Corn Expressing Cry1Ab Endotoxin for Management of Fall Armyworm and Corn Earworm (Lepidoptera: Noctuidae) in Silage Production[1]

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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 for silage production in the southeastern United States. Transgenic hybrids expressing the Cry1Ab (MON810 event) insecticidal endotoxin from *Bacillus thuringiensis* (*Bt*) were evaluated for management of fall armyworm and corn earworm in central Georgia during 2006 and 2007. Hybrids with a temperate or semitropical background were planted at the recommended time in mid-April and in late June to simulate a double-crop corn planting. Whorl infestation and damage by fall armyworm was significantly reduced in hybrids with the *Bt* trait when infestations were large. Fall armyworm infestation levels and damage were similar in both temperate and semitropical types. Hybrids with the *Bt* trait also had a small reduction in ear infestation and less kernel damage in ears infested by corn earworm than susceptible hybrids in most trials. Corn earworm infestation level were less in the semitropical than the temperate hybrids in 2006 but were not different in 2007. Silage yield was not significantly different among hybrids with and without the *Bt* trait in the first planting in both years. The *Bt* trait prevented significant yield loss of 17.1% during the second planting in 2006 when fall armyworm whorl infestations exceeded 39% in susceptible hybrids, but did not significantly affect silage yield in the late planting in 2007 when fall armyworm infestations were low. Temperate hybrids yielded more than semitropical hybrids in the early planting, but the semitropical type tended to perform better in the late planting. Corn silage quality as measured by neutral detergent fiber, acid detergent fiber and crude protein content did not differ among hybrids with or without the *Bt* trait indicating silage dry matter yield was the main silage component affected by the *Bt* trait and insect damage.

Key Words plant incorporated protectant, *Spodoptera frugiperda*, *Helicoverpa zea*, transgenic crops, Cry1Ab, *Bt* trait, silage

Transgenic corn hybrids expressing the insecticidal Cry protein from *Bacillus thuringiensis* (*Bt*) Berliner have been shown to reduce damage and losses by fall armyworm, *Spodoptera frugiperda* (J. E. Smith), and corn earworm, *Helicoverpa zea* Boddie, in field corn for grain production in the southeastern United States (Buntin et al. 2001, 2004, Buntin 2008, Wiatrak et al. 2004). Fall armyworm often infests whorl stage plants causing leaf injury but also may infest ears during large infestations. The impact of whorl defoliation on yield varies with infestation level, but an economic threshold of 30% infested plants is recommended in Georgia (Buntin 2010). Corn

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earworm often infests ears causing direct loss of grain, but also may defoliate whorls especially during large infestations. Typically, early planting times are recommended in the Southeast partly to avoid damaging levels of both insects, which often occur in large numbers later in the season (Buntin 2010).

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 Protection, RTP, NC) contain the Cry1Ab gene and have been available in the Southeast since 1998. These events express endotoxin in vegetative and reproductive structures throughout the season (Armstrong et al. 1995, Williams et al. 1997). 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 and Pollan 2004). However, fall armyworm is less susceptible to Cry1Ab endotoxins than other lepidopteran pests of corn (Williams et al. 1997, Abel and Pollan 2004), and field observations indicate that hybrids containing the MON810/Bt11 events can still suffer substantially whorl damage by fall armyworm when large infestations occur (Buntin 2010). In field studies, corn containing Cry1Ab events stunt the growth of *H. zea* larvae and partly reduces kernel damage in infested ears but the reduction in damage can be variable (Storer et al. 2001, Buntin et al. 2004, Allen and Pitre 2006). Trials in Georgia and northern Florida with corn for grain production, showed that MON810 and Bt11 events 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 (Buntin et al. 2001, 2004, Wiatrak et al. 2004). Benefits of *Bt* traits generally occur in plantings more than 1 month after the recommended planting time, with losses in susceptible hybrids exceeding 50% in some later plantings (Buntin et al. 2001, 2004).

Availability of *Bt* hybrids has increased interest in late-planted and double-cropped corn especially for silage production. Hybrids with tropical germplasm tend to perform better in the Southeast in late plantings than temperate midwestern type hybrids (Wiatrak et al. 2004, Wright et al. 1991). The study objective was to evaluate corn expressing Cry1Ab endotoxins and tropical type hybrids for protection against fall armyworm and corn earworm infestations and damage in field corn for silage production. Comparisons were done during a recommended time in April and a late-June 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. 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 (Monosem Inc., Edwardsville, KS) 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 (RCBD) 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 was in late April (24 April 2006 and 30 April 2007), and the second planting was in late June (23 June 2006 and 26 June 2007) to simulate a double-crop corn planting.

Adapted non*Bt* hybrids were compared with near-isogenic temperate or semitropical hybrids containing the transformation event MON810, which expresses the Cry1Ab toxin. Temperate hybrids pairs were Dekalb DKC 69 - 72 (non*Bt*) and DKC 69 - 71 (MON810) (Dekalb Seeds, Monsanto Comp., St. Louis, MO), Pioneer Brand 31G66 (non*Bt*) and 31G68 (MON810), Pioneer Brand 31N27 (non*Bt*) and 31N28 (MON810) (2007 only) (Pioneer Hi-Bred International, Des Moines, IA). Tropical hybrids in both years were Pioneer hybrid 33F33 (non*Bt*) and 33F34 (MON810).

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 June plantings at about the 10-leaf stage. Plants were rated for damage using 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 $\geq$4 indicating substantially more damage than ratings of $\leq$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 wks after green-silk stage after nearly all larvae had exited the ears in the non*Bt* hybrids. Ear damage was rated in both years using the Widstrom (1967) system were 1 = silk feeding, 2 = 1 cm of tip feeding and each additional cm of tip feeding counting as another point.

Silage yield was measured from the one of the center rows of each plot using a small plot silage chopper when temperate hybrids had reached the black layer stage of kernel development. Silage was weighed in the field. A subsample taken from each plot to measure moisture content and silage yield was calculated as dry matter. The subsample was ground, and neutral detergent fiber (NDF), acid detergent fiber (ADF), and crude protein content were measured by the University of Georgia Forage Quality Laboratory, Athens, GA (http://aesl.ces.uga.edu).

Results were analyzed by trial using a RCBD. Before analysis, percentage data were transformed by square-root arcsine transformation. Results were compared among all hybrids using an ANOVA, and means were separate using Fisher's Protected LSD (α = 0.05). Single degree-of-freedom contrasts also were used to compare hybrids without and with *Bt* traits and temperate versus semitropical types (Proc GLM, SAS Institute 2003).

Results

The MON810 is highly effective in controlling both European corn borer, *Ostrinia nubilalis* (Hübner), and southwestern corn borer, *Diatraea grandiosella* Dyar, in field corn (Archer et al. 2000, Williams et al. 1998, Abel and Pollan 2004, Allen and Pitre 2006), but neither species was present during the current study. 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 ranged from 0 - 6.5% in 2006 and from 0 - 3.0% in 2007 (Table 1). Significantly fewer whorls were infested in *Bt* hybrids than non*Bt* hybrids in both years. In the second plantings hybrids with the *Bt* trait had significantly fewer infested whorls at the 6 and 10 leaf stages than non*Bt* hybrids in both years (Table 2). Whorl infestations in the *Bt* hybrids were low in most cases but reached relatively high levels especially in the tropical hybrids in the 10-leaf sample in the first 2006 planting. In both years and plantings the percentage of infested whorls was not significantly different among temperate and tropical hybrids. One exception was the 6-leaf sample in the second 2006 planting where infestations were greater in the tropical than temperate hybrids.

Fall armyworm whorl damage ratings of infested plants were significantly smaller *Bt* hybrids than non*Bt* hybrids in both plantings and years with the exception of the 10-leaf sample in the first 2006 planting (Tables 1 and 3). Whorl damage ratings also varied among hybrids with different base genetics but were not different between tropical and temperate type hybrids in any trial.

Ear infestations in the first planting in both years and in the second 2007 planting were caused almost entirely by corn earworm. In the second 2006 planting, ears were infested by both corn earworm and fall armyworm. The percentage of infested ears was significantly different among hybrids in all trials (Table 4). The ears of hybrids with the *Bt* trait were infested less than ears of non*Bt* hybrids in all trials except the first 2006 planting. Furthermore, ear infestation in 2006 was significantly affected by hybrid type with infestations being lower in tropical than temperate hybrids (Table 4). In 2007 all non*Bt* hybrids had 100% infested ears, but the average of all temperate type hybrids was lower than the tropical type hybrids. Ear damage ratings also differed significantly among hybrids, and single degree-of-freedom contrasts also indicated that ratings were less in hybrids with the *Bt* trait than the non*Bt* hybrids in all trials (Table 5). Nevertheless, ear damage ratings within pairs of *Bt* and non*Bt* hybrids with the same base genetics were not always significantly different (Table 5). Ear damage ratings also were significantly less in tropical than temperate hybrids in both 2006 plantings and the second 2007 planting but not in the first 2007 planting (Table 5).

Silage yields were not significantly different between *Bt* and non*Bt* hybrids in the first planting in either year (Table 6). Single degree-of-freedom contrasts indicated that hybrids with the *Bt* trait yielded more than the non*Bt* hybrids in the second planting in 2006, but silage yields were not significantly different between *Bt* and non*Bt* hybrids in the second planting in 2007 (Table 6). Contrasts also indicated that tropical hybrids yielded less than temperate hybrids in the first planting in 2006, but yields of temperate and tropical hybrids were not significantly different in the other plantings.

Silage crude protein content, ADF and NDF content were not significantly affected by *Bt* trait in any of the 4 trials (data not shown, 2006: $F = 0.04 - 2.15$; df = 1, 15; $P = 0.8537 - 0.1632$; 2007: $F = 0.05 - 1.23$; df = 1, 21; $P = 0.8269 - 0.2807$). Silage ADF and NDF content differed among hybrids with different base genetics and also was greater in tropical than temperate hybrids in both plantings in 2006 (data not shown, April planting: $F = 33.67$ and 25.44; df = 1, 15; $P < 0.0001$; June planting: $F = 4.65$ and 6.47; df = 1, 21; $P = 0.0480$ and 0.0190, respectively) and the first planting in 2007 ($F = 64.73$ and 66.16; df = 1, 21; $P < 0.0001$, respectively). Crude protein content was not different among hybrids or hybrid types in all trials (data not shown, $P > 0.05$) with the exception of the second 2006 planting where crude protein content was greater in tropical than temperate hybrids ($F = 6.28$; df = 1, 15; $P = 0.0242$).

Table 1. Effect of hybrid type and *Bt* trait on percentage of fall armyworm infested whorls and whorl damage rating in the April corn planting in 2006 and 2007.

		% Infested whorls		Whorl damage rating of infested whorls	
Brand/Hybrid	*Bt* event	2006	2007	2006	2007
DKC 6972	-	6.5 ± 2.1 a	0.4 ± 3.9 b	3.78 ± 0.47 ab	0.75 ± 0.75 ab
DKC 6971	MON810	0.9 ± 0.4 bc	0.0 ± 0.0 b	0.67 ± 0.24 c	0.00 ± 0.00 a
Pioneer 31G66	-	5.9 ± 3.0 ab	0.7 ± 3.0 b	4.23 ± 1.67 a	1.63 ± 1.32 ab
Pioneer 31G68	MON810	0.1 ± 0.1 c	0.0 ± 0.0 b	1.25 ± 1.25 bc	0.00 ± 0.00 b
Pioneer 31N27	-	-	0.6 ± 2.7 b	-	1.63 ± 0.99 ab
Pioneer 31N28	MON810	-	0.0 ± 0.0 b	-	0.00 ± 0.00 b
Pioneer 30F33	-	3.7 ± 2.2 ab	3.0 ± 2.8 a	3.52 ± 1.27 ab	2.13 ± 1.27 a
Pioneer 30F34	MON810	0.0 ± 0.0 c	0.0 ± 0.0 b	0.00 ± 0.00 c	0.00 ± 0.00 b
$LSD_{(0.05)}$		-	-	2.76	2.08
Source of variation§					
Hybrid		5.62**	2.94*	3.94***	1.62ns
Non-*Bt* v. MON810		24.28***	12.09**	18.43***	9.38**
Temperate v. Tropical		2.21ns	4.03ns	0.84ns	0.48ns

Means within columns followed by the same lower case letter 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.
§ 2006: Hybrid df = 5, 15; contrast df = 1, 15; 2007: Hybrid df = 7, 21; contrast df = 1, 21.

Table 2. Effect of hybrid type and *Bt* trait 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
Dekalb DKC 6972	-	65.0 ± 22.0 ab	56.8 ± 11.6 a	11.0 ± 5.1 a	23.4 ± 7.5 a
Dekalb DKC 6971	MON810	5.5 ± 2.0 cd	18.2 ± 4.7 b	2.0 ± 1.2 b	3.0 ± 0.9 b
Pioneer 31G66	-	43.0 ± 22.1 abc	38.8 ± 10.8 ab	12.5 ± 3.0 a	17.9 ± 3.7 a
Pioneer 31G68	MON810	2.2 ± 0.7 d	24.8 ± 1.4 b	0.4 ± 0.2 b	1.8 ± 0.8 b
Pioneer 31N27	-	-	-	16.8 ± 6.4 a	23.8 ± 9.9 a
Pioneer 31N28	MON810	-	-	2.1 ± 1.6 b	3.3 ± 1.7 b
Pioneer 30F33	-	83.3 ± 3.5 a	51.0 ± 0.8 a	16.5 ± 3.8 a	26.7 ± 2.8 a
Pioneer 30F34	MON810	21.3 ± 7.0 bcd	61.0 ± 3.9 a	0.2 ± 0.2 b	3.8 ± 2.0 b
$LSD_{(0.05)}$		-	-	-	-
Source of variation[§]					
Hybrid		5.43**	5.76**	11.15***	10.69***
Non-*Bt* v. MON810		72.80***	5.92*	66.31***	72.04***
Temperate v. Tropical		8.19*	0.48ns	0.01ns	1.65ns

Means within columns followed by the same lower case letter 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.
[§] 2006: Hybrid df = 5, 15; contrast df = 1, 15; 2007: Hybrid df = 7, 21; contrast df = 1, 21.

Table 3. Effect of hybrid type and *Bt* trait on damage rating 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
Dekalb DKC 6972	-	5.10 ± 0.32 a	6.16 ± 0.17 a	3.14 ± 0.25 a	6.54 ± 0.09 a
Dekalb DKC 6971	MON810	1.82 ± 0.64 b	5.59 ± 0.12 a	1.13 ± 0.66 b	4.63 ± 0.22 bc
Pioneer 31G66	-	4.21 ± 0.41 a	5.80 ± 0.29 a	3.86 ± 0.72 a	5.77 ± 0.28 ab
Pioneer 31G68	MON810	1.43 ± 0.21 b	5.26 ± 0.14 a	0.50 ± 0.29 b	3.23 ± 0.52 c
Pioneer 31N27	-	-	-	3.61 ± 0.64 a	6.05 ± 0.31 ab
Pioneer 31N28	MON810	-	-	1.60 ± 0.63 b	3.94 ± 1.34 c
Pioneer 30F33	-	4.66 ± 0.17 a	5.09 ± 0.71 a	3.45 ± 0.47 a	6.05 ± 0.17 ab
Pioneer 30F34	MON810	1.79 ± 0.34 b	5.45 ± 0.09 a	0.25 ± 0.25 b	3.98 ± 0.23 c
$LSD_{(0.05)}$		1.16	NS	1.52	1.58
Source of variation[§]					
Hybrid		18.57***	1.28ns	8.27***	5.25**
Non-*Bt* v. MON810		89.58***	0.78ns	52.54***	32.31***
Temperate v. Tropical		0.06ns	2.14ns	1.19ns	0.01ns

Means within columns followed by the same lower case letter 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.
[§] 2006: Hybrid df = 5, 15; contrast df = 1, 15; 2007: Hybrid df = 7, 21; contrast df = 1, 21.

Table 4. Effect of planting time[1], hybrid type, and *Bt* trait on percentage of infested ears in 2006 and 2007.

		2006		2007	
Brand/Hybrid	*Bt* event	PD1†	PD2	PD1	PD2
Dekalb DKC 6972	-	100.0 ± 0.0 a	95.0 ± 3.1 a	100.0 ± 0 a	100.0 ± 0.0 a
Dekalb DKC 6971	MON810	97.8 ± 1.7 a	70.0 ± 14.1 a	97.5 ± 2.5 a	81.7 ± 5.0 c
Pioneer 31G66	-	100.0 ± 0.0 a	76.8 ± 7.9 a	100.0 ± 0.0 a	100.0 ± 0.0 a
Pioneer 31G68	MON810	98.3 ± 1.8 a	56.5 ± 6.9 a	98.8 ± 1.3 a	68.3 ± 6.9 cd
Pioneer 31N27	-	-	-	100.0 ± 0.0 a	100.0 ± 0.0 a
Pioneer 31N28	MON810	-	-	81.3 ± 6.3 b	63.3 ± 4.3 d
Pioneer 30F33	-	55.0 ± 8.1 b	53.5 ± 4.7 b	100.0 ± 0.0 a	100.0 ± 0.0 a
Pioneer 30F34	MON810	60.0 ± 17.4 b	35.3 ± 10.7 b	100.0 ± 0.0 a	91.7 ± 6.3 b
$LSD_{(0.05)}$		-	-	-	-
Source of variation§					
Hybrid		14.29***	5.24**	11.42***	25.76***
Non-*Bt* v. MON810		0.17ns	7.00*	20.80***	141.55***
Temperate v. Tropical		70.07***	13.61**	6.93*	15.40***

Means within columns followed by the same lower case letter 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.

†PDI = recommended midApril planting time, PD2 = midJune planting time.

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

Table 5. Effect of planting time[1], hybrid type, and *Bt* trait on damage rating of infested corn ears in 2006 and 2007.

		2006		2007	
Brand/Hybrid	*Bt* event	PD1†	PD2	PD1	PD2
Dekalb DKC 6972	-	2.82 ± 0.13 a	2.66 ± 0.46 a	5.63 ± 0.57 ab	4.94 ± 0.24 a
Dekalb DKC 6971	MON810	1.09 ± 0.02 c	1.58 ± 0.09 bc	4.74 ± 2.02 abc	2.75 ± 0.28 c
Pioneer 31G66	-	3.02 ± 0.17 a	2.49 ± 0.12 a	3.48 ± 0.26 bcd	4.70 ± 0.19 a
Pioneer 31G68	MON810	1.39 ± 0.07 b	1.95 ± 0.21 ab	2.39 ± 0.29 cd	2.56 ± 0.11 c
Pioneer 31N27	-	-	-	3.54 ± 0.07 bcd	4.89 ± 0.39 a
Pioneer 31N28	MON810	-	-	1.59 ± 0.04 d	2.41 ± 0.25 c
Pioneer 30F33	-	1.03 ± 0.03 c	1.35 ± 0.36 bc	5.66 ± 0.92 a	3.57 ± 0.14 b
Pioneer 30F34	MON810	1.00 ± 0.00 c	1.10 ± 0.16 c	2.31 ± 0.16 cd	2.75 ± 0.19 c
$LSD_{(0.05)}$		0.25	0.83	2.44	0.71
Source of variation§					
Hybrid		129.96***	5.04**	4.48**	20.81***
Non-*Bt* v. MON810		281.44***	7.47*	12.38**	123.07***
Temperate v. Tropical		224.13***	15.29**	1.86ns	7.61*

Means within columns followed by the same lower case letter 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.
†PDI = recommended midApril planting time, PD2 = midJune planting time.
§ 2006: Hybrid df = 10, 30; contrast df = 1, 15; 2007: Hybrid df = 7, 21; contrast df = 1, 21.

Table 6. Effect of planting time[1], *Bt* trait, and hybrid type on corn silage yield (Mg/ha) in 2006 and 2007.

		2006		2007	
Brand/Hybrid	*Bt* event	PD1†	PD2	PD1	PD2
Dekalb DKC 6972	-	14.35 ± 0.86 ab	7.60 ± 0.84 a	22.09 ± 0.93 a	14.73 ± 1.02 a
Dekalb DKC 6971	MON810	14.77 ± 0.99 a	9.14 ± 0.60 a	22.07 ± 2.93 a	13.41 ± 1.54 ab
Pioneer 31G66	-	11.91 ± 0.78 bc	6.27 ± 0.63 a	21.18 ± 1.84 a	11.26 ± 0.39 cd
Pioneer 31G68	MON810	14.51 ± 0.83 ab	8.70 ± 0.58 a	21.26 ± 1.04 a	11.61 ± 0.93 bcd
Pioneer 31N27	-	-	-	19.17 ± 2.58 a	10.48 ± 0.55 cd
Pioneer 31N28	MON810	-	-	20.68 ± 1.14 a	10.02 ± 0.63 d
Pioneer 30F33	-	9.25 ± 0.85 d	8.73 ± 0.65 a	18.77 ± 1.01 a	13.83 ± 0.85 ab
Pioneer 30F34	MON810	10.03 ± 1.08 cd	9.43 ± 0.80 a	19.66 ± 1.60 a	12.17 ± 0.49 bc
$LSD_{(0.05)}$		2.61	NS	NS	2.07
Source of variation§					
Hybrid		7.88***	2.58ns	0.46ns	5.92**
Non-*Bt* v. MON810		3.20ns	6.03*	0.21ns	2.19ns
Temperate v. Tropical		31.97***	3.32ns	1.46ns	3.63ns

Means within columns followed by the same lower case letter 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.
†PDI = recommended midApril planting time, PD2 = midJune planting time.
§ 2006: Hybrid df = 10, 30; contrast df = 1, 15; 2007: Hybrid df = 7, 21; contrast df = 1, 21.

Discussion

The MON810 event was effective in preventing whorl infestations and damage by fall armyworm which is consistent with previous studies on Bt corn in the Southeast (Buntin et al. 2001, 2004, Buntin 2008, Wiatrak et al. 2005). 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). The *Bt* trait only prevented significant loss of silage yield in the second planting in 2006 when fall armyworm infestations in whorl stage plant were large and exceeded 39% infested whorls in the non*Bt* hybrids. Infestations in the second 2007 planting also were below the threshold for economic loss although considerable visible defoliation was evident in non*Bt* hybrids. The *Bt* trait also reduced kernel damage in ears by corn earworm in all trials. However, silage yield losses were more closely associated with the level of fall armyworm damage than kernel damage by corn earworm. Allen and Pitre (2006) also did not find a yield response between hybrids with the MON810 event and susceptible hybrids due to a reduction in ear damage by corn earworm.

Corn silage quality parameters also were not significantly affected by the *Bt* trait in any trial indicating that the primary effect of the trait is in preventing loss of silage dry matter. Furthermore, the *Bt* trait prevented loss of silage yield in the later plantings in June but not in the earlier plantings in April. Previous studies in the Southeast also have found that *Bt* traits for lepidopteran control usually only prevent loss of yield in late corn plantings (Buntin et al. 2001, 2004, Buntin 2008, Wiatrak et al. 2005). In the current study, the MON810 event prevented most whorl defoliation by fall armyworm but noticeable damage occurred in the *Bt* lines in the second 2006 planting when infestations were large. Fall armyworm is less sensitive to Cry1Ac, Cry1Bb, and Cry1Ca endotoxins than the Cry1F endotoxin (Lou et al. 1999), which may account for the moderate defoliation by fall armyworm of hybrids with the Cry1Ab endotoxin from the MON810 event.

Fall armyworm infestations and damage were not different between temperate and tropical type corns. Corn earworm infestations in ears and kernel damage were less in tropical than temperate hybrids in the 2006 trials but not consistently different in 2007. Tropical hybrids used in this study have a relative maturity of 132 days compared with 114 - 119 days for temperate hybrids. Ear damage ratings in 2006 may have been too early to fully measure ear infestation in the tropical hybrids. Irrespective of *Bt* trait presence, silage yield of tropical hybrids was less than temperate hybrids in the April plantings but was similar to yields of temperate hybrids in the June plantings. Wiatrak et al. (2004) showed that tropical corn hybrids generally have greater silage yield and quality than temperate hybrids in late plantings in the Southeast.

In conclusion, this study indicates that high-yielding temperate hybrids are useful for April plantings for corn silage production, whereas hybrids with tropical germplasm may be useful in late plantings. The Cry1Ab *Bt* trait did not provide a clear benefit in the April plantings but did reduce the risk of yield losses by fall armyworm in late plantings of corn for silage production.

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