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Source: Florida Entomologist, 91(4) : 523-530

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/0015-4040-91.4.523

CORN EXPRESSING CRY1AB OR CRY1F ENDOTOXIN FOR FALL ARMYWORM AND CORN EARWORM (LEPIDOPTERA: NOCTUIDAE) MANAGEMENT IN FIELD CORN FOR GRAIN PRODUCTION

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ABSTRACT

Fall armyworm, *Spodoptera frugiperda* (J. E. Smith), and corn earworm, *Helicoverpa zea* (Boddie), perennially cause leaf and ear damage to corn in the southeastern United States. Transgenic hybrids expressing the Cry1Ab (MON810 event) or Cry 1F (TC1507 event) insecticidal endotoxin from *Bacillus thuringiensis* (*Bt*) were evaluated for management of fall armyworm and corn earworm in central Georgia during 2006 and 2007. Corn was planted at the recommended time in mid-Apr and in late Jun to simulate a double-crop corn planting. Both *Bt* events reduced whorl infestation and damage by fall armyworm, but TC1507 provided greater protection from whorl injury than MON 810 under severe fall armyworm infestations. Hybrids with the MON810 event usually had less ear infestation by corn earworm than susceptible hybrids, whereas the TC1507 event usually did not reduce ear infestations. Nevertheless, both events prevented ear damage, but there was no consistent difference between the two *Bt* traits in preventing ear damage. *Bt* traits did not affect grain yield in either year during the first planting when fall armyworm infestations were low. Both events prevented significant yield loss during the second planting in 2006 when whorl infestation levels exceeded 50% in susceptible hybrids. Because of the greater activity in preventing whorl damage by fall armyworm, the TC1507 event would be useful in mitigating the risk of severe lepidopteran damage to later plantings of field corn for grain production in the southeastern U.S.

Key Words: plant resistance, *Spodoptera frugiperda*, *Helicoverpa zea*, transgenic crops, Cry1F, Cry1Ab, *Bt* traits

RESUMEN

El gusano cogollero, *Spodoptera frugiperda* (J. E. Smith) y el gusano de elote de maíz, *Helicoverpa zea* (Boddie), perennemente causan daño a las hojas y mazorcas de maíz en el sureste de los Estados Unidos. Los híbridos transgénicos que expresan las endotoxinas Cry1Ab (evento MON810) o Cry 1F (evento TC1507) de *Bacillus thuringiensis* (*Bt*) con propiedades de insecticidas fueron evaluados para el manejo del gusano cogollero y el gusano del elote de maíz en la región central del estado de Georgia durante los años 2006 y 2007. El maíz fue sembrado al tiempo recomendado en el medio de abril y en la última parte de junio para estimular la siembra de un doble cultivo de maíz. Ambos eventos de *Bt* reducieron la infestación y daño hecho por el gusano cogollero en el cogollo, pero el TC1507 proveyó una protección mejor al cogollo que MON810 bajo durante infestaciones severas del gusano cogollero. Los elotes de los híbridos con el evento MON810 usualmente tenían un nivel menor de infestación del gusano de elote que en los híbridos susceptibles, mientras que el evento de TC1507 usualmente redujo las infestaciones del elote. No obstante, ambos eventos previnieron daño a los elotes, pero no hubo suficientes diferencias entre las características de *Bt* en cuanto de la prevención del daño al elote. Las características de *Bt* no afectaron el rendimiento del grano en ninguno de los dos años durante la primera siembra cuando las infestaciones del gusano cogollero fueron bajas. Ambos eventos previnieron una pérdida significativa en el rendimiento durante la segunda siembra en 2006 cuando el nivel de infestación en los cogollos fue más de 50% en los híbridos susceptibles. Por causa de la mayor actividad en prevenir el daño al cogollo hecho por el gusano cogollero, el evento TC1507 seria mas útil en mitigar el riesgo de daño severo hecho por los lepidópteros a siembras posteriores de maíz del campo para la producción de granos en el sureste de los Estados Unidos.

Fall armyworm, *Spodoptera frugiperda* (J. E. Smith), and corn earworm, *Helicoverpa zea* (Boddie), are the most important lepidopteran pests of corn in the southeastern United States. Fall armyworm often infests whorl stage plants causing leaf injury. Corn earworm often infests ears causing direct loss of grain, but fall armyworm also may infest ears especially during large infestations. Insecticidal control to prevent ear damage in field corn is difficult and generally not cost effective. Typically, early planting times are recommended in the Southeast partly to avoid damaging levels of both insects, which often occur later in the season (Buntin 2007). Transgenic corn hybrids expressing the insecticidal Cry protein from *Bacillus thuringiensis* (*Bt*) has been available in the Southeast since 1998, and this technology offers the potential for reducing losses by fall armyworm and corn earworm in field corn (Buntin et al. 2001, 2004).

Several events of transgenic *Bt* corn have been developed with different modes of toxin expression (Ostlie et al. 1997). The MON810 event (Monsanto Co., St. Louis, MO) and a similar event Bt11 (Syngenta Crop Sciences, RTP, NC) contain the Cry1Ab gene. These events are marketed as YieldGard® corn borer (YGCB) corn, and express endotoxin in vegetative and reproductive structures throughout the season (Armstrong et al. 1995; Williams et al. 1997). More recently, a new transformation event TC1507 expressing a *Bt*-derived insecticidal protein Cry1F is being marketed as Herculex® I *Insect Protection* (HX) (Dow AgroSciences, Indianapolis, IN). Both MON810 and TC1507 events are very effective against the European corn borer, *Ostrinia nubilalis* (Hübner), and southwestern corn borer, *Diatraea grandiosella* Dyar (Williams et al. 1998; Graeber et al. 1999; Lauer & Wedberg 1999; Archer et al. 2000; Abel & Pollan 2004; Allen & Pitre 2006; Siebert et al. 2008). European corn borer occurs throughout most of Georgia but usually is not an important pest of field corn. Southwestern corn borer does not occur in the coastal plain region of the southeastern United States but is present in northwestern Georgia and northern Alabama where it can cause economic damage (Buntin 2007).

Laboratory feeding trials and small controlled field trials have shown that hybrids containing Cry1Ab endotoxin reduced fall armyworm and corn earworm growth and survival (Williams et al. 1997, 1998; Bokonon-Ganta et al. 2003; Abel & Pollan 2004). However, fall armyworm is less susceptible to Cry1Ab endotoxins than southwestern corn borer (Williams et al. 1977; Abel & Pollan 2004). Storer et al. (2001) showed that corn containing Cry1Ab (Bt11) stunted growth of *H. zea* larvae, reduced *H. zea* adult emergence from *Bt*-corn fields by about 75% and delayed adult emergence by 6-12 d. Furthermore, kernel damage was reduced an average of 80% in *Bt* hybrids. Buntin et al. (2001, 2004) conducted a series of trials in 1998-2000 in Georgia with corn planted at the recommended time and one and two months later, which showed that MON810 and Bt11 events prevented whorl damage, kernel damage, and yield loss by lepidopterans, primarily fall armyworm and corn earworm, in later plantings at all locations. *Bt* traits generally did not improve the performance of corn planted at recommended times (March and April depending on location), because these plantings mostly escaped severe lepidopteran damage. However, *Bt* traits prevented yield loss of 50% or more in some later plantings. Nevertheless, field observations indicate that hybrids containing the MON810/Bt11 events can still suffer substantial whorl damage by fall armyworm when serve infestations occur (GDB, personal observation). More recently, Siebert et al. (2008) showed that Cry1F provided a high level of protection in corn against fall armyworm leaf feeding and whorl damage. Adapted field corn hybrids expressing Cry1F have only become available in the last few years in the southeastern United States.

The study objective was to evaluate corn expressing either Cry1Ab or Cry1F endotoxins for protection against fall armyworm and corn earworm infestations and damage in field corn. The effect on corn grain yield also was measured. Comparisons were done during 2 planting times, a recommended time in Apr and a late-Jun planting to simulate a double-crop planting of corn.

Materials and Methods

Trials were conducted in 2006 and 2007 at the University of Georgia Bledsoe Research farm located near Williamson (Pike Co.), GA. Soil was an Appling sandy loam, and tillage was conventional with chisel plowing followed by disk harrowing. Before disking 440 kg/ha of 3-18-9 (N-P-K) granular fertilizer was applied and an additional 112 kg of nitrogen as ammonium nitrate was side-dress applied about 20 d after planting. Seed was planted with a Monosem® air-planter at the rate of 66,700 plants per ha with 76-cm row spacing. Pendimethalin (Prowl 3.3 EC, BASF, Research Triangle Park, NC) at 0.71 L/ha and atrazine (Aatrex 4L, Syngenta Crop Protection, Greensboro, NC) at 0.57 L/ha were applied to control weeds. Seed of all hybrids were treated with clothianidin seed treatment at 0.25 mg ai per kernel (Poncho 250, Bayer CropSciences, Research Triangle Park, NC). No other pesticides were applied. Natural rainfall was supplemented by irrigating weekly with 6 cm of water as needed.

The experimental design of all trials was a randomized complete block design of hybrids with 4 replications. In 2006, plots were 4 rows and 10 m long and in 2007 plots were 8 rows and 10 m long. Early and late planting trials were conducted in both years. The first planting at the recommend time in late Apr (24 Apr 2006 and 30 Apr 2007) and the second planting was in late Jun (23 Jun 2006 and 26 Jun 2007) to simulate a double-crop corn planting.

Adapted non-*Bt* hybrids were compared with near-isogenic hybrids containing either the transformation event MON810, which expresses the Cry1Ab toxin, or the transformation event TC1507, which expresses the Cry1F toxin. Hybrids pairs in both years were Dekalb DKC 69-72 (non-*Bt*) and DKC 69-71 (MON810) (Dekalb

TABLE 1. EFFECT OF BT EVENTS ON PERCENTAGE OF FALL ARMYWORM INFESTED WHORLS IN THE SECOND CORN PLANTING IN 2006 AND 2007.

		2006		2007	
Brand/Hybrid	*Bt* event	6-leaf	10-leaf	6-leaf	10-leaf
DKC 6972	—	57.8 ± 3.6 a	60.5 ± 3.9 a	13.1 ± 2.2 a	18.9 ± 3.6 a
DKC 6971	MON810	15.2 ± 6.6 cd	37.3 ± 4.3 b	0.3 ± 0.3 b	1.5 ± 1.1 bc
Pioneer 31G66	—	54.0 ± 4.9 a	63.3 ± 3.0 a	16.7 ± 5.7 a	23.5 ± 3.5 a
Pioneer 31G68	MON810	18.8 ± 10.1 c	39.3 ± 7.2 b	2.2 ± 2.2 b	3.2 ± 2.4 b
Pioneer 31G97	—	50.5 ± 6.6 ab	66.0 ± 5.0 a	18.1 ± 4.1 a	24.2 ± 4.2 a
Pioneer 31G96	TC1507	10.0 ± 6.0 cd	4.8 ± 2.4 c	0.4 ± 0.4 b	0.0 ± 0.0 c
Pioneer 31N27	—	44.3 ± 6.0 ab	62.3 ± 3.6 a	16.6 ± 2.7 a	23.0 ± 4.4 a
Pioneer 31N28	MON810	10.0 ± 1.6 cd	35.5 ± 2.4 b	1.2 ± 1.0 b	2.6 ± 1.8 b
Pioneer 34B97	—	34.5 ± 4.5 b	63.1 ± 2.8 a	—	—
Pioneer 34B98	MON810	18.0 ± 5.0 c	36.8 ± 3.5 b	—	—
Pioneer 34B99	TC1507	5.3 ± 2.4 d	8.8 ± 2.6 c	—	—
$LSD_{(0.05)}$		—	—	—	—
Combined	—	48.2 ± 13.5 x	63.0 ± 6.9 x	19.0 ± 2.6 x	26.5 ± 4.0 x
Combined	MON810	15.5 ± 12.3 y	37.2 ± 9.9 y	1.2 ± 1.2 y	2.4 ± 3.3 y
Combined	TC1507	7.6 ± 8.8 z	6.8 ± 5.1 z	0.4 ± 0.8 y	0.0 ± 0.0 y
Source of variation[2]					
Hybrid		14.22***	28.86***	16.62***	26.37***
Non—*Bt* v. MON810		72.80***	57.50***	77.95***	145.25***
Non—*Bt* v. TC1507		51.58***	205.46***	36.97***	61.66***
MON810 v. TC1507		5.29*	95.46***	0.24ns	4.98*

Means within columns followed by the same lower case letter among hybrids or combined are not significantly different (LSD; $P = 0.05$).

*, **, *** indicate significant contrast F value at $P < 0.05$, $P < 0.01$, and $P < 0.001$ respectively; ns, not significant.

[2] 2006: Hybrid $df = 10, 30$; contrast $df = 1, 15$; 2007: Hybrid $df = 7, 21$; contrast $df = 1, 21$.

Seeds, Monsanto Comp., St Louis, MO), Pioneer Brand 31G66 (non-*Bt*) and 31G68 (MON810), Pioneer Brand 31N27 (non-*Bt*) and 31N28 (MON810), Pioneer Brand 31G97 (non-*Bt*) and 31G96 (TC1507) (Pioneer Hi-bred International, Des Moines, IA). In 2006, Pioneer Brand 34B97 (non-*Bt*), 34B98 (MON810), and 34B99 (TC1507) also were included.

In all trials, stand counts of all rows were made about 21 d after planting. Whorl defoliation was assessed by rating all plants in 2 rows per plot at the 6-leaf stage in each planting date. A second rating was made in the Jun plantings at about the 10-leaf stage. Plants were rated for damage on a 0-9 scale where 0 is no damage and 9 is whorl and furl almost completely defoliated (Davis et al. 1992). The damage scale is not linear with ratings of ≥4 indicating substantially more damage than ratings of ≤3. Twenty to 30 larvae were collected for species identification from infested whorls in border rows at the edge of plots. Ear damage was measured on 20 ears per plot about 2 wk after green-silk stage after nearly all larvae had exited the ears in the non-*Bt* hybrids. Ear damage was rated in both years by the Widstrom (1967) system where 1 = silk feeding, 2 = 1 cm of tip feeding, and each additional cm of tip feeding counts as another point. In 2007 final ear damage of 20 ears per plot was assessed at physiological maturity by measuring the total area (cm^2) of kernel damage.

Grain yield was measured from the 2 center rows of each plot in 2006 and from rows 2 and 3 in 2007. Grain was harvested with a Hege two-row corn combine in Aug and Sep when respective plantings reached about 16-18% moisture content. Grain weight, test weight, and moisture content were measured. Grain yields and test weights were adjusted to 15.5% moisture content.

Results were analyzed by trial with a RCBD. Before analysis, percentage data were transformed by square-root arcsine transformation. Results were compared among all hybrids by ANOVA, and means were separate by Fisher's Protected LSD ($\alpha = 0.05$). Single degree-of-freedom contrasts were used to compare hybrids without and with *Bt* traits and to compare among *Bt* traits (PROC GLM, SAS Institute 2003). Furthermore the effects of *Bt* traits (non-*Bt*, MON810, and TC1507) were averaged across all

TABLE 2. EFFECT OF BT EVENTS ON DAMAGE RATING (0–9) F FALL ARMYWORM INFESTED WHORLS IN THE SECOND CORN PLANTING IN 2006 AND 2007.

		2006		2007	
Brand/Hybrid	*Bt* event	6-leaf	10-leaf	6-leaf	10-leaf
DKC 6972	—	2.57 ± 0.31 bc	6.57 ± 0.31 a	4.61 ± 0.65 a	6.53 ± 0.11 a
DKC 6971	MON810	1.34 ± 0.11 d	5.55 ± 0.09 b	0.25 ± 0.25 b	1.38 ± 0.85 cd
Pioneer 31G66	—	3.04 ± 0.22 ab	6.61 ± 0.21 a	3.40 ± 0.67 a	5.87 ± 0.09 a
Pioneer 31G68	MON810	1.26 ± 0.06 d	5.15 ± 0.18 b	0.61 ± 0.60 b	2.75 ± 1.03 bc
Pioneer 31G97	—	2.46 ± 0.30 c	7.00 ± 0.56 a	3.68 ± 0.60 a	6.44 ± 0.17 a
Pioneer 31G96	TC1507	1.35 ± 0.20 d	4.08 ± 0.44 c	0.75 ± 0.75 b	0.0 ± 0.0 d
Pioneer 31N27	—	2.18 ± 0.08 c	6.52 ± 0.21 a	3.22 ± 0.23 a	5.91 ± 0.27 a
Pioneer 31N28	MON810	1.33 ± 0.12 d	5.16 ± 0.14 b	1.15 ± 0.68 b	3.80 ± 0.64 b
Pioneer 34B97	—	3.52 ± 0.25 a	6.68 ± 0.19 a	—	—
Pioneer 34B98	MON810	1.23 ± 0.09 d	4.99 ± 0.14 b	—	—
Pioneer 34B99	TC1507	1.08 ± 0.08 d	4.04 ± 0.38 c	—	—
$LSD_{(0.05)}$		0.53	0.88	1.75	1.59
Combined	—	2.75 ± 0.65 x	6.68 ± 0.61 x	3.65 ± 0.27 x	6.24 ± 0.12 x
Combined	MON810	1.29 ± 0.19 y	5.21 ± 0.33 y	0.67 ± 0.29 y	2.64 ± 0.42 y
Combined	TC1507	1.22 ± 0.32 y	4.00 ± 0.76 z	0.75 ± 0.38 y	0.00 ± 0.00 z
Source of variation[2]					
Hybrid		21.22***	12.80***	8.07***	21.38***
Non-*Bt* v. MON810		138.99***	41.54***	39.99***	61.15***
Non-*Bt* v. TC1507		92.59***	87.66***	12.11**	70.71***
MON810 v. TC1507		0.20ns	21.22***	0.01ns	17.85***

Means within columns followed by the same lower case letter among hybrids or combined are not significantly different (LSD; $P = 0.05$).

*, **, *** indicate significant contrast F value at $P < 0.05$, $P < 0.01$, and $P < 0.001$ respectively; ns, not significant.

[2]2006: Hybrid $df = 10, 30$; contrast $df = 1, 15$; 2007: Hybrid $df = 7, 21$; contrast $df = 1, 21$.

hybrids and analyzed by one-way ANOVA (PROC GLM, SAS Institute 2003), and means were separated by Protected LSD ($\alpha = 0.05$).

RESULTS

Plant stand was significantly different among hybrids in all trials, but most stand differences were associated with hybrid pedigree and not *Bt* traits (data not shown). In 2006, stands of the Pioneer 34B series hybrids were about 20% and 30% less than other hybrids in the first and second planting dates, respectively. These hybrids were planted in 2007 but not included in further analysis due to poor stand establishment.

Whorl infestations in all trials consisted almost entirely of fall armyworm. Fall armyworm infestations were substantially greater in 2006 than 2007 and also were greater in the second than the first plantings in both years. Whorl infestations in the first planting in 2006 ranged from 0 to 4.75%. Significantly fewer whorls were infested in hybrids with *Bt* traits than non-*Bt* hybrids in 2006 ($F = 45.2$, $df = 1, 30$; $P < 0.0001$; data not shown), but infestations were not different between *Bt* traits ($F = 0.75$, $df = 1, 30$; $P = 0.40$). Likewise, damage ratings of infested whorls in the first planting in 2006 were significantly lower in hybrids with *Bt* traits than susceptible hybrids ($F = 112.3$; $df = 1, 30$; $P < 0.0001$; data not shown) but were not different between *Bt* traits ($F = 0.34$; $df = 1, 30$; $P = 0.56$). In 2007, whorl infestations ranged from 0 to 1.4% in the first planting and were not different among hybrids ($F = 1.1$, $df = 7, 21$; $P = 0.39$, data not shown). Whorl damage ratings in the first planting in 2007 also were not different among hybrids ($F = 1.5$, $df = 7, 21$; $P = 0.22$).

In the second plantings hybrids with *Bt* traits had significantly fewer infested whorls at the 6- and 10-leaf stages than non-*Bt* hybrids in both years (Tables 1 and 2). Furthermore, in 2006 hybrids with the TC1507 event had significantly fewer infested whorls and less damage of infested whorls than hybrids with the MON810 event except for damage ratings at the 6-leaf stage. In 2007 whorl damage was not significantly different between *Bt* traits at the 6-leaf stage but was significantly lower at the 10-leaf stage in the hybrid with the TC1507 trait than in hybrids with the MON810 trait.

TABLE 3. EFFECT OF BT EVENTS AND PLANTING TIME[1] ON PERCENTAGE OF INFESTED EARS IN 2006 AND 2007.

		2006		2007	
Brand/Hybrid	*Bt* event	PD1	PD2	PD1	PD2
DKC 6972	—	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a
DKC 6971	MON810	98.3 ± 1.8 a	86.8 ± 5.5 bc	97.5 ± 2.5 a	81.7 ± 5.0 c
Pioneer 31G66	—	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a
Pioneer 31G68	MON810	100 ± 0 a	96.8 ± 3.3 ab	98.8 ± 1.3 a	68.3 ± 6.8 d
Pioneer 31G97	—	100 ± 0 a	96.5 ± 2.0 ab	100 ± 0 a	100 ± 0 a
Pioneer 31G96	TC1507	100 ± 0 a	93.3 ± 4.7 de	100 ± 0 a	93.3 ± 2.7 b
Pioneer 31N27	—	100 ± 0 a	100 ± 0 a	100 ± 0 a	100 ± 0 a
Pioneer 31N28	MON810	96.8 ± 3.3 a	70.3 ± 13.7 c	81.3 ± 6.3 b	63.3 ± 4.3 d
Pioneer 34B97	—	100 ± 0 a	100 ± 0 a	—	—
Pioneer 34B98	MON810	98.3 ± 1.8 a	100 ± 0 a	—	—
Pioneer 34B99	TC1507	100 ± 0 a	100 ± 0 a	—	—
$LSD_{(0.05)}$		NS	—	—	—
Combined	—	100 ± 0 x	99.3 ± 0.71 x	100 ± 0 x	100 ± 0 x
Combined	MON810	98.4 ± 0.4 x	88.5 ± 0.21 y	92.5 ± 3.4 y	71.1 ± 5.0 z
Combined	TC1507	100 ± 0 x	96.7 ± 0.71 xy	100 ± 0. x	93.3 ± 5.1 y
Source of variation[2]					
Hybrid		0.83ns	3.96**	11.42***	40.62***
Non-*Bt* v. MON810		4.15*	14.99***	27.73***	237.67***
Non-*Bt* v. TC1507		0.01ns	0.09ns	0.00ns	12.77**
MON810 v. TC1507		2.77ns	3.59ns	13.87***	42.57***

Means within columns followed by the same lower case letter among hybrids or combined are not significantly different (LSD; $P = 0.05$).

*, **, *** indicate significant contrast F value at $P < 0.05$, $P < 0.01$, and $P < 0.001$ respectively; ns, not significant.

[1]PD1 = recommended mid-Apr planting time, PD2 = mid-Jun planting time.

[2]2006: Hybrid $df = 10, 30$; contrast $df = 1, 15$; 2007: Hybrid $df = 7, 21$; contrast $df = 1, 21$.

Ear damage in the first planting in both years and in the second planting in 2007 was caused almost entirely by corn earworm. In the second planting in 2006, ears were infested by both corn earworm and fall armyworm. The percentage of infested ears was not different among hybrids in the first planting in 2006 (Table 3). In the other trials, hybrids with the MON810 event had significantly fewer infested ears than the non-*Bt* hybrids. Ear infestations in 2007 also were lower in hybrids with the MON810 event than hybrids with the TC1507 event in both plantings. Ear damage ratings were significantly less in hybrids with *Bt* traits than the non-*Bt* hybrids in all trials (Table 4). Ear damaging ratings were similar among *Bt* traits except the first planting in 2007 where ear damage was less in hybrids with the MON810 event than the TC1507 event.

Grain yields were not significantly different between *Bt* and non-*Bt* hybrids in the first planting in either year (Table 5). Hybrids with either the MON810 or the TC1507 events yielded more than the non-*Bt* hybrids in the second planting in 2006, but the yield of hybrids with either *Bt* traits were similar. In 2007, grain yield in the second planting was lower in the non-*Bt* hybrids than hybrids with either type of *Bt* but this difference was not significant. Grain test weight was significantly affected by hybrid pedigree but was not significantly affected by *Bt* trait in any trial ($F = 0.01 - 1.72$; $df = 1, 30$ (2006) or 21 (2007); $P = 0.20 - 0.96$; data not shown).

DISCUSSION

The Pioneer 34B series hybrids in 2006 provided a direct comparison of the 2 *Bt* events with a non-transformed hybrid with the same base genetics. Results were similar to those previous listed for the comparison of near-isogenic pairs of hybrids, which indicates that the broader comparison of *Bt* activity among hybrids with different pedigrees is appropriate.

Both *Bt* events were effective in preventing whorl infestations and damage by fall armyworm. Infestation levels in the first planting dates in both years were substantially below the level of whorl infestation needed to cause economic losses (Buntin 1986). Both the MON810 and TC1507 events provide similar levels of protection from

TABLE 4. EFFECT OF BT EVENTS AND PLANTING TIME[1] ON DAMAGE RATING OF INFESTED CORN EARS IN 2006 AND 2007.

Brand/Hybrid	*Bt* event	2006 PD1	2006 PD2	2007 PD1	2007 PD2
DKC 6972	—	5.34 ± 0.24 a	4.47 ± 0.12 b	4.36 ± 0.57 a	4.94 ± 0.24 a
DKC 6971	MON810	3.97 ± 0.34 b	2.32 ± 0.18 de	2.63 ± 0.18 e	2.27 ± 0.33 b
Pioneer 31G66	—	3.47 ± 0.22 bcd	3.67 ± 0.25 b	3.71 ± 0.17 bc	4.70 ± 0.19 a
Pioneer 31G68	MON810	3.25 ± 0.17 cd	2.27 ± 0.43 e	3.05 ± 0.19 d	1.73 ± 0.15 b
Pioneer 31G97	—	3.93 ± 0.37 bc	3.43 ± 0.22 bc	3.96 ± 0.02 b	5.21 ± 0.39 a
Pioneer 31G96	TC1507	3.24 ± 0.15 d	2.57 ± 0.31 de	3.46 ± 0.13 c	2.14 ± 0.13 b
Pioneer 31N27	—	4.14 ± 0.45 b	3.87 ± 0.05 ab	3.72 ± 0.12 bc	4.85 ± 0.39 a
Pioneer 31N28	MON810	2.47 ± 0.21 e	1.30 ± 0.35 f	1.69 ± 0.20 f	1.51 ± 0.17 b
Pioneer 34B97	—	3.63 ± 0.22 bcd	3.90 ± 0.18 ab	—	—
Pioneer 34B98	MON810	2.95 ± 0.18 de	2.97 ± 0.20 cd	—	—
Pioneer 34B99	TC1507	3.23 ± 0.27 d	2.75 ± 0.34 cde	—	—
$LSD_{(0.05)}$		0.69	0.68	0.38	0.80
Combined	—	4.10 ± 0.27 x	3.87 ± 0.71 x	3.94 ± 0.37 x	4.66 ± 0.78 x
Combined	MON810	3.16 ± 0.41 y	2.22 ± 0.21 y	2.46 ± 0.69 z	1.84 ± 0.58 y
Combined	TC1507	3.24 ± 0.27 y	2.66 ± 0.71 y	3.46 ± 0.26 y	2.14 ± 0.26 y
Source of variation[2]					
Hybrid		9.93***	15.09***	42.29***	35.96***
Non-*Bt* v. MON810		33.95***	110.78***	192.06***	181.77***
Non-*Bt* v. TC1507		5.29*	18.03***	7.32*	63.35***
MON810 v. TC1507		0.13ns	4.77*	44.63***	0.88ns

Means within columns followed by the same lower case letter among hybrids or combined are not significantly different (LSD; $P = 0.05$).

*, **, *** indicate significant contrast F value at $P < 0.05$, $P < 0.01$, and $P < 0.001$ respectively; ns, not significant.

[1]PD1 = recommended mid-Apr planting time, PD2 = mid-Jun planting time.

[2]2006: Hybrid $df = 10, 30$; contrast $df = 1, 15$; 2007: Hybrid $df = 7, 21$; contrast $df = 1, 21$.

whorl damage by fall armyworm under low to moderate infestation levels. However, hybrids with the MON810 event had substantially more infested whorls and damage per infested whorl than hybrids with the TC1507 event under large infestation levels that occurred during the second planting in 2006.

In previous studies the MON810 event was effective in preventing whorl damage under large infestations that occurred during a fall armyworm outbreak in 1998 (Buntin et al. 2001) and more moderate infestations in studies in 1999 and 2000 (Buntin et al. 2004). Fall armyworm is more sensitive to Cry1F endotoxin than Cry1Ac, Cry1Bb, and Cry1Ca endotoxins (Lou et al. 1999). Siebert et al. (2008) also demonstrated that Cry1F (TC1507 event) provides high level of prevention to leaf feeding in field corn but did not evaluate other *Bt* endotoxins.

In the current study, corn earworm infested virtually 100% of the ears in susceptible hybrids. Hybrids with the MON810 event had less ear infestation than susceptible hybrids except in the first planting in 2006, although infestations in all trials exceeded 63% in all hybrids with MON810 and often had greater than 90% infested ears. In three of four trials, the TC1507 event did not reduce ear infestations. Where a reduction did occur in the second 2007 planting, the difference was small. Nevertheless, both *Bt* traits partly reduced ear damage ratings in all trials. There was no consistent difference between the 2 *Bt* traits in preventing ear damage. The reduction in ear damage was similar to reduction in grain damage of about 52% from earworms and armyworms previously reported (Buntin et al. 2004). Furthermore, Storer et al. (2001) showed that corn containing the MON810 or Bt11 events reduced kernel damage by an average of 80%. Corn containing Cry1Ab endotoxin usually reduces the growth of *H. zea* larvae, and reduces and delays *H. zea* adult emergence from *Bt*-corn fields (Storer et al. 2001; Allen & Pitre 2006).

Bt traits did not prevent grain yield loss in the first planting in either year. Fall armyworm infestations were low with <5% infested whorls in the

TABLE 5. EFFECT OF BT EVENTS AND PLANTING TIME[1] ON CORN GRAIN YIELD (MG/HA) IN 2006 AND 2007.

		2006		2007	
Brand/Hybrid	*Bt* event	PD1	PD2	PD1	PD2
DKC 6972	—	12.60 ± 0.30 a	5.43 ± 0.84 b-f	13.40 ± 0.48 a	5.19 ± 0.18 ab
DKC 6971	MON810	11.10 ± 0.80 a	7.96 ± 0.60 a	13.00 ± 0.68 a	5.90 ± 0.13 a
Pioneer 31G66	—	12.21 ± 1.21 a	4.90 ± 0.63 def	11.92 ± 0.43 a	3.98 ± 0.16 bc
Pioneer 31G68	MON810	10.62 ± 2.07 a	8.04 ± 1.08 a	13.02 ± 0.34 a	4.32 ± 0.05 b
Pioneer 31G97	—	11.02 ± 0.76 a	4.75 ± 1.00 ef	13.67 ± 0.75 a	2.65 ± 0.79 cd
Pioneer 31G96	TC1507	12.18 ± 0.57 a	6.94 ± 1.53 abc	11.36 ± 0.30 a	4.23 ± 0.29 b
Pioneer 31N27	—	11.22 ± 1.07 a	4.36 ± 0.65 f	13.49 ± 0.91 a	1.49 ± 0.53 d
Pioneer 31N28	MON810	11.71 ± 0.45 a	7.29 ± 0.80 ab	13.16 ± 0.41 a	1.94 ± 0.87 d
Pioneer 34B97	—	8.47 ± 1.28 a	5.02 ± 0.58 d-f	—	—
Pioneer 34B98	MON810	8.78 ± 0.84 a	6.78 ± 0.49 a-d	—	—
Pioneer 34B99	TC1507	10.06 ± 1.19 a	6.76 ± 0.71 a-e	—	—
$LSD_{(0.05)}$		NS	2.02	NS	1.39
Combined	—	11.10 ± 2.30 x	4.90 ± 1.39 x	12.40 ± 2.03 a	3.74 ± 1.86 a
Combined	MON810	10.55 ± 4.39 x	7.52 ± 1.49 y	13.06 ± 1.44 a	4.05 ± 1.76 a
Combined	TC1507	11.12 ± 2.06 x	6.85 ± 2.22 y	11.36 ± 1.71 a	4.23 ± 0.29 a
Source of variation[2]					
Hybrid		1.88 ns	2.88***	1.32 ns	10.82***
Non-*Bt* v. MON810		0.74 ns	27.23***	0.05 ns	1.6 5ns
Non-*Bt* v. TC1507		2.14 ns	6.30*	5.36*	5.59*
MON810 v. TC1507		0.49 ns	1.52 ns	4.33*	0.11 ns

Means within columns followed by the same lower case letter among hybrids or combined are not significantly different (LSD; $P = 0.05$).

*, **, *** indicate significant contrast F value at $P < 0.05$, $P < 0.01$, and $P < 0.001$ respectively; ns, not significant.

[1]PD1 = recommended mid-Apr planting time, PD2 = mid-Jun planting time.

[2]2006: Hybrid df = 10, 30; contrast df = 1, 15; 2007: Hybrid df = 7, 21; contrast df = 1, 21.

first planting in both years. During the second planting, *Bt* traits prevented significant yield loss in 2006, but the same trend in 2007 was not significant. Previous studies also in Georgia have found that *Bt* traits for lepidopteran control usually only prevent yield loss in late plantings (Buntin et al. 2001, 2004).

Comparing the 4 trials in the current study, the yield responses to *Bt* traits were associated with the level of fall armyworm whorl infestation and damage with *Bt* preventing significant yield loss only during the second planting in 2006 when whorl infestation levels exceeded 50% in susceptible hybrids. Differences in ear infestation were fairly minimal between hybrids with and without Bt traits and not generally associated with observed differences in grain yields. Abel & Pitre (2004) also did not find a yield response to reduction in ear damage by corn earworm between MON810 trait and susceptible hybrids. Despite large differences in the prevention of whorl damage between the 2 *Bt* traits in the second plantings, this difference in damage did not significantly affect grain yield. Nevertheless it is difficult to convince farmers that the difference in the level of defoliation seen in late 2006 in the hybrids with the MON810 event or the TC1507 event was not important. Because of the greater activity in preventing whorl damage by fall armyworm, the TC1507 event would be useful in preventing fall armyworm damage to late planted field corn for grain production in the southeastern U.S.

ACKNOWLEDGMENTS

I thank William R. Slaughter, Jr. for technical assistance and Xinzhi Ni for reviewing an early version of this manuscript. I thank Jerry Davis for advice on statistical procedures used in this study.

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