5 (5.0)	a

Table 7. Weight (gm) of seed cotton on atypical plants

Density	Infestation Week					
	1	2	3	4	5	6
0	143c	170a	45a	116a	83a	146a
1	149c	48b				
3	127c	49ab				
10	232bc	63ab				
30	309b	40b	17a	130a	166a	68a
100	637a	93ab	71a	126a	93a	161a

Table 8. Mean (Std. Dev.) harvested weight (gm) per plant for plants infested on various dates that were harvested by individual cohorts (C) and the sum of the cohorts (AC) which were significantly different between infestation densities

Initial Infestation Density									
				18-Jun Cohort					
	C_3			C_{30}			AC_3		
0	0.13	(0.15)	a	1.79	(0.88)	a	0.13	(0.15)	a
1	0.00	(0.00)	b	1.06	(0.41)	b-d	0.00	(0.00)	b
3	0.00	(0.00)	b	3.03	(0.72)	a	0.00	(0.00)	b
10	0.00	(0.00)	b	1.28	(0.73)	bc	0.00	(0.00)	b
30	0.00	(0.00)	b	0.41	(0.48)	cd	0.00	(0.00)	b
100	0.00	(0.00)	b	0.34	(0.42)	d	0.00	(0.00)	b
				8-Jul Cohort					
	C_{27}								
0	2.46	(0.88)	b						
30	2.28	(1.46)	b						
100	8.97	(3.22)	a						
				10-Jul Cohort					
	C_{27}			C_{39}			C_{45}		
0	1.43	(0.84)	b	0.44	(0.40)	b	0.01	(0.02)	b
30	2.18	(0.37)	ab	0.77	(0.58)	a	0.11	(0.09)	a
100	2.80	(1.43)	a	0.44	(0.44)	b	0.06	(0.08)	ab
				25-Jul Cohort					
	C_{33}			C_{39}					
0	0.61	(0.25)	b	0.48	(0.74)	b			
30	1.86	(0.81)	a	0.66	(0.48)	ab			
100	1.40	(0.46)	ab	0.95	(0.50)	a			

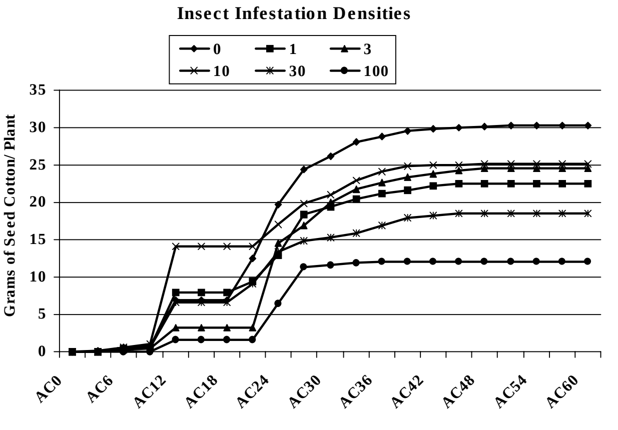

Figure 1. Accumulation of harvested weight (gms) from fruit cohorts (AC) beginning at mainstem node 4 (AC_0) and accumulated to node 24 (AC_{60}) for various initial infestation densities infested on June 18 which was approximately when the C_6 cohort was being initialized.

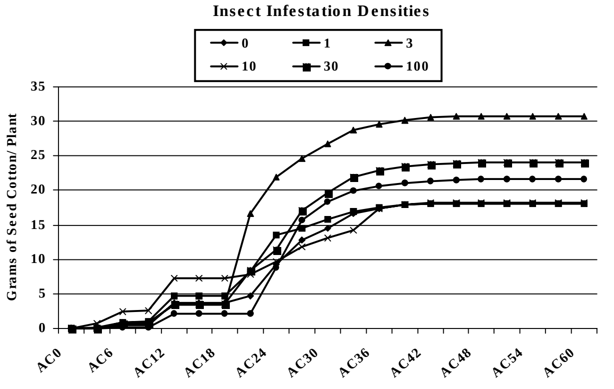

Figure 2. Accumulation of harvested weight (gms) from fruit cohorts (AC) beginning at mainstem node 4 (AC_0) and accumulated to node 24 (AC_{60}) for various initial infestation densities infested on June 26 which was approximately when the C_{12} cohort was being initialized.

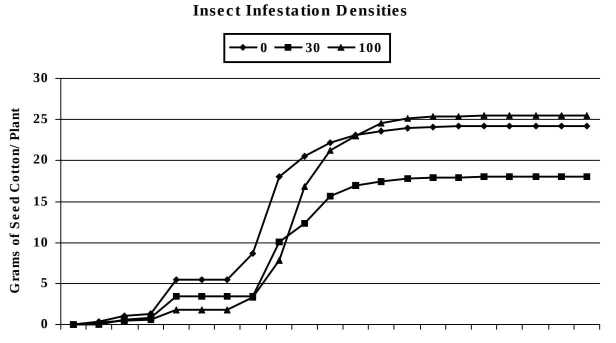

Figure 3. Accumulation of harvested weight (gms) from fruit cohorts (AC) beginning at mainstem node 4 (AC_0) and accumulated to node 24 (AC_{60}) for various initial infestation densities infested on July 8 which was approximately when the C_{24} cohort was being initialized.

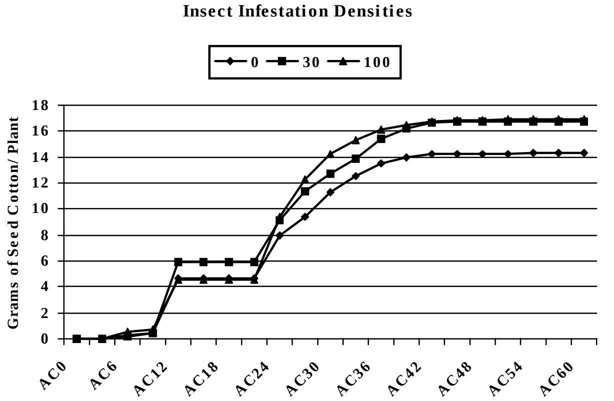

Figure 4. Accumulation of harvested weight (gms) from fruit cohorts (AC) beginning at mainstem node 4 (AC_0) and accumulated to node 24 (AC_{60}) for various initial infestation densities infested on July 10 which was approximately when the C_{27} cohort was being initialized.

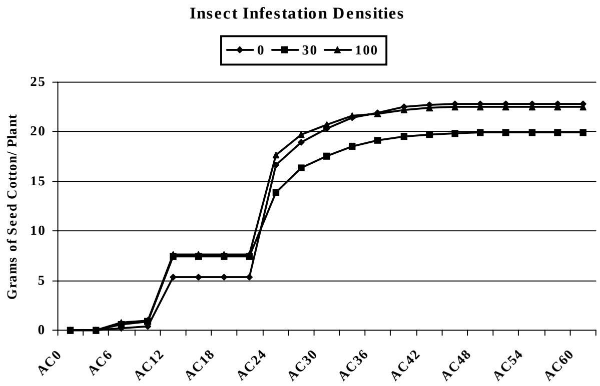

Figure 5. Accumulation of harvested weight (gms) from fruit cohorts (AC) beginning at mainstem node 4 (AC_0) and accumulated to node 24 (AC_{60}) for various initial infestation densities infested on July 15 which was approximately when the C_{33} cohort was being initialized.

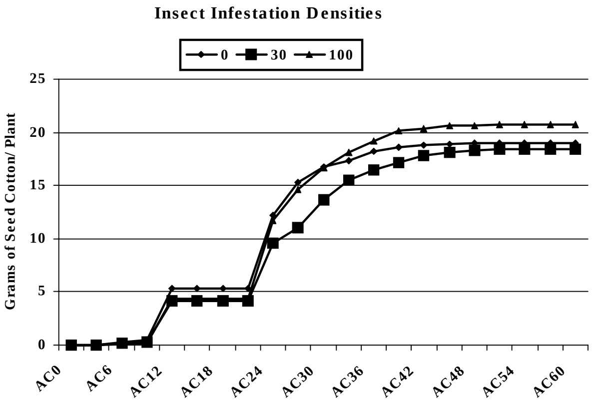

Figure 6. Accumulation of harvested weight (gms) from fruit cohorts (AC) beginning at mainstem node 4 (AC_0) and accumulated to node 24 (AC_{60}) for various initial infestation densities infested on July 24 which was approximately when the C_{39} cohort was being initialized.