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ARTHROPOD MANAGEMENT

Opportunities to Manage Fall Armyworm (Lepidoptera: Noctuidae) on Bollgard II® Cotton with Reduced Rates of Insecticides

Jarrod T. Hardke*, Ryan E. Jackson, and B. Rogers Leonard

ABSTRACT

The occurrence of selected late-instar lepidopteran larvae, such as fall armyworm, *Spodoptera frugiperda* (J. E. Smith), on *Bacillus thuringiensis* Berliner (Bt) cotton, *Gossypium hirsutum* (L.), plants has become a common problem in recent years. In some instances, there is a need to manage these infestations with supplemental foliar insecticide applications. The objective of these studies was to evaluate the efficacy of selected insecticides (chlorantraniliprole, flubendiamide, lambda-cyhalothrin, novaluron, and spinetoram) against fall armyworm in transgenic Bt (Bollgard II®) and non-Bt (conventional) cotton. Bollgard II plants were sprayed with reduced (one-half of full)) rates of insecticides and conventional cotton was sprayed with recommended (full) rates of the same products. Plant terminal leaves and bolls were removed from sprayed and non-sprayed (control) field plots, returned to the laboratory, and infested with a single third-instar fall armyworm. Larval mortality ranged from 30.0 to 95.0% and from 22.5 to 82.5% on insecticide-sprayed (reduced rates) Bollgard II and insecticide-sprayed (full rates) conventional terminal leaves, respectively, 3 d after infestation. Fall armyworm survivorship did not differ on insecticide-sprayed Bollgard II plant tissue compared to that for the same insecticide used on conventional plants. Reduced insecticide rates on Bollgard II cotton did not negatively affect efficacy of any insecticide used compared to full rates on conventional cotton. Insecticide-sprayed Bollgard II and insecticide-sprayed conventional bolls caused fall armyworm mortality ranging from 5.0 to 80.0% and from 17.5 to 80.0%, respectively, 3 d after infestation. These same insecticide treatments produced fall armyworm mortality on Bollgard II (55-100%) and conventional bolls (52.5-100%) at 7 d after infestation. Reduced rates of selected insecticides were efficacious against fall armyworms on Bollgard II cotton plant tissues and could reduce chemical control costs against field infestations of this pest.

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is an occasional, but often serious, pest of cotton, *Gossypium hirsutum* (L.), across the Mid-Southern U.S. Annual infestations are unpredictable because fall armyworm migrates from the Gulf Coast region and the Caribbean Islands into U.S. cotton production areas each year (Knipling, 1980; Luginbill, 1928; Sparks, 1979). In addition, fall armyworm larvae usually occur in the lower two-thirds of the plant canopy and can be difficult to detect prior to the establishment of high populations in cotton fields. The significance of this pest has been further enhanced by the inconsistent performance of foliar insecticide sprays and *Bacillus thuringiensis* Berliner (Bt) transgenic cotton lines (Adamczyk et al., 2001; Stewart et al., 2001).

Fall armyworm adults generally deposit eggs in the lower cotton plant canopy; although they might oviposit throughout the entire plant profile when high populations of adults occur. Early instars feed on leaves at the site of the egg mass before dispersing vertically within the plant canopy, as well as horizontally to adjacent plants (Ali et al., 1989, 1990). Late instars (≥ 4^{th} instars) prefer to feed within bolls low in the canopy, which further protects them from insecticide sprays and exposure to residues on plant structures (Pitre, 1986; Young, 1979). Furthermore, broad-leaved crops such as cotton tend to reduce the efficiency of insecticide deposition low in the plant canopy (Reed and Smith, 2001). In addition, fall armyworm larvae become more tolerant to insecticides as larvae increase in age and size (Mink and

J.T. Hardke*, Formerly Department of Entomology, Louisiana State University Agricultural Center, 404 Life Sciences Building, Baton Rouge, LA 70803; R.E. Jackson, Formerly USDA-ARS, Southern Insect Management Research Unit, 141 Experiment Station Rd., Stoneville, MS 38776; and B.R. Leonard, Louisiana State University Agricultural Center, Macon Ridge Research Station, 212A Macon Ridge Rd, Winnsboro, LA 71295
*Corresponding author: jhardke@uaex.edu

Luttrell, 1989; Yu, 1983). This increase in insecticide tolerance makes controlling fall armyworm progressively more difficult because many infestations are not discovered until larvae develop to late instars.

Transgenic Bt cotton cultivars, expressing crystalline (Cry) proteins, have become the standard management strategy for lepidopteran pests and are planted on approximately 70% of the total U.S. cotton acreage (Williams, 2010). These proteins cause insect death upon ingestion by causing pore formation in the midgut, eventually leading to starvation and septicemia (IRAC MoA Working Group, 2012). Bollgard® cotton technology (Monsanto, St. Louis, MO), introduced in 1996, expressed the Cry1Ac protein and was effective in controlling tobacco budworm, *Heliothis virescens* (F.), and pink bollworm, *Pectinophora gossypiella* (Saunders). However, this technology failed to consistently provide high levels of efficacy against other lepidopteran pests such as bollworm, *Helicoverpa zea* (Boddie), and fall armyworm. Insecticide applications were common and necessary to control these pests in Bollgard cotton (Adamczyk et al., 2001, 2008). The success of Bollgard in controlling tobacco budworm and pink bollworm, coupled with its weaknesses in controlling additional species, led to the development of additional Bt cotton lines that express pyramided Bt proteins, including Bollgard II® (Cry1Ac + Cry2Ab) (Monsanto, St. Louis, MO) in 2003 and WideStrike™ (Cry1Ac + Cry1F) (Dow AgroSciences, Indianapolis, IN) in 2005. These pyramided Bt lines have demonstrated higher efficacy against bollworm and fall armyworm compared to Bollgard, but none of these traits offer complete protection from these pests (Chitkowski et al., 2003; Hardke et al., 2014; Siebert et al., 2008).

There has been a more frequent need in recent years to control fall armyworm populations with supplemental foliar insecticide applications in the mid-south and southeastern areas of the U.S. The current insecticide control recommendations for fall armyworm in Louisiana cotton include a variety of insecticides representing several classes, including: diacylhydrazine (methoxyfenozide); diamides (chlorantraniliprole, flubendiamide); Insect Growth Regulator (novaluron); pyrethroids (cyfluthrin, lambda-cyhalothrin, zeta-cypermethrin); and spinosyn (spinosad) (Anonymous, 2013). These recommendations historically have been based upon insecticide performance on conventional non-Bt cotton. Unfortunately, there have been no previous studies to examine the influence of the Bt proteins expressed in transgenic cotton lines on the effectiveness of insecticide applications for fall armyworm. Therefore, the objective of this study was to evaluate the effectiveness of reduced (one-half of full) rates of insecticides applied to Bollgard II- cotton lines compared to full rates applied to non-Bt (conventional) cotton lines in field trials. These trials evaluated insecticide efficacy against fall armyworm in situations where insecticide coverage is sufficient (terminal area of the cotton plant) and where spray coverage might be compromised (mid-canopy). Although there are differences in Bt expression between plant parts, the leaves and bolls chosen for this study were of a relatively young age to prevent a discrepancy in the age and subsequent protein expression of plant tissue. In most cotton insect control guides, there is no distinction between conventional and Bt cottons in their recommendations of foliar sprays for control of fall armyworm or other caterpillar pests (Adams et al., 2013; Anonymous et al., 2013; Carson et al., 2013). Insecticide performance information on Bollgard II cotton can be important in identifying chemical control recommendations for managing natural fall armyworm infestations and can provide reference data for future studies of insecticide and Bt cotton interactions.

MATERIALS AND METHODS

Fall Armyworm Colony Establishment and Maintenance. The fall armyworm colony used in this study originated from a field collection on cotton near Winnsboro, LA during 2005 and was supplemented with collections from field corn in the same area during 2006 and 2008. The colony was validated as the corn strain of fall armyworm using mitochondrial markers (Unpublished communication, R. Nagoshi, USDA-ARS, Gainesville, FL). The colony has been maintained in the laboratory on meridic diet (Stonefly Heliothis Diet, Ward's Natural Science, Rochester, NY) using the methods described in Adamczyk et al. (1998).

Site and Treatment Description. Field studies were conducted at the Macon Ridge Research Station (MRRS) near Winnsboro, LA in Franklin Parish (32° 8' 8" N 91° 41' 23" W) and at the USDA-ARS Southern Insect Management Research Unit (SIMRU) near Stoneville, MS in Washington County (33° 25' 23" N 90° 53' 36" W) during 2010. Cotton lines included Phytogen 425 RF (non-Bt; Roundup Ready Flex;

Phytogen Cottonseed, Dow AgroSciences, Indianapolis, IN) and Stoneville 4554 B2/RF (Bollgard II [Cry1Ac + Cry2Ab]; Roundup Ready Flex; Stoneville Pedigreed Seeds, Bayer CropScience, Research Triangle Park, NC). Multiple blocks of each variety were planted from early May to early June at each site on sequential planting dates to provide adequate availability of plants.

Insecticide Application. Tests were initiated when quarter-size bolls (~ 200 accumulated heat units) were common throughout the lower cotton canopy and were terminated prior to plants developing to cutout (main stem nodes above a sympodial first position white flower [NAWF] = 5). Insecticides were applied on 30 August and 4 September at MRRS and on 17 and 28 September at SIMRU. Insecticides at MRRS were applied using a high-clearance sprayer and a CO_2-charged spray system calibrated to deliver 107.6 l/ha through TX-8 hollow cone nozzles (Spraying Systems Company, Wheaton, IL). Insecticides at SIMRU were applied with a high-clearance sprayer and a CO_2-charged spray system calibrated to deliver 106.6 l/ha through TXVS-12 cone jet nozzles. Insecticides included chlorantraniliprole, flubendiamide, lambda-cyhalothrin, novaluron, and spinetoram, as well as a non-sprayed control (Table 1). Conventional cotton plots were sprayed with full recommended rates of insecticides whereas Bollgard II plots were sprayed with one-half of the recommended rates (Table 1). In similar bioassays, Tindall et al. (2006) showed that reduced-rate insecticide applications in conventional non-Bt cotton result in greater than 20% reduction in control. For this reason, insecticides applied at reduced rates were not evaluated on conventional cotton in this study.

Infestations on Cotton Leaves and Bolls. Fall armyworm larvae were infested on cotton plant tissue in a manner similar to that described by Tindall et al. (2006). Plant tissues were removed from field plots approximately 1 h after treatment once insecticide residue had dried. Ten leaves (second fully expanded leaf; second node from top of plant; upper canopy) and 10 bolls (~ quarter-size; first position on a sympodial branch; mid-canopy [mean plant height ~ 109 cm]) were collected from each plot and returned to the laboratory. A single third instar (30-45 mg; 7-9 d old) was placed into a plastic cup (96 ml; Solo Cup Co., Lake Forest, IL) containing either a leaf or a boll. For each infestation event (insecticide application), 10 larvae were exposed to each treatment (cotton line and insecticide combination) on both leaves and bolls. Larval mortality was evaluated at 3 d after infestation (DAI) on leaves and at 3 and 7 DAI on bolls. A larva was considered dead if it was incapable of movement after being placed on its dorsal surface (back). Larval mortality was compared based upon cotton line, treatment (cotton line x insecticide), location, and cotton line x location. Two replications were conducted at each location (MRRS and SIMRU) for a total of four replications and 40 larvae on each treatment.

Table 1. Insecticide treatments evaluated on non-Bt and Bollgard II cotton lines in field studies.

Common name	Trade name	Formulation (g/liter)	Insecticide Rates[z] Non-Bt[y] (Full)	Insecticide Rates[z] Bollgard II[y] (Reduced)	Class[x]	Manufacturer
chlorantraniliprole	Coragen	200 SC[w]	0.102	0.051	Diamide (28)	DuPont Crop Protection, Wilmington, DE
flubendiamide	Belt	480 SC	0.105	0.053	Diamide (28)	Bayer Crop Science, Research Triangle Park, NC
lambda-cyhalothrin	Karate Z	250 EC[v]	0.046	0.023	Pyrethroid (3A)	Syngenta Crop Protection, Greensboro, NC
novaluron	Diamond	100 EC	0.044	0.022	Benzoylurea (15) [IGR]	Makhteshim Agan of North America, Inc., Raleigh, NC
spinetoram	Radiant	120 SC	0.070	0.035	Spinosyn (5)	Dow AgroSciences, Indianapolis, IN

[z] kg AI/ha; Louisiana Insect Pest Management Guide (Anonymous, 2013).

[y] Cotton varieties: non-Bt = Phytogen 425 RF and Bollgard II = Stoneville 4554 B2RF.

[x] IRAC MoA Classification Scheme (IRAC MoA Working Group, 2012).

[w] Soluble concentrate.

[v] Emulsifiable concentrate.

Data Analysis. Treatments (cotton line and insecticide combinations) were randomly arranged within each replication (spray date/infestation event). Larval mortality percentages were transformed (arcsine square-root [X+1]) and subjected to a one-way analysis of variance with PROC GLM (SAS Institute, 2004). Means with a significant F value ($\alpha = 0.05$) were separated using the LSMEANS statement and compared according to Fisher's Protected LSD (SAS Institute, 2004). Whereas means were transformed for analysis; non-transformed means are presented in the results.

RESULTS

Differences were not detected for treatment (cotton line and insecticide) by location interaction for terminal leaves 3 d after infestation (DAI) (df = 11, 23; F = 1.66; $p = 0.1471$), for bolls 3 DAI (df = 11, 23; F = 1.08; $p = 0.4198$), and for bolls 7 DAI (df = 11, 23; F = 0.54, $p = 0.8534$). Therefore, data for the two locations were combined. Fall armyworm mortality on non-sprayed Bollgard II terminal leaves (7.5%) was not significantly greater than that observed on non-sprayed conventional leaves (0.0%). Fall armyworm mortality on insecticide-sprayed Bollgard II leaves at 3 DAI ranged from 30.0 to 95.0% compared to 22.5 to 82.5% on insecticide-sprayed conventional leaves (Table 2). On Bollgard II leaves sprayed with reduced insecticide rates, chlorantraniliprole, flubendiamide, lambda-cyhalothrin, and spinetoram caused significantly greater mortality ($p < 0.05$) than was observed on non-sprayed Bollgard II leaves. Significantly higher fall armyworm mortality was observed on chlorantraniliprole, flubendiamide, and spinetoram-sprayed Bollgard II leaves compared to mortality on novaluron-sprayed Bollgard II leaves ($p < 0.05$). Full rates of chlorantraniliprole, flubendiamide, lambda-cyhalothrin, and spinetoram on conventional leaves caused significantly greater mortality than was observed on the non-sprayed control. In addition, chlorantraniliprole-sprayed, flubendiamide-sprayed, and spinetoram-sprayed conventional leaves had higher fall armyworm mortality than novaluron-sprayed conventional leaves. Differences were not observed for fall armyworm mortality when comparing the reduced rate of an insecticide on Bollgard II cotton to each respective insecticide at the full rate on conventional cotton ($p > 0.05$).

Table 2. Mortality (± SE) of fall armyworm third instars on non-Bt and Bollgard II cotton terminal leaves 3 days after infestation.

Technology	Insecticide	Rates	% Mortality[z]
Bollgard II[y] (reduced rates)	chlorantraniliprole	0.051	90.0 ± 10.0a
	flubendiamide	0.053	80.0 ± 13.5abc
	lambda-cyhalothrin	0.023	55.0 ± 9.6cd
	novaluron	0.022	30.0 ± 17.8de
	spinetoram	0.035	95.0 ± 2.9a
	non-treated	----	7.5 ± 4.8ef
Non-Bt[y] (full rates)	chlorantraniliprole	0.102	82.5 ± 11.8abc
	flubendiamide	0.105	67.5 ± 19.7abc
	lambda-cyhalothrin	0.046	52.5 ± 18.0bcd
	novaluron	0.044	22.5 ± 11.1def
	spinetoram	0.070	82.5 ± 17.5ab
	non-treated	----	0.0 ± 0.0f
	df		11, 33
	F		8.63
	P		<0.0001

[z] Means followed by the same letter are not significantly different according to Fisher's Protected LSD ($p = 0.05$).

[y] Cotton varieties: non-Bt = Phytogen 425 RF and Bollgard II = Stoneville 4554 B2RF.

No significant differences were detected for fall armyworm mortality on non-sprayed Bollgard II bolls (2.5%) compared to mortality on non-sprayed conventional bolls (5.0%) at 3 DAI (Table 3). Insecticide-sprayed Bollgard II bolls caused fall armyworm mortality ranging from 5.0 to 80.0% compared to 17.5 to 80.0% on conventional bolls at 3 DAI. On Bollgard II, mortality was higher on bolls sprayed with chlorantraniliprole and spinetoram compared to mortality on lambda-cyhalothrin-sprayed, novaluron-sprayed, and non-sprayed Bollgard II bolls. Flubendiamide-sprayed bolls also caused higher mortality than non-sprayed Bollgard II bolls. Conventional bolls sprayed with full rates of chlorantraniliprole and spinetoram had greater fall armyworm mortality compared to conventional bolls sprayed with novaluron, as well as non-sprayed bolls. Conventional bolls sprayed with spinetoram also had higher mortality ($p < 0.05$) compared to conventional bolls sprayed with flubendiamide and lambda-cyhalothrin. Fall armyworm mortality levels were similar for conventional bolls sprayed with full insecticide rates and Bollgard II bolls sprayed with reduced rates of the same insecticide ($p > 0.05$).

Fall armyworm mortality observed on Bollgard II bolls (27.5%) did not significantly differ from mortality on non-sprayed conventional bolls (20.0%) at 7 DAI (Table 4). Fall armyworm mortality on insecticide-sprayed Bollgard II bolls at 7 DAI ranged from 55.0 to 100% and from 52.5 to 100% on conventional bolls. Fall armyworm mortality was higher on chlorantraniliprole, flubendiamide, novaluron, and spinetoram-sprayed Bollgard II bolls compared to non-sprayed Bollgard II bolls. Bollgard II bolls sprayed with chlorantraniliprole, flubendiamide, and spinetoram also had significantly higher mortality compared to lambda-cyhalothrin-sprayed Bollgard II bolls. Conventional bolls sprayed with chlorantraniliprole, flubendiamide, novaluron, and spinetoram had significantly greater fall armyworm mortality compared to non-sprayed conventional bolls. Significantly higher fall armyworm mortality was observed on chlorantraniliprole-sprayed conventional bolls compared to lambda-cyhalothrin-sprayed and novaluron-sprayed conventional bolls. No significant differences were observed in fall armyworm mortality between full rates applied to conventional bolls and reduced rates on Bollgard II bolls for the same insecticide ($p > 0.05$).

Table 3. Mortality (± SE) of fall armyworm third instars on non-Bt and Bollgard II cotton bolls 3 days after infestation.

Technology	Insecticide	Rates	% Mortality[z]
Bollgard II[y] (reduced rates)	chlorantraniliprole	0.051	70.0 ± 23.8ab
	flubendiamide	0.053	42.5 ± 17.0bcd
	lambda-cyhalothrin	0.023	17.5 ± 10.3def
	novaluron	0.022	5.0 ± 2.9ef
	spinetoram	0.035	80.0 ± 14.1a
	non-treated	----	2.5 ± 2.5f
Non-Bt[y] (full rates)	chlorantraniliprole	0.102	65.0 ± 11.9abc
	flubendiamide	0.105	40.0 ± 17.8bcde
	lambda-cyhalothrin	0.046	30.0 ± 12.2cde
	novaluron	0.044	17.5 ± 7.5def
	spinetoram	0.070	80.0 ± 13.5a
	non-treated	----	5.0 ± 2.9ef
	df		11, 33
	F		6.85
	P		<0.0001

[z] Means followed by the same letter are not significantly different according to Fisher's Protected LSD ($p = 0.05$).

[y] Cotton varieties: non-Bt = Phytogen 425 RF and Bollgard II = Stoneville 4554 B2RF.

Table 4. Mortality (± SE) of fall armyworm third instars on non-Bt and Bollgard II cotton bolls 7 days after infestation.

Technology	Insecticide	Rates	% Mortality[z]
Bollgard II[y] (reduced rates)	chlorantraniliprole	0.051	100.0 ± 0.0a
	flubendiamide	0.053	97.5 ± 2.5a
	lambda-cyhalothrin	0.023	55.0 ± 18.5cde
	novaluron	0.022	75.0 ± 10.4abc
	spinetoram	0.035	87.5 ± 9.5ab
	non-treated	----	27.5 ± 10.3de
Non-Bt[y] (full rates)	chlorantraniliprole	0.102	100.0 ± 0.0a
	flubendiamide	0.105	72.5 ± 17.0abc
	lambda-cyhalothrin	0.046	52.5 ± 17.5cde
	novaluron	0.044	62.5 ± 9.5bcd
	spinetoram	0.070	85.0 ± 11.9ab
	non-treated	----	20.0 ± 5.8e
	df		11, 33
	F		5.55
	P		<0.0001

[z] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (p = 0.05).
[y] Cotton varieties: non-Bt = Phytogen 425 RF and Bollgard II = Stoneville 4554 B2RF.

Individual insecticide efficacy against fall armyworm remained similar across conventional and Bollgard II cotton lines, despite the use of reduced rates on Bollgard II. Overall mortality values were significantly higher ($F = 15.13$; df = 1, 80; $p = 0.0002$) for larvae infested on terminal leaves (3 DAI) compared to those infested on bolls (3 DAI), which would be expected due to the adequate insecticide coverage achieved in the terminal area of the plant canopy. Fall armyworm mortality on non-sprayed Bollgard II cotton terminal leaves and bolls was low and did not significantly differ from that on non-sprayed conventional cotton for the same plant structure ($p > 0.05$).

DISCUSSION

The Bollgard II trait did not significantly reduce fall armyworm survivorship compared to that on conventional cotton under the conditions of the current study. Greater than 40% fall armyworm survivorship from third-instar to pupation on Bollgard II bolls has been documented in recent laboratory studies (Hardke et al., 2014). In addition, Hardke et al. (2014) reported greater than 55% third-instar survival on Bollgard II bolls in field studies 5 to 6 DAI.

Insecticide toxicity to fall armyworm varied among products on both Bt and conventional cotton lines. The more recently-registered insecticides (chlorantraniliprole, flubendiamide, and spinetoram) were more efficacious against fall armyworm than the older standards (lambda-cyhalothrin and novaluron) recommended against this pest. Field studies with these same insecticides against fall armyworm in grain sorghum showed efficacy levels similar to that in the present study, with newer products significantly reducing infested whorls and exhibiting greater residual efficacy compared to standard insecticides (Hardke et al., 2011). Smith and Catchot (2009) also reported a significant reduction in fall armyworm larvae on chlorantraniliprole-sprayed conventional corn plants compared to plants sprayed with novaluron and lambda-cyhalothrin, and the non-sprayed control. In addition, dose-mortality responses developed for these insecticides against fall armyworm in laboratory studies follow a similar trend in order of toxicity (Hardke et al., 2011). The LC_{50} values of these insecticides against fall armyworm, from most to least toxic, were spinetoram, chlorantraniliprole, novaluron, flubendiamide, and lambda-cyhalothrin, respectively.

Few studies have examined the combined effects of Bt plants and foliar insecticide sprays against pests of field crops. Many of the Bt traits are highly effective against specific species, and additional foliar sprays are used for non-target pests. However, many species of Lepidoptera, either as primary or secondary pests, express a range of susceptibility to Bt traits in cotton and other field crops. Due to the widespread use of Bt crops, the effects of the Bt traits become important when determining the need for supplemental insecticide sprays and actual selection of a treatment. Lynch et al. (1999) evaluated corn earworm damage to sweet corn ears on Bt and conventional corn hybrids that were either non-sprayed or sprayed with one, three, or five insecticide applications. Non-sprayed Bt hybrids were successful in reducing corn earworm damaged ears compared to non-sprayed conventional hybrids. Foliar insecticide sprays on Bt hybrids further reduced the incidence and severity of corn earworm damage to ears compared to Bt hybrids receiving no foliar insecticide applications and sprayed conventional hybrids. Insecticide rate was not evaluated in this study, but Lynch et al. (1999) were able to establish the usefulness of combining Bt hybrids and insecticide sprays for management of a target pest.

In some instances, Bt crops alone can provide sufficient efficacy and reduce the potential benefits of a supplemental insecticide spray. Cooper et al. (2006) evaluated Colorado potato beetle survivorship and damage on conventional and Bt potatoes with and without an insecticidal protein (avidin) in laboratory experiments. Insecticide treatment did not significantly affect insect survivorship and plant damage on Bt potatoes due to the low larval survival on non-treated Bt potatoes. Bommireddy and Leonard (2008) reported extremely low survivorship of bollworm and tobacco budworm on pyramided cotton lines expressing Vip3A and Cry1Ab proteins. Vip3A + Cry1Ab plants sprayed with an insecticide might not significantly reduce bollworm or tobacco budworm survivorship below that on non-sprayed Vip3A + Cry1Ab plants. The value of foliar sprays on Bt crops should be evaluated for each pest, crop, and Bt trait(s).

Limited information currently exists on the interactions between cotton lines expressing Bt proteins and foliar insecticides for control of lepidopteran pests. Jackson et al. (2003, 2005) evaluated insecticide sprays on Bollgard II cottons for bollworm control. Damaged bolls and larval survivors were reduced 9.5-fold and greater than 2,000-fold, respectively, in insecticide-sprayed Bollgard II plots compared to non-sprayed Bollgard II plots (Jackson et al., 2003). Insecticide-sprayed Bollgard II plots had fewer damaged fruiting forms (flower buds [squares] and bolls) and higher seedcotton yields compared to non-sprayed Bollgard II plots (Jackson et al., 2005).

The findings in the present study illustrate the need for further examination of insecticide recommendations against target and non-target pests of Bollgard II and other pyramided Bt cottons. Many current chemical control recommendations for fall armyworm on cotton do not differentiate between insecticide rates used on conventional and Bollgard II fields (Adams et al., 2013; Anonymous et al., 2013; Carson et al., 2013). The common practice of recommending maximum insecticide rates listed on the label for fall armyworm management in Bollgard II cultivars needs to be reconsidered. The results herein should be validated in a series of field trials to confirm satisfactory efficacy with lower rates. Future field and laboratory studies should evaluate insecticide performance (initial and residual efficacy) and dose-response on WideStrike and other pyramided Bt cotton traits. Finally, the fall armyworm provided an effective model insect for this study, but further research is needed to determine if similar results can be obtained when targeting other lepidopteran pest populations, such as bollworm, in Bt cotton cultivars.

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