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ARTHROPOD MANAGEMENT

Field Performance of Transgenic Cottons Expressing One or Two *Bacillus thuringiensis* Endotoxins Against Bollworm, *Helicoverpa zea* (Boddie)

R. E. Jackson*, J. R. Bradley, Jr., and J. W. Van Duyn

ABSTRACT

Bollworm, *Helicoverpa zea* (Boddie), survival on Bollgard cottons is an economic problem and also a concern for dealing with the development of bollworm resistance. Bollgard II cottons that produce two Bt proteins have been developed to provide increased bollworm control. Bollgard and Bollgard II cottons were evaluated along with their conventional sister line for susceptibility against bollworm in North Carolina field studies from 1999-2002. The impact of supplemental pyrethroid oversprays on bollworm control and yields was also evaluated. Comparisons of untreated genotypes averaged across four years demonstrated that both Bt genotypes reduced infestation rates by larvae and damage to squares and bolls compared with the conventional cultivar. Bollgard II had fewer squares and bolls infested with larvae and less square and boll damage compared with Bollgard. Larval infestations and damage levels were also lower in pyrethroid-treated conventional cotton, and both pyrethroid-treated and untreated Bt genotypes, compared with the untreated conventional cultivar. A reduction in larval numbers and square and boll damage was achieved with pyrethroid oversprays in both conventional and Bollgard cultivars, but not in Bollgard II. Except for square damage, larval numbers and damage were comparable among pyrethroid-treated conventional and untreated Bollgard cottons. Pyrethroid-treated Bollgard contained numbers of larvae and damage comparable to that of untreated Bollgard II. Pyrethroid-treated and untreated Bollgard and Bollgard II cottons on average produced similar yields. Only pyrethroid-treated and untreated Bollgard II cottons produced significantly higher yields compared with the pyrethroid-treated conventional cultivar.

The availability of transgenic Bollgard cottons (Monsanto Co., St. Louis, MO), which contain a gene from the soil bacterium *Bacillus thuringiensis* var. *kurstaki* encoding for the Cry1Ac δ-endotoxin, has provided a novel alternative for management of certain lepidopteran pests. Two major lepidopteran pests of cotton in North Carolina that are affected by this technology are the bollworm, *Helicoverpa zea* (Boddie), and the tobacco budworm, *Heliothis virescens* (Fab.). Although control of tobacco budworm with transgenic cottons has been absolute, bollworm susceptibility to the Cry1Ac protein is lower and more variable. For example, purified Cry1Ac endotoxin and spore/crystal combination LC_{50} values for bollworm populations were 4 to 60 times higher than those of tobacco budworm populations (Stone and Sims, 1993). Field trials conducted in North Carolina confirmed that supplemental insecticide oversprays were frequently required to achieve satisfactory bollworm control and avoid yield reductions in Bollgard cottons (Lambert et al., 1996, 1997; Mahaffey et al., 1994, 1995). Survival of a portion of the bollworm population on Bollgard cottons may also be partially explained by the significant drop in the average levels of Cry1Ac protein in cotton fruit at approximately 80 days after planting (Greenplate, 1999; Greenplate et al., 2001), which is coincident with the major bollworm flight into North Carolina cotton. Bollworm survival on Bollgard cottons is not only an economic problem, but also causes concern for the development of resistance. Thus, further advances in Bt cotton technology to decrease bollworm survival are needed to address these problems.

Bollgard II cottons (Monsanto Co., St. Louis, MO) produce two Bt endotoxins, Cry1Ac and Cry2Ab, whereas commercially available Bollgard cultivars produce only the Cry1Ac endotoxin. The

R. E. Jackson and J. R. Bradley, Jr., North Carolina State University, Department of Entomology, Campus Box 7630, Raleigh, NC 27695-7630, and J. W. Van Duyn, North Carolina State University, Department of Entomology, Vernon James Center, 207 Research Station Road, Plymouth, NC 27962.
*Corresponding author (ryan_jackson@ncsu.edu)

dual-gene cottons produce approximately the same level of the Cry1Ac protein as the single-gene Bollgard cultivars, but are further protected by the Cry2Ab protein (Greenplate et al., 2000; Adamczyk et al., 2001). With the potential increased efficacy against bollworm due to the additional Cry toxin compared with Bollgard cultivars, Bollgard II cottons may represent the new standard with respect to control of heliothines in cotton. Furthermore, they are expected to delay the development of resistance in bollworm. The results of field studies evaluating Bollgard and Bollgard II cottons for performance against bollworm and for agronomic productivity as measured by yield under North Carolina conditions are reported here.

MATERIALS AND METHODS

Field studies were conducted at the Upper Coastal Plain Research Station, Edgecombe Co., NC, in 1999-2002; the Tidewater Research Station, Washington Co., NC, in 1999-2002; the Central Crops Research Station, Johnston Co., NC, in 2000; C. A. Martin Farm, Martin Co., NC, in 1999 and 2002; and Albemarle Beach Farm, Washington Co., NC, in 2002. Each test site represented a randomized complete split-plot design with four replicates. Whole plots consisted of cotton genotypes and subplots were unsprayed or sprayed with a pyrethroid insecticide. Whole plots were 12 and 20 rows (0.91-m row width) by 13.7 m in 1999 and 2002, respectively. Whole plots measured 16, 20, and 24 rows by 15.2 m for conventional (Deltapine 50; DP 50), Bollgard (Deltapine 50B; DP 50B), and Bollgard II (Deltapine DP 50BX; DP 50BX) genotypes, respectively, in 2000-2001. All seed were obtained from Delta and Pine Land Co. (Scottt, MS). The areas of whole plots for respective genotypes were varied during these two years in order to increase the probability of collecting large bollworm larvae from Bollgard and Bollgard II lines since larval survival should be lower in these genotypes. Subplots consisted of 4 rows that were treated with a pyrethroid as needed for supplemental bollworm control and the remaining area of each whole plot which were unsprayed.

All cotton genotypes were planted on 20 May in Martin Co., 21 May in Washington Co., and 24 May in Edgecombe Co. in 1999; on 15 May in Edgecombe Co., 17 May in Johnston Co., and 18 May in Washington Co. in 2000; on 2 May in Edgecombe Co. in 2001; and on 14 May in Edgecombe Co. and Washington Co., and 15 May in Martin Co. and Washington Co. in 2002. Aldicarb (Temik 15 G, Aventis CropScience, Research Triangle Park, NC) was applied in-furrow at planting at 0.84 kg a.i./hectare for control of early season insect pests in each test. Acephate (Orthene 97 PE, Valent USA Corp., Walnut Creek, CA) was applied at 0.84 kg a.i./hectare as a mid-season overspray for control of tarnished plant bugs and stink bugs and to eliminate arthropod natural enemies. Supplemental bollworm control within appropriate subplots was triggered initially by an egg threshold (10 eggs per 100 terminals), and if necessary followed by a larval threshold (3 live larvae per 100 fruit). Control of bollworm was accomplished by applications of cypermethrin (Ammo 2.5 EC, FMC Corp., Philadelphia, PA), lambda cyhalothrin (Karate Z 2.08 CS, Syngenta Crop Protection, Inc., Greensboro, NC), cyfluthrin (Baythroid 2.0 EC, Bayer Corp., Kansas City, MO), or spinosad (Tracer 4 SC, Dow AgroSciences, LLC, Indianapolis, IN). Pyrethroid applications consisting of cypermethrin at 0.112 kg a.i./hectare and lambda cyhalothrin at 0.045 kg a.i./hectare were sprayed at Martin Co. (4 and 16 August, respectively) and at Washington Co. (6 and 19 August, respectively), whereas cyfluthrin at 0.056 kg a.i./hectare was sprayed at Edgecombe Co. (5 August) in 1999. Lambda cyhalothrin at 0.045 kg a.i./hectare was applied to appropriate subplots for supplemental bollworm control at Johnston and Edgecombe counties (19 July and 7 August) and at Washington Co. (27 July and 9 August) in 2000, as well as at Edgecombe Co. (10 and 16 August) in 2001. In 2002, lambda cyhalothrin at 0.045 kg a.i./hectare plus spinosad at 0.100 kg a.i./hectare was applied to all test sites on 23 July and 1 August; spinosad was added to control any tobacco budworms that infested test sites. Weed control, fertilization, plant growth regulation, and defoliation followed the recommendations of the North Carolina Cooperative Extension Service.

Bollworm eggs were counted in the terminal region of cotton plants, and live larvae and damage were assessed on squares and bolls. Fifty terminals or squares were examined per plot on the respective sample dates. Bolls were sampled at either 50 or 100 per plot on a given sample date. Terminal and square samples were taken on either one or two dates after egg threshold had been reached. Boll samples were taken on a weekly basis beginning one week after initial bollworm infestation (late July-early August) and terminating at the end of the larval generation (early to mid September). Egg, larval, and damage ratings were made only in the untreated subplots in 1999 and 2000, but 2001 and 2002 ratings were made in both pyrethroid-treated and untreated subplots. Yields were determined by picking the entire lengths of the two middle rows of each subplot using a mechanical cotton picker. Yields were converted to kg seed cotton/ha prior to analysis.

Numbers of eggs, live bollworm larvae, and damaged fruit were converted to percentages and subjected to arcsine square root transformation prior to analysis. These data, along with yields, were then subjected to ANOVA using PROC MIXED. Due to the unbalanced nature of locations within years, all tests (year by location combinations) were analyzed across locations and years. Effects of genotype and insecticide were considered fixed, whereas effects of test (year by location combinations) and replicates were considered random. Treatments were compared ($P \leq 0.05$) on the basis of least-squares means (PDIFF option of the LSMEANS statement; SAS, version 8, SAS Institute Inc., Cary, NC). Results for data transformed before analysis are reported as untransformed arithmetic means and standard errors.

RESULTS

Heliothine egg deposition on cotton terminals was not different among the untreated conventional, Bollgard, and Bollgard II genotypes averaged across eleven test sites from 1999-2002 (F = 0.16; df = 2, 22; $P = 0.854$). The percentage of terminals with heliothine eggs ranged from 8.1% in the conventional cultivar to 8.7% in the Bollgard II genotype; thus, each genotype was exposed to similar levels of bollworm infestations.

The percentage of squares infested with larvae was lower in both untreated Bollgard genotypes compared with the untreated conventional cultivar (F = 96.74; df = 2, 22; $P < 0.001$) (Table 1). A lower percentage of squares from the Bollgard II genotype contained a live larva compared with the Bollgard cultivar. The percentage of squares sustaining bollworm damage was also reduced by both Bollgard cottons compared with the conventional cultivar (F = 61.81; df = 2, 22; $P < 0.001$) (Table 1); however, as with larval ratings, the percentage of squares suffering damage by bollworm was significantly less in the Bollgard II genotype than in the Bollgard cultivar. The reduction in the percentage of squares infested with larvae was approximately 10-fold and 19-fold for Bollgard and Bollgard II lines, respectively, while the percentage of squares sustaining damage was reduced 6-fold by Bollgard and 16-fold by Bollgard II genotypes compared with the conventional cultivar.

Table 1. Mean (SE) percentage of squares with live bollworm larvae or associated damage for three untreated cotton genotypes averaged across eleven test sites (1999-2002) in North Carolina.

Genotype	Percentage live larvae[z]	Percentage damage[z]
Conventional (DP50)	8.7 (0.844) a	28.2 (2.48) a
Bollgard (DP50B)	0.9 (0.166) b	4.6 (0.57) b
Bollgard II (DP50BX)	0.5 (0.202) c	1.8 (0.59) c

[z] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

Both untreated Bt genotypes reduced the percentage of bolls infested with late-instar (L4 and L5) larvae (F = 60.75; df = 2, 22; $P < 0.001$) and the percentage of bolls with bollworm damage (F = 79.71; df = 2, 22; $P < 0.001$) compared with the untreated conventional cultivar when averaged across eleven study sites from 1999-2002 (Table 2). The percentage of bolls infested with larvae was reduced 4-fold by Bollgard and 30-fold by Bollgard II genotypes compared with the conventional cultivar, whereas, boll damage was lowered 5-fold and 36-fold, respectively. Bollgard II reduced the percentage of bolls infested with larvae and damaged bolls below the Bollgard cultivar by 8-fold and 7-fold, respectively.

Table 2. Mean (SE) percentage of bolls with live bollworm larvae (L4 and L5) or associated damage for three untreated cotton genotypes averaged across eleven test sites (1999-2002) in North Carolina.

Genotype	Percentage live larvae[z]	Percentage damage[z]
Conventional (DP50)	10.1 (1.012) a	46.2 (2.147) a
Bollgard (DP50B)	2.9 (0.375) b	9.3 (0.798) b
Bollgard II (DP50BX)	0.3 (0.084) c	1.3 (0.229) c

[z] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

In 2001 and 2002, both pyrethroid-treated and untreated subplots were evaluated for egg, larval, and damage numbers. The percentage of terminals containing eggs were not different across all treatment combinations (F = 0.43; df = 2, 8; $P = 0.662$). Therefore, all treatment combinations of genotype and insecticide regime were subjected to comparable levels of bollworm populations.

A genotype by insecticide interaction for the percentage of squares infested with larvae (F = 60.40; df = 2, 10; $P < 0.001$) and the percentage of squares with associated damage (F = 51.37; df = 2, 10; $P < 0.001$) suggested that the effect of insecticide was not the same among all genotypes when averaged across five study sites from 2001-2002. In untreated conventional cotton, 13% of the squares contained a live larva, which was the highest infestation of squares among all treatment combinations (Table 3). The percentage of squares infested with larvae was not different between the pyrethroid-treated conventional cotton and the untreated Bollgard cotton. Similarly, the percentage of squares infested with larvae were not different among the treatment combinations of pyrethroid-treated Bollgard cotton and both untreated and pyrethroid-treated Bollgard II cottons; however, each of these treatment combinations reduced the percentage of squares infested with larvae below that of pyrethroid-treated conventional and untreated Bollgard cottons.

The untreated conventional cultivar sustained 44.3% damaged squares, and this level of damage was significantly reduced to 13.1% with the addition of pyrethroid oversprays (Table 3). The untreated Bollgard cultivar sustained approximately half the square damage of the pyrethroid-treated conventional cultivar. As with the conventional cultivar, oversprays with pyrethroids to the Bollgard genotype significantly lowered the percentage of squares with bollworm damage compared with the untreated Bollgard cultivar. There were no differences between the pyrethroid-treated Bollgard cultivar and both pyrethroid-treated and untreated Bollgard II lines in the percentage of squares sustaining bollworm damage.

As with square ratings, a genotype by insecticide interaction for the percentage of bolls infested with late-instar (L4 and L5) larvae (F = 7.74; df = 2, 10; $P = 0.009$), as well as the percentage of bolls with associated damage (F = 40.51; df = 2, 10; $P < 0.001$), indicated that the insecticide effect varied among genotypes. Approximately 14.2% of bolls from the untreated conventional cultivar contained a late-instar bollworm larva (Table 4). The percentage of bolls infested with larvae was not different between the pyrethroid-treated conventional cultivar and the untreated Bollgard cotton, but the addition of pyrethroid oversprays to Bollgard cotton successfully reduced the percentage of bolls infested with larvae below that of the untreated Bollgard cultivar. Pyrethroid-treated Bollgard cotton, and untreated and pyrethroid-treated Bollgard II cottons had similar percentages of bolls infested with larvae, and each of these treatment combinations significantly reduced the percentage of bolls infested with larvae below that of untreated Bollgard and pyrethroid-treated conventional cottons.

The addition of pyrethroid oversprays to the conventional cultivar and the use of untreated Bollgard cotton effectively reduced the percentages of damaged bolls by 3.6-fold and 4.9-fold, respectively, compared with the 63% boll damage in the untreated conventional cultivar. The pyrethroid-treated conventional cultivar and the untreated Bollgard genotype were not different (Table 4). As with larval ratings on bolls, the percentage of dam-

Table 3. Mean (SE) percentage of squares infested by bollworm larvae and damaged for pyrethroid-treated and untreated subplots of three cotton genotypes averaged across five test sites (2001 and 2002) in North Carolina

Genotype	Insecticide regime	Percentage squares infested w/larvae[z]	Percentage damaged squares[z]
Conventional (DP50)	Untreated	12.8 (1.403) a	44.3 (3.042) a
Conventional (DP50)	Pyrethroid-treated	2.5 (0.542) b	13.1 (1.103) b
Bollgard (DP50B)	Untreated	1.3 (0.287) b	6.6 (1.207) c
Bollgard (DP50B)	Pyrethroid-treated	0.1 (0.083) c	0.8 (0.264) d
Bollgard II (DP50BX)	Untreated	0.1 (0.083) c	0.1 (0.083) d
Bollgard II (DP50BX)	Pyrethroid-treated	0.0 (0.000) c	0.3 (0.155) d

[z] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

Table 4. Mean (SE) percentage of bolls containing a live (L4 and L5) bollworm larva for pyrethroid-treated and untreated subplots of three cotton genotypes averaged across five test sites (2001 and 2002) in North Carolina.

Genotype	Insecticide regime	Percentage bolls infested w/larvae [z]	Percentage damaged bolls [z]
Conventional (DP50)	Untreated	14.2 (1.865) a	63.0 (3.601) a
Bollgard (DP50B)	Untreated	4.5 (0.687) b	12.9 (1.437) b
Conventional (DP50)	Pyrethroid-treated	4.3 (0.520) b	17.6 (1.343) b
Bollgard (DP50B)	Pyrethroid-treated	0.6 (0.130) c	2.9 (0.465) c
Bollgard II (DP50BX)	Untreated	0.4 (0.120) c	1.5 (0.305) c
Bollgard II (DP50BX)	Pyrethroid-treated	0.0 (0.000) c	0.2 (0.071) c

[z] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

aged bolls was not different among the pyrethroid-treated Bollgard cotton and the untreated and pyrethroid-treated Bollgard II cottons. Furthermore, these treatment combinations reduced the percentage of damaged bolls below that of the untreated Bollgard and pyrethroid-treated conventional cultivars.

Seed cotton yields were characterized by a significant genotype by insecticide interaction when averaged across eleven study sites from 1999-2002 ($F = 14.25$; df = 2, 20; $P = 0.001$). Both untreated and pyrethroid-treated Bollgard and Bollgard II cottons produced similar yields, but pyrethroid-treated and untreated Bollgard II yielded more seed cotton than the pyrethroid-treated and untreated conventional cottons (Table 5). Yields of the pyrethroid-treated or the untreated Bollgard cottons were not different from that of the pyrethroid-treated conventional cultivar.

Table 5. Mean (SE) yields expressed in kg seed cotton per hectare for pyrethroid-treated and untreated subplots of three cotton genotypes averaged across eleven test sites (1999-2002) in North Carolina.

Genotype	Insecticide regime	Seed cotton (kg/ha) [z]
Bollgard II (DP50BX)	Pyrethroid-treated	3264.0 (294.83) a
Bollgard II (DP50BX)	Untreated	3222.7 (294.17) a
Bollgard (DP50B)	Pyrethroid-treated	3016.4 (294.35) ab
Bollgard (DP50B)	Untreated	2870.5 (294.17) ab
Conventional (DP50)	Pyrethroid-treated	2691.4 (294.17) b
Conventional (DP50)	Untreated	1466.2 (294.17) c

[z] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD ($P \leq 0.05$).

DISCUSSION

Low to moderate bollworm numbers characterized the 1999-2001 field seasons in North Carolina, but the 2002 field season was characterized by extremely high numbers of bollworms. Therefore, numbers of eggs, live larvae, and damaged fruit were evaluated under infestation levels typically encountered in the region, as well as under unusually high bollworm population levels. Distribution of heliothine eggs in the terminal region of cotton plants was similar across test sites. These observations were consistent with results of previous studies that demonstrated oviposition was not affected by Bt cottons (Lambert et al., 1996, 1997).

The percentages of squares infested with larvae or subsequent damaged squares were reduced by both Bt genotypes below that of the conventional cultivar. The Bollgard II genotype sustained less feeding damage on squares compared with the Bollgard cultivar, but larval survival on squares were not different between the Bt cottons and survival was very low on both. With the additional production of the Cry2Ab endotoxin, the Bollgard II genotype expresses a much higher overall protein titer than the Bollgard cultivar. Additionally, total activity against lepidopterans does not differ between Bollgard II terminals and squares, as demonstrated in Bollgard cultivars (Penn et al., 2001). Therefore, less square tissue would need to be ingested to achieve a toxic dose of Cry proteins, and this factor likely resulted in the reduced square damage with the Bollgard II genotype.

Reduced larval survival and damage on bolls in Bollgard II cottons may be explained by the overall increase (3.5-fold) in activity against lepidopterans for the dual gene technology compared with the single toxin cultivars, as demonstrated by Penn et al. (2001). Farrar and Bradley (1985) demonstrated that the majority of bollworm eggs are deposited within the upper one-third of the plant canopy and larval movement proceeds down the plant with larval age. In addition, Gore et al. (2001) reported that larval movement away from the terminal portion of Bt cotton plants was increased above that of conventional cultivars. Larvae feed briefly on leaves and squares in the Bollgard genotypes as they move down the plant in search of suitable nutrient sources. Since the rate of larval movement down Bt cotton plants is high, similar numbers of larvae should infest bolls in Bollgard and Bollgard II genotypes. With the increased activity against lepidopterans demonstrated by Bollgard II lines, a significantly higher proportion of larvae apparently die before feeding on bolls. Thus, the percentage of bolls infested and damaged would be less in Bollgard II than in the Bollgard cultivar.

In 2001 and 2002, bollworm larval survival was lower in the pyrethroid-treated conventional cultivar because the pyrethroid was the only means of suppression without the presence of Bt toxins. Since pyrethroid oversprays are very effective against bollworm (Bradley, 1996), the pyrethroid-treated conventional cultivar exhibited similar levels of larval survival to that of the untreated Bollgard cultivar. Similarly, the addition of pyrethroid oversprays to the Bollgard cultivar lowered larval survival below that of the untreated Bollgard genotype and performed comparably to the untreated and pyrethroid-treated Bollgard II line. Although the production of the Cry1Ac toxin in squares of the Bollgard cultivar most often provides adequate suppression of bollworm larvae, 19% square damage has been measured in previous years (Mahaffey et al., 1995). In order for pyrethroid oversprays to significantly reduce square damage, significant numbers of larvae capable of causing this level of damage must have been present; therefore, these pyrethroid oversprays were able to reduce the numbers of larvae that were more tolerant of the Cry1Ac endotoxin and could have caused significant damage to the squares. The production of the Cry2Ab endotoxin in addition to the Cry1Ac protein appeared to increase larval mortality on squares compared with the single toxin cultivar, but increased larval movement down the plant as reported by Gore et al. (2001) may have given the appearance of reduced larval survival on squares.

The percentage of squares sustaining bollworm damage was similar to larval survival. Although the percentage of squares with a live larva was not different among pyrethroid-treated conventional and untreated Bollgard cottons, the untreated Bollgard cultivar reduced square damage compared with the pyrethroid-treated conventional cultivar. The difference may have been a result of reduced coverage of the pyrethroid overspray on squares. A reduction in coverage could have resulted in some squares having little to no insecticide, whereas the Bollgard cultivar produced its internal insecticide in every square on the plant. Therefore, feeding damage would occur on a higher proportion of squares in the pyrethroid-treated conventional cultivar in comparison to the untreated Bollgard cultivar. In addition, larvae in the untreated Bollgard cultivar could have fed minimally upon square tissue and ingested enough of the Cry1Ac protein to cease feeding without causing immediate mortality. Coverage with the pyrethroid-overspray, however, was sufficient enough to reduce the percentage of squares with damage in the pyrethroid-treated Bollgard cultivar compared with the untreated Bollgard.

A portion of the susceptible bollworm larvae, as well as those that may carry Bt resistance alleles, have demonstrated the ability to complete larval development on Bollgard cottons because Bollgard cultivars do not express a high enough dose of Cry1Ac endotoxin to prevent resistance development (Anonymous, 1998). Therefore, survivors in the untreated Bollgard cottons could have caused feeding damage to squares, whereas, most larvae surviving the Cry1Ac toxin in the pyrethroid-treated Bollgard cultivar would have been eliminated by the pyrethroid oversprays. Moreover, the addition of a second Cry endotoxin in the Bollgard II genotype appeared to have an effect of similar magnitude in the reduction of square damage as the pyrethroid oversprays to the Bollgard genotype.

Larval survival and boll damage of pyrethroid-treated conventional cotton were similar to untreated Bollgard cotton because of the level of bollworm control achieved with a pyrethroid. The increased control of bollworm gained through the use of a pyrethroid was due to suppression by the pyrethroid oversprays of that portion of the bollworm population that survived on Bollgard cottons. The Bollgard cultivar required pyrethroid oversprays in order to achieve a similar level of bollworm control as the Bollgard II genotype, which was likely due to the 3.5-fold less activity against lepidopterans provided by the Bollgard cultivar (Penn et al., 2001). In addition, the level of bollworm suppression attained by the dual gene line negated the necessity of a pyrethroid application.

Bollgard and Bollgard II cotton genotypes under pyrethroid-treated and untreated conditions produced similar yields when averaged across the eleven studies. The probable lack of coverage provided by the pyrethroid oversprays on the conventional cultivar allowed some level of bollworms to continue feeding on fruiting structures, thus reducing yields. In contrast, the Bollgard II genotype expressed a high level of endotoxins that provided season-long protection of fruit from bollworm feeding.

Results from these studies suggest that Bollgard II cottons may provide an added value to farmers since these genotypes appear comparable to the pyrethroid-treated Bollgard cultivars in terms of bollworm control and yield potential. Furthermore, the increased level of control gained by the Bollgard II cottons adds a level of convenience in that timely insecticide applications will likely not be necessary for lepidopteran pests and that the risk of late detection of an infestation would be virtually eliminated. These convenience factors may be an important consideration of commercial producers when choosing cultivars. However, it is likely that hemipterous pests may present a problem in Bollgard II cottons because of the lack of insecticide sprays directed at caterpillars. Bacheler (2003) reported that Bollgard fields averaged 1.12 late-season applications with insecticides active against bollworm in 2002, which were either directed at hemipterous pests or aimed towards caterpillars and coincidentally provided control of these hemipterous pests. Thus, Bollgard II has two apparent values: 1) the control of occasional caterpillar pests such as the armyworms, loopers, etc., which provides insurance against these pests (Sivasupramaniam et al., 2003; Sherrick et al., 2003), and 2) the potential of Bollgard II as a mechanism to delay resistance evolution in heliothines to these Bt toxins.

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