PERFORMANCE OF SELECTED *BT* COTTON GENOTYPES AGAINST BOLLWORM IN NORTH CAROLINA

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Abstract

The performance of various *B.t.* cotton varieties was evaluated against *Helicoverpa zea* (Boddie)(bollworm) in North Carolina in 1997 and 1998. The test was designed to determine if any inherent differences were present among the different cultivars with respect to their susceptibility to bollworm (i.e. differences in fruit damage and larval populations), their maturity profiles, and yields. A pyrethroid (Karate™) was also used to determine if treatment with this insecticide had any significant yield benefit in *B.t.* cotton and how yield relationships varied among varieties. Results from plant mapping data for 1997 and 1998 confirmed that ST 4740 BG was a significantly later maturing variety compared to the others tested. ST 4740 had significantly lower numbers of first and second position bolls and lower values of percent open bolls compared to the other varieties. Results also showed that non-pyrethroid treated *B.t.* cottons sustained considerable damage, and yield loss ranged from 6.6-31.7% compared to pyrethroid treated *B.t.* cottons. ST 4740 BG untreated subplots suffered significantly more damage and subsequently greater yield loss than all other untreated varieties.

Introduction

The recent commercialization of *B.t.* cottons which contain the Bollgard™ gene that encodes the CryIA(c) insecticidal toxin from the soil microbe *Bacillus thurigiensis* var. *kurstaki* has provided a new approach to management of lepidopteran pests on cotton. Bollworm is the major insect pest of cotton in North Carolina and among the species targeted by this technology; however, bollworm susceptibility to CryIA(c) has been shown to be highly variable and considerably lower than that of *Heliothis virescens* (Fab.). Stone and Sims (1993) reported LC_{50} values for *H. zea* populations that were 4 to 60 times higher than the mean LC_{50} value for populations of *H. virescens*. Field studies conducted in North Carolina (Lambert et al. 1996, 1997, Mahaffey et al. 1994, 1995) confirmed that high bollworm populations occurring after late July damage *B.t.* cotton and reduce yields unless supplemental control is achieved with insecticides. Greenplate et al. (1998) demonstrated that average levels of CryIA(c) found in primary cotton fruit dropped significantly by 80 days after planting which is coincident with the period that bollworm invades cotton in North Carolina. Because of the need for supplemental insecticide applications on *B.t.* cotton for bollworm control and the technology fee, limited amounts of *B.t.* cottons have been planted in North Carolina. However, tobacco budworm population increases and reported pyrethroid resistant bollworm populations have made *B.t.* cottons a more attractive insect management option. It is imperative that the most bollworm resistant and agronomically acceptable *B.t.* cotton varieties be identified and recommended to North Carolina farmers.

This study will report upon the evaluation of selected *B.t.* cottons for comparative varietal performance with regard to resistance to bollworm, phenological development, and productivity as measured by yield under North Carolina conditions.

Materials and Methods

The test was conducted at the C. A. Martin Farm, Martin County, Jamesville, NC in 1997 and repeated in 1998. The test consisted of a randomized complete split-block design with four replicates. Whole plots were 8 rows by 40 feet in 1997 and 50 feet in 1998 with 36 inch row spacing, while subplots consisted of 6 rows which were not sprayed with Karate™ for supplemental bollworm control and 2 rows which were sprayed with Karate™. The pyrethroid sprayed versus non-sprayed subplots were included to determine the amount of yield reduction caused by bollworm for each variety. A 10-foot alley separated blocks.

The following varieties were planted in 1997: Deltapine (DPL) 33B, 35B, 90B, 50B, 20B, 32B, Paymaster (PM) 1330 BG and Stoneville (ST) 4740 BG. Identical varieties were used in 1998 with the exception of PM 1330 BG. This variety was replaced with DPL 428B. The planting date for both 1997 and 1998 was May 15. Aldicarb (Temik™ 15G, Rhone-Poulenc Ag. Company, Research Triangle Park, NC) was applied @ 0.75 lb. a.i./acre in-furrow at planting (in 1997 & 1998) for control of early season seedling insect pests. Control of plant bugs, stink bugs and disruption of arthropod natural enemies was accomplished over the entire test with a mid-season application (27 July 1997 and 20 July 1998) of acephate (Orthene™ 75S, Valent USA Corp., Walnut Creek, CA) @ 0.975 lb. a.i./acre. Lambda cyhalothrin (Karate™ 1EC, Zeneca Inc., Wilmington, DE) @ 0.04 lb. a.i./acre was applied once in 1997 (August 9) and twice in 1998 (July 28 and August 11) on the appropriate rows of each subplot for the reduction of bollworm populations. Only one pyrethroid treatment was used in 1997 due to the uncharacteristically low bollworm population numbers. Various other cotton production practices including fertilization, weed control, plant growth regulation and defoliation were performed throughout the

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season (1997 and 1998) as recommended by North Carolina State University (1998) to maximize yields.

Plant mapping was undertaken on two separate dates each year to compare the maturity characteristics of the eight varieties. The initial plant mapping was performed to evaluate the canopy location and the numbers of potentially harvestable first and second position bolls within the fruiting profile of each cultivar. This assessment consisted of counting the numbers of first as well as second position bolls on each fruiting branch from ten randomly selected plants per plot. The plant fruiting profile was divided into three zones; zone 1 consisted of sympodia 4-6, zone 2 consisted of sympodia 7-9 and zone 3 consisted of sympodia 10-12. The second plant mapping episode consisted of sampling five plants per subplot and determining the average percent open bolls for each of the treated and untreated subplots of the eight varieties.

Assessments of bollworm damaged fruit and live bollworm larvae were made during the period of bollworm occurrence (13, 22, 29 August 1997 and 10, 18, 25 August 1998). On the first scoring date of each year, fifty squares per plot were examined for bollworm larvae and damaged fruit. On the final two scoring dates for each year, fifty bolls per plot were examined for live bollworm larvae and damaged bolls. Yields were determined by picking the entire lengths of the two middle rows of the untreated subplots and both rows of the treated subplots. This was done using a John Deere 9920 cotton harvester on 21 November 1997 and 28 October 1998.

All damaged fruit and live bollworm larvae numbers per plot were converted to percentages prior to analysis. Yield data are expressed as lb. seed cotton/acre. All data were subjected to ANOVA using PROC GLM (SAS Institute 1990). Means for each treatment were separated ($p \leq 0.05$) using LSMEANS procedure of SAS.

Results

1997

Unusually low numbers of bollworm characterized the 1997 field season in North Carolina. Subsequently, boll damage due to bollworms was extremely low in *B.t.* cottons as well as conventional cottons. Thus, there were no significant differences among the eight cultivars with respect to boll damage, larval numbers or yields. Therefore, the 1997 data on bollworm are not presented here.

However, there were significant phenological and maturity differences recorded among the eight varieties in 1997. Plant mapping results from August 6 revealed significant differences among the eight genotypes for the total number of first and second position bolls averaged over the three canopy zones ($p \leq 0.05$). PM 1330 BG, DPL 50B and DPL 20B had significantly more first position bolls (Table 1) than the remaining 5 genotypes and would be classified as the most mature on this sampling date. ST 4740 BG had a significantly lower number of first position bolls (ca. 35-60% lower) than all other varieties. PM 1330 BG, DPL 50B and DPL 20B had more second position bolls than the other varieties and ST 4740 BG had an average of only 0.25 second position bolls (Table 1). For first and second position bolls, zone 2 had significantly higher numbers of bolls than the other two zones (Table 2).

The second set of plant mapping results (October 3) focused on the percent open bolls among the eight genotypes. Statistical analyses revealed significant differences among the eight varieties ($p \leq 0.05$). Table 3 lists the overall percent open boll means for the eight genotypes. PM 1330 BG had significantly higher percent open bolls than all other varieties. ST 4740 BG was significantly lower than all other varieties (with the exception of DPL 90B).

1998

Plant mapping results of August 4 once again revealed significant differences among the eight genotypes with respect to total number of first and second position bolls averaged over the three canopy zones ($p \leq 0.05$). DPL varieties 20B, 50B, 32B and 428B possessed significantly greater numbers of first position bolls (Table 1) and were more reproductively mature when compared to the remaining five cultivars. DPL 33B, 35B and 90B possessed about 30% fewer first position bolls than the top three cultivars. ST 4740 BG once again had a significantly lower number of first position bolls (ca. 53-67%) than all other varieties. Second position bolls once again followed a similar pattern as in 1997. The DPL varieties varied somewhat from one another but all had significantly greater numbers of second position bolls than ST 4740 BG ($p \leq 0.05$)(Table 1). Table 2 shows the differences among the three canopy zones for first and second position bolls. Zone 2 (sympodia 7-9) had significantly greater numbers of first and second position bolls than the other zones as was observed in 1997.

The second set of plant mapping results (October 16) again focused on percent open bolls among the eight varieties. Results were similar to that of 1997. The DPL varieties differed very little (Table 3) but all had significantly more open bolls than ST 4740 BG. The ST 4740 BG had a significantly greater number of vegetative bolls, open vegetative bolls, percent vegetative bolls and percent open vegetative bolls (Table 4).

Percent boll damage in untreated subplots was significantly greater for ST 4740 BG than all other varieties for all three scoring dates ($p \leq 0.05$)(Table 5). Percent live bollworm larvae in untreated subplots was also significantly greater for ST 4740 BG than other varieties, but only for the first two scoring dates (Table 5). There were no significant differences in fruit damage or live larvae in any of the Karate™ treated subplots. The overall average percent boll damage in untreated subplots for ST 4740 BG was 37.7%

while the other seven varieties averaged 14.3%. The overall average percent larvae in untreated subplots for ST 4740 BG was 11.2% while the other seven varieties averaged 3.9%. Average % boll damage in an adjacent non-*B.t.* plot was 70%.

Yields (lb. seed cotton/acre) for treated and untreated subplots are listed in Table 6. Treated subplots yielded an average of 3176 lb. seed cotton/acre while untreated subplots yielded 2697lb. seed cotton/acre over all varieties. DPL 428B yielded on average the most seed cotton in the treated subplots at 3454 lbs. DPL 35B yielded the lowest in the treated subplots with 3000 lb. of seed cotton. In the untreated subplots, DPL 20B yielded the most seed cotton with 2884 lb. The most significant difference was the untreated subplot of ST 4740 BG which produced only 2107 lb. seed cotton/acre.

Discussion

Due to low bollworm populations in North Carolina in 1997, damage to cotton (transgenic and conventional) was minimal. Conversely, extremely high populations of bollworms in North Carolina characterized the 1998 field season. Boll damage estimates from 1997 showed no significant differences among the eight genotypes. However, there were differences in phenology and maturity between the eight genotypes. Significant differences were apparent with respect to the total numbers of first and second position bolls averaged over three canopy zones in 1997 and 1998. The same trends followed in consecutive field seasons. According to data from 1997 (Table 1), PM 1330, DPL 50B and DPL 20B would be classified as the most reproductively mature cultivars in comparison to the remaining five genotypes on the basis of first and second position bolls. In 1998, once again, DPL 50B and DPL 20B along with DPL 428B (not used in 1997) had the greatest number of first and second position bolls. In both years, ST 4740 BG was the least mature with first and second position bolls averaging only 6.1 & 0.25 respectively in 1997 and 2.8 & 0.5 respectively in 1998.

There were also significant differences among the three fruiting branch zones for first and second position bolls. In 1997 and 1998, zone 2 had significantly greater numbers of first and second position bolls. This is expected because zone 2 (sympodia 7-9) typically has the heaviest boll load on a cotton plant. In both years, second position bolls did not vary across zones 1 and 2 as much as first position bolls. This is because there is normally a decline in the number of second position bolls with higher fruiting branches. This explains why zone 2 second position boll numbers were not much different from zone 1 and also why zone 3 had extremely reduced numbers of second position bolls.

In 1998, Karate-treated *B.t.* cotton (2 applications) suffered significantly less boll damage than untreated *B.t.* cotton with overall damages of 0.7% and 17.2% respectively. There were also few, if any, live bollworm larvae found in treated subplots. Timely pyrethroid applications in *B.t.* cotton provided excellent bollworm control. These results are consistent with other studies that have shown the beneficial effects of spraying *B.t.* cotton with a pyrethroid (Lambert et al. 1996, 1997, Mahaffey et al. 1994, 1995). ST 4740 BG suffered the greatest overall damage in untreated subplots (37.7% boll damage). For some reason, this variety did not perform as well in North Carolina as other tested varieties. It may be due to its late maturity characteristics or possibly due to the expression of lower levels of endotoxin in the plant. Whatever the reason, it is clear that this variety, if untreated in the presence of high bollworm populations, will sustain significantly more damage than other *B.t.* varieties.

Karate-treated subplots yielded significantly more seed cotton than untreated subplots (3176 vs. 2697). The overall average percent yield decrease for all untreated subplots was 15.1%. This would be expected since the untreated subplots sustained greater boll damage than the treated subplots. The average percent yield decrease for the untreated DPL varieties was 12.7% while the percent yield decrease for untreated ST 4740 BG was 31.7%. Untreated ST 4740 BG showed much greater yield loss than other *B.t.* lines. For comparison, the average percent yield decrease in an adjacent untreated non-*B.t.* plot was 61%. Both tests, non-*B.t.* and *B.t.*, used identical agricultural practices. It should be noted that Karate-treated ST 4740 BG performed, on average, just as well as the other treated varieties. This was not expected because percent open boll data taken late in the season revealed that ST 4740 BG had significantly fewer open bolls than all other varieties (26.5% vs. 60.2%). However, late season plant mapping revealed that ST 4740 had significantly greater numbers of total vegetative bolls and open vegetative bolls. Therefore, it appears that this variety compensated by producing more fruit on vegetative branches which matured as the result of unusually favorable late season weather.

Overall, this test showed the similarities and differences of a number of *B.t.* genotypes under the North Carolina environment. The results confirmed the importance of treating *B.t.* cotton to suppress bollworm. Also, some varieties if left untreated suffer significantly more damage and subsequent yield loss than other varieties.

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Table 1. Total # of first and second position bolls averaged over the 3 zones from data taken on August 6, 1997 and August 4, 1998 at C. A. Martin Farm, Martin County, Jamesville, NC.

	Mean # of Bolls			
	1997		1998	
Variety	First Position	Second Position	First Position	Second Position
DPL 33B	12.08 b	4.17 c	5.83 b	2.5 cd
DPL 35B	11.08 b	4.67 bc	6.08 b	1.83 d
DPL 90B	10.83 b	4.00 c	5.83 b	2.17 cd
DPL 50B	15.00 a	6.33 ab	8.58 a	4.42 ab
DPL 20B	14.42 a	6.00 ab	8.92 a	4.83 a
DPL 32B	12.17 b	4.17 c	8.25 a	3.33 bc
DPL 428 B	---	---	7.67 a	3.25 bc
PM 1330 BG	15.08 a	7.33 a	---	---
ST 4740 BG	6.08 c	0.25 d	2.75 c	0.50 e

Means in columns within each variety followed by the same letter are not significantly different according to LSMEANS ($p \leq 0.05$).

Table 2. Average # of first and second position bolls by zone from data taken on August 6, 1997 and August 4, 1998 at C. A. Martin Farm, Martin County, Jamesville, NC.

	Mean # of Bolls			
	1997		1998	
Zone #	First Position	Second Position	First Position	Second Position
1	6.41 b	6.59 a	6.00 b	3.22 b
2	23.28 a	7.25 a	8.22 a	4.19 a
3	6.59 b	0.00 b	6.00 b	1.16 c

Means in columns within each zone followed by the same letter are not significantly different according to LSMEANS ($p \leq 0.05$).

Table 3. Percent open boll means from data taken on October 3, 1997 and October 16, 1998 at C. A. Martin Farm, Martin County, Jamesville, NC.

	% Open Bolls	
Variety	1997	1998
DPL 33B	46.8 bc	55.0 b
DPL 35B	48.5 bc	48.5 b
DPL 90B	37.0 cd	59.0 ab
DPL 50B	57.6 b	69.0 a
DPL 20B	54.9 b	64.0 a
DPL 32B	54.2 b	64.0 a
DPL 428B	---	62.0 ab
PM 1330 BG	78.8 a	---
ST 4740 BG	29.2 d	26.5 c

Means in columns within each variety followed by the same letter are not significantly different according to LSMEANS ($p \leq 0.05$).

Table 4. Average # of vegetative bolls, open vegetative bolls, percent vegetative bolls and percent open vegetative bolls for the eight varieties from data taken on October 16, 1998 at C. A. Martin Farm, Martin County, Jamesville, NC.

Variety	Vegetative Bolls	Open Vegetative Bolls	Percent Vegetative Bolls	% Open Vegetative Bolls
DPL 33B	1.25 b	1.25 b	2.96 bc	2.96 b
DPL 35B	2.38 b	2.38 b	7.15 b	7.15 b
DPL 20B	2.63 b	2.50 b	6.01 bc	5.69 b
DPL 50B	1.50 b	1.38 b	3.62 bc	3.34 b
DPL 32B	1.50 b	1.50 b	4.14 bc	4.14 b
DPL 90B	0.88 b	0.88 b	2.28 bc	2.28 b
DPL 428B	0.38 b	0.38 b	0.99 c	0.99 b
ST 4740BG	11.75 a	10.75 a	29.59 a	26.79 a

Means in columns within each variety followed by the same letter are not significantly different according to LSMEANS ($p \leq 0.05$).

Table 5. Percent boll damage and percent live bollworm larvae for the eight genotypes in treated and untreated subplots from data taken on August 10, 18 and 25, 1998 at C. A. Martin Farm, Martin County, Jamesville, NC.

	August 10		August 18		August 25	
Variety (T)	% boll dam.	% live larvae	% boll dam.	% live larvae	% boll dam.	% live larvae
DPL 33B	1.6 d	0.0 d	0.6 d	0.0 d	0.0 d	0.0 d
DPL 35B	3.0 d	0.0 d	0.0 d	0.0 d	0.0 d	0.0 d
DPL 20B	1.0 d	0.0 d	0.0 d	0.0 d	0.0 d	0.0 d
DPL 50B	0.6 d	0.0 d	0.0 d	0.0 d	0.0 d	0.0 d
DPL 32B	2.6 d	0.0 d	0.6 d	0.0 d	0.0 d	0.0 d
DPL 90B	1.0 d	0.0 d	0.0 d	0.0 d	0.0 d	0.0 d
DPL428B	0.6 d	0.0 d	0.0 d	0.0 d	0.0 d	0.0 d
ST 4740 BG	4.6 d	1.0 d	1.0 d	0.0 d	0.0 d	0.0 d
	August 10		August 18		August 25	
Variety (UT)	% boll dam.	% live larvae	% boll dam.	% live larvae	% boll dam.	% live larvae
DPL 33B	16.0 bc	6.0 bc	13.0 b	6.0 b	12.0 bc	0.6 ab
DPL 35B	19.0 b	4.6 c	15.0 b	6.6 b	11.6 bc	1.6 ab
DPL 20B	13.6 bc	4.6 c	16.6 b	3.0 bc	8.0 c	1.0 ab
DPL 50B	16.0 bc	5.6 bc	15.6 b	4.0 bc	11.6 bc	1.6 ab
DPL 32B	12.0 bc	7.0 bc	18.6 b	5.0 bc	15.0 bc	0.0 b
DPL 90B	14.6 bc	8.0 b	17.6 b	6.0 b	9.6 bc	0.6 b
DPL428B	11.6 c	5.0 bc	17.0 b	3.6 bc	16.0 b	2.0 a
ST 4740 BG	32.6 a	15.0 a	46.0 a	16.3 a	34.6 a	2.0 a

Means in columns within each variety for T or UT followed by the same letter are not significantly different according to LSMEANS ($p \leq 0.05$).

Table 6. Yield data in pounds of seed cotton per acre for pyrethroid-treated and untreated subplots taken October 28, 1998 at C. A. Martin Farm, Martin County, Jamesville, NC.

Variety	Karate Treated	Untreated
DPL 33B	3207 abc	2750 de
DPL 35B	3000 bcd	2583 e
DPL 20B	3087 bcd	2884 cde
DPL 50B	3307 ab	2848 cde
DPL 32B	3160 abc	2830 cde
DPL 90B	3109 abcd	2746 de
DPL 428B	3454 a	2831 cde
ST 4740BG	3084 bcd	2107 f
OVERALL MEANS	3176	2697

Means in columns within each variety followed by the same letter are not significantly different according to LSMEANS ($p \leq 0.05$).