Bt Sweet Corn and Selective Insecticides: Impacts on Pests and Predators

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J. Econ. Entomol. 96(1): 71–80 (2003)

ABSTRACT Sweet corn, *Zea mays* L., is attacked by a variety of insect pests that can cause severe losses to the producer. Current control practices are largely limited to the application of broad-spectrum insecticides that can have a substantial and deleterious impact on the natural enemy complex. Predators have been shown to provide partial control of sweet corn pests when not killed by broad-spectrum insecticides. New products that specifically target the pest species, while being relatively benign to other insects, could provide more integrated control. In field trials we found that transgenic Bt sweet corn, and the foliar insecticides indoxacarb and spinosad are all less toxic to the most abundant predators in sweet corn (*Coleomegilla maculata* [DeGeer], *Harmonia axyridis* [Pallas], and *Orius insidiosus* [Say]) than the pyrethroid lambda cyhalothrin. Indoxacarb, however, was moderately toxic to coccinellids and spinosad and indoxacarb were somewhat toxic to *O. insidiosus* nymphs at field rates. Bt sweet corn and spinosad were able to provide control of the lepidopteran pests better than or equal to lambda cyhalothrin. The choice of insecticide material made a significant impact on survival of the pests and predators, while the frequency of application mainly affected the pests and the rate applied had little effect on either pests or predators. These results demonstrate that some of the new products available in sweet corn allow a truly integrated biological and chemical pest control program in sweet corn, making future advances in conservation, augmentation and classical biological control more feasible.

KEY WORDS *Zea mays*, egg predators, pests, insecticide

SWEET CORN, *Zea mays* L., is attacked by a complex of insects, but the most important pests in North America are the lepidopteran species *Ostrinia nubilalis* (Hübner) (European corn borer), *Spodoptera frugiperda* (J. E. Smith) (fall armyworm), and *Helicoverpa zea* (Boddie) (corn earworm) (Flood et al. 1995). In northern regions of the United States, *O. nubilalis* is the main pest throughout the season while the other Lepidoptera are primarily late-season pests. Pest management programs have been developed for sweet corn pests in several states including New York, which ranked second and fifth nationally in sweet corn acreage for fresh market and processing, respectively (NYASS 2001). The New York program has relied primarily on the use of insecticide treatments based on sampling and threshold decision criteria (Shelton 1986, CCE 2002). Our more recent efforts have focused on integrating biological control into the program by including natural enemies in grower guidelines. Our emphasis has been on the most abundant predators in the system, the coccinellids *Coleomegilla maculata* (DeGeer) and *Harmonia axyridis* (Pallas), and the anthocorid *Orius insidiosus* (Say). Coccinellids and anthocorids have been shown to provide significant control of primary and secondary pests when not killed by insecticides (Andow and Risch 1985, Corey et al. 1988, Andow 1992, Coll and Bottrell 1992). Therefore, conservation of these predators is a logical first step in integrating biological control into sweet corn management.

The standard insect controls for the sweet corn pest complex over the last decade have been broad-spectrum pyrethroids, which have provided good control of the primary pests. In 2000 in New York, lambda cyhalothrin (Warrior, Syngenta Crop Protection, Inc., Greensboro, NC, formerly Zeneca Ag Products) was by far the most widely used insecticide with 68% of the processing fields treated with lambda cyhalothrin an average of 1.7 times (USDA NASS 2001). No other foliar insecticide was used. In fresh market sweet corn, lambda cyhalothrin was applied to 71% of the fields an average of 2.7 times followed by methomyl applied to 27% of the fields an average of 2.8 times (USDA NASS 2001).

Spinosad, indoxacarb, and transgenic Bt sweet corn are products that have entered the sweet corn market since 1998 for control of Lepidoptera. Spinosad (SpinTor 2 SC), produced by Dow AgroSciences (India-

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napolis, IN), was registered for sweet corn in 1999 for control of lepidopteran pests. Studies on various crops have shown that it does not disrupt coccinellids, anthocorids, nabids, or spiders (Duffie et al. 1997, Murray and Lloyd 1997, Duffie et al. 1998, Elzen and Elzen 1999, Studebaker and Kring 1999). It has also been shown to provide good control of Lepidoptera in sweet corn, although not always as good as lambda cyhalothrin (Linduska et al. 1999, Straub 1999). A DuPont (Wilmington, DE) product, indoxacarb (Avaunt), was registered for use in 2000 and is also targeted at lepidopteran pests. Like spinosad, laboratory testing has revealed that indoxacarb is toxic to Lepidoptera (Hammes et al. 1998) but relatively nontoxic to natural enemies such as anthocorids, nabids, chrysopids, and spiders (Hammes 2000). However, there have been some studies showing that indoxacarb is toxic to some natural enemies. Studebaker and Kring (1999) found that indoxacarb caused >60% mortality in *O. insidiosus,* compared with 100% and 19% mortality from lambda cyhalothrin and spinosad, respectively. Tillman et al. (1998) found that indoxacarb was toxic to the lygaeid *Geocoris punctipes* (Say) at high rates, but was less toxic to natural enemies than lambda cyhalothrin. Transgenic Bt sweet corn varieties were released on a limited basis in 1998 by Syngenta Crop Protection, Inc. (Greensboro, NC) (formerly Novartis Seeds, Inc.). These varieties express the CryIAb toxin from the bacteria *Bacillus thuringiensis* (Berliner) (Bt) (Lynch et al. 1999a). Although Bt has been registered as a foliar spray for sweet corn Lepidoptera for decades, it has provided inconsistent control that is generally inferior to the chemical insecticides available (Bartels and Hutchinson 1995, Bartels et al. 1995, Cagan et al. 1995, Shelton and Wilsey 1997, 1998, Straub 1999). However, transgenic Bt sweet corn has provided consistently excellent control of Lepidoptera (Lynch et al. 1999b, Sorenson and Holloway 1999, Burkness et al. 2001). While the control of sweet corn Lepidoptera by Bt differs depending on whether it is applied foliarly or expressed by the plant, Bt has low toxicity to natural enemies, regardless of the delivery system (Horn 1983, Pilcher et al. 1997, Boyd and Boethel 1998, Lozzia et al. 1998, Obrycki and Kring 1998).

While the above studies give an indication of the results expected from these new products, Pietrantonio and Benedict (1999) caution against generalizing insecticide impacts within families and even within genera. The impact of an insecticide on a predator may also vary depending on the life stage of the insect (Zeleny et al. 1988).

One of the considerations when using new products which specifically target certain insects (e.g., Lepidoptera) is that secondary pests like aphids or sap beetles, formerly controlled by a broad spectrum insecticide, may become significant pests. However, it has also been suggested that the conservation of predators will reduce the need for chemical control against these pests (Peterson et al. 1996). Another consideration is that these products may cause sublethal effects to natural enemies (Wright and Verkerk 1995, Elzen and Elzen 1999). This could result in reduced predation even though predator numbers are not reduced by these new insecticides. To assess the lethal and sublethal impacts of these products on the pest and predator complex present in sweet corn in New York, field tests were conducted in 2000–2001 with the goal of developing a pest management program for sweet corn that integrates biological and chemical control. This research was conducted in the field rather than a laboratory to enable the impact of the products on both pests and natural enemies to be predicted under conditions more likely to be encountered under commercial situations.

Materials and Methods

Methods Common to All Trials in 2000 and 2001

Cultivation Methods. Corn was grown in conventionally tilled plots using recommended herbicides and fertilizer (CCE 2002). Plots were seven rows wide and 6.1 m long planted on 76 cm centers with 20 cm plant spacing.

Foliar Insecticides. Foliar insecticides were applied at full rates (middle of the range of labeled rates) and half rates (one-half of the full rate). Treatments were: indoxacarb at 0.0616 and 0.0308 kg (AI)/ha., Bt spray (DiPel ES, *Bacillus thuringiensis* subsp. *kurstaki,* Valent Biosciences Corp., Libertyville, IL) at 39.5 and 19.8 billion IU/ha, spinosad at 0.0790 and 0.0395 kg (AI)/ha, and lambda cyhalothrin at 0.0262 and 0.0131 kg (AI)/ha. An untreated check was also included in all trials. The interior five rows of the plots were sprayed with a 5-row CO_2 pressurized high-clearance, tractor-mounted boom having three nozzles per row (one over the top and a drop nozzle on each side). The sprayer delivered 411 liters/ha at 450 kPa.

Insect Monitoring Methods. Predators were counted on 10 consecutive plants selected randomly from one of the middle three rows. These visual field counts were done without destroying the plant. At the same time as each field count, two randomly selected plants were cut from the same row at the soil surface, carefully placed in large plastic bags and frozen. These frozen plants were later examined in the laboratory and all insects found were identified and enumerated. Coccinellid data are from the field counts. *Orius insidiosus* and aphid data are from the laboratory counts.

Harvest Assessment Method. Pest damage to the crop was assessed at late milk stage by harvesting 25 ears selected randomly from the five treated rows, husking the ears and recording all insects and damage found on both the ears and husks.

2000 Field Season

Two field trials were conducted at the Vegetable Research Farm in Geneva, NY.

Single Spray. This trial compared the Bt variety 'GS 0966' to the nontransgenic isoline 'Prime Plus' (both from Syngenta Crop Protection, Inc.) in a factorial experiment with insecticide treatments (two varieties by eight insecticides plus a check = 18 treatments). This factorial design was chosen to measure the impact of the products on secondary pests that are not controlled by the Bt corn. The trial was planted 1 July using a randomized block design with three replications. The insecticides were applied once during silk stage (5 September). Monitoring occurred three and 13 d after spraying, and the harvest evaluation was done on 25 September.

Multiple Sprays. This trial compared the foliar insecticides applied four times at 5–7 d intervals beginning at early silk stage (18 August). The trial was planted 20 June and had three replications in a completely randomized design. Insects were monitored 3 d after each insecticide application and a harvest evaluation was conducted on 14 September. Bt corn was not part of this trial.

2001 Field Season

A single trial with two objectives was conducted at the Vegetable Research Farm in Geneva, NY. The first objective was to compare the Bt variety 'GS 0966' with foliar insecticides applied to the non-Bt isoline 'Prime Plus'. A second objective was to evaluate the impact of different rates and application frequencies of the foliar insecticides on the pests and predators. The foliar insecticide treatments were the same as in 2000 except that the Bt spray treatments were omitted. This trial was planted 18 May (early planting) and again on 27 June (late planting) in a randomized block design with four replications using planting date as the blocking factor. Foliar insecticides were applied twice (27 July, 2 August) in the multiple spray treatments in the early planting and three times (23, 30 August, 6 September) in the late planting. The single spray treatments were sprayed on 27 July and 30 August for the early and late plantings, respectively. Monitoring for predators was conducted on all plots 3–5 d after each application date. The harvest evaluations were done on 20 August and 18 September for the early and late plantings, respectively.

Egg Predation Rate. To assess the combined lethal and sublethal effects from the insecticides, *O. nubilalis* egg predation rates were directly monitored by placing laboratory-reared egg masses laid on wax paper in the field 2–4 d after each insecticide application in the late planting of 2001. The wax paper was pinned onto the underside of the ear leaf and then removed from the plant after 2 d. The number of missing (eaten) egg masses was recorded. An egg mass was considered eaten if at least half of the egg mass was gone. One egg mass was attached to 10 randomly selected plants in a single row of the plot. A different row was used after each insecticide application.

Data Analysis. All data were analyzed using PROC GLM (SAS Institute 1999) with significance determined at $\alpha = 0.05$. LSMEANS were used to determine treatment differences. Within PROC GLM, contrasts (ESTIMATE) were used to analyze rate and frequency effects over all insecticides and to analyze insecticide materials over all rates and frequencies. Harvest data and *O. nubilalis* egg predation rates are presented as a percentage and were transformed by the arcsine of the square root to equalize variance. To equalize variance for count data of aphids and *H. axyridis*, data were transformed by logarithm, while counts of *O. insidiosus* and *C. maculata* were transformed by square root. Count data in successive weeks were analyzed together using date as a factor in the analysis. When a significant treatment by date interaction occurred, individual dates were analyzed. To compare the relative tolerance of *C. maculata* and *H. axyridis* populations to the insecticides, differential toxicity was determined with the equation:

$$\frac{\text{Treatment 'x' } C.\ maculata}{\text{Untreated check } C.\ maculata} - \frac{\text{Treatment 'x' } H.\ axyridis}{\text{Untreated check } H.\ axyridis} = \text{Differential toxicity for treatment 'x'}$$

Adult and larval populations were compared separately. When the impact of the treatment was the same on both species, the differential toxicity equals zero. If the treatment was more toxic to *C. maculata*, then the differential toxicity will be less than zero. If the treatment was more toxic to *H. axyridis*, then he differential toxicity will be greater than zero. Results were analyzed using PROC GLM.

Results

Impact on Pests

Single Spray, 2000. Pest control was measured by the percentage of ears infested with *O. nubilalis*, total of *S. frugiperda* and *H. zea*, or undamaged (ears without any lepidopteran pests). By all three measures, there was a significant effect from the treatments (*O. nubilalis* $F = 17.38$; df = 19,34; $P < 0.0001$; total *S. frugiperda* and *H. zea* $F = 6.88$; df = 19,34; $P < 0.0001$; undamaged ears $F = 30.43$; df = 19,34; $P < 0.0001$). The variety factor was significant by all three measures (*O. nubilalis* $F = 277.06$; df = 1,38; $P < 0.0001$; total *S. frugiperda* and *H. zea* $F = 108.09$; df = 1,38; $P < 0.0001$; undamaged ears $F = 497.96$; df = 1,38; $P < 0.0001$). The insecticide factor was significant for *O. nubilalis* ($F = 2.85$; df = 3,45; $P = 0.0477$) and undamaged ears ($F = 7.24$; df = 3,45; $P = 0.0005$), but not for total *S. frugiperda* and *H. zea* ($F = 2.39$; df = 3,45; $P = 0.0815$). In no case was the variety by insecticide interaction significant (*O. nubilalis* $F = 0.45$; df = 4,38; $P = 0.7699$; total *S. frugiperda* and *H. zea* $F = 0.83$; df = 4,38; $P = 0.5161$; undamaged ears $F = 0.93$; df = 4,38; $P = 0.4545$). As there were no significant differences in pest damage between insecticide treatments within the Bt corn (least significant difference [LSD] test with $\alpha = 0.05$) (data not shown) and because there was very little nonlepidopteran pest pressure in any of the treatments, results from only the unsprayed Bt corn and all the non-Bt treatments are presented (Table 1). All the Bt variety plots had >95%

Table 1. Impact of transgenic Bt sweet corn and insecticides applied to nontransgenic sweet corn on Lepidoptera populations in sweet corn ears at harvest in 2000. Geneva, NY

Treatment	Rate	Single spray trial			Multiple sprays trial		
		% ears infested		% undamaged[a]	% ears infested		% undamaged[a]
		O. nubilalis	FAW + CEW[b]		*O. nubilalis*	FAW + CEW[b]	
Bt corn		0.4a	1.8a	97.4a	—	—	—
Bt spray	Full	38.3cde	49.2c	30.4cd	27.3bc	14.3d	57.4c
Bt spray	Half	45.0de	48.7c	21.2d	25.7bc	9.3cd	74.3bc
Cyhalothrin	Full	25.8bcd	15.6ab	61.7b	0.4a	0.0a	99.6a
Cyhalothrin	Half	42.4cde	24.5bc	43.9bc	3.4a	0.9ab	95.9a
Indoxacarb	Full	25.0bc	28.1bc	56.1b	7.7ab	0.0a	92.3ab
Indoxacarb	Half	43.9cde	34.3bc	30.8cd	3.6a	0.4ab	95.5a
Spinosad	Full	18.2b	19.4abc	57.6b	0.9a	0.0a	99.1a
Spinosad	Half	38.5cde	29.1bc	46.6bc	1.8a	0.4ab	97.4a
Untreated		48.0e	44.6bc	30.0cd	32.8c	3.6bc	70.2c

Means with the same letter in the same column are not significantly different (LSD test with $\alpha = 0.05$). Data transformed by arcsine of square root for statistical analysis. Back-transformed totals presented.
[a] Ears without lepidopteran pests.
[b] Fall armyworm (*S. frugiperda*) plus corn earworm (*H. zea*).

undamaged ears while both rates of the Bt spray plots had damage equal to the check. All other foliar insecticides sprayed at the full rate had fewer damaged ears than the unsprayed check, but none of the insecticides applied at the half rate differed from the unsprayed check. As a result, higher rates of insecticides were very significant for producing undamaged ears ($F = 8.48$; df = 1,38; $P = 0.0060$) and reducing populations of *O. nubilalis* ($F = 6.34$; df = 1,38; $P = 0.0162$). The insecticide by rate interaction was insignificant for undamaged ears ($F = 0.84$; df = 3,38; $P = 0.4793$) and *O. nubilalis* damage ($F = 0.07$; df = 3,38; $P = 0.9749$), showing that higher rates had a similar effect for all the insecticides.

Multiple Sprays, 2000. There was an overall insecticide effect on the number of *O. nubilalis* infested ears ($F = 4.09$; df = 8,18; $P = 0.0062$), total *S. frugiperda* and *H. zea* ($F = 5.95$; df = 8,18; $P = 0.0008$) and undamaged ears ($F = 6.48$; df = 8,18; $P = 0.0005$) (Table 1). Lambda cyhalothrin, spinosad and indoxacarb each provided equal control against Lepidoptera while the Bt spray failed to provide any control. The rate applied made no significant difference in pest control for any of the products.

2001. By the overall measure of undamaged ears, there were significant treatment effects ($F = 15.38$; df = 33,77; $P < 0.0001$) as well as a significant planting by treatment interaction ($F = 5.48$; df = 13,77; $P < 0.0001$). To better understand the interaction, the results were analyzed separately for each planting.

2001 Early Planting. Nearly all the lepidopteran pest pressure was from *O. nubilalis*, so the percent undamaged ears is also a measure of *O. nubilalis* control (Table 2). The insecticide treatment was significant ($F = 3.60$; df = 16,39; $P = 0.0006$) with all the treatments having significantly fewer damaged ears than the untreated check. While the overall factor of insecticide rate was not significant ($F = 0.01$; df = 1,42; $P = 0.9338$), the insecticide by rate interaction was significant ($F = 4.69$; df = 2,42; $P = 0.0145$) because

Table 2. Impact of transgenic Bt sweet corn and insecticides applied to nontransgenic sweet corn on Lepidoptera populations in sweet corn ears at harvest in the early planting, 2001. Geneva, NY

Treatment	Spray Frequency	Rate	% ears infested		% undamaged[a]
			O. nubilalis	FAW + CEW[b]	
Bt corn	—	—	0.0a	0.0a	100.0a
Cyhalothrin	single	Half	6.6cd	0.3a	92.6cd
Cyhalothrin	single	Full	1.5abc	0.3a	98.6abc
Cyhalothrin	multiple	Half	4.4bcd	0.0a	95.6bcd
Cyhalothrin	multiple	Full	0.3ab	0.0a	99.7ab
Indoxacarb	single	Half	2.3abcd	0.0a	97.7abcd
Indoxacarb	single	Full	9.9de	0.0a	90.1d
Indoxacarb	multiple	Half	2.7abcd	0.0a	97.3abcd
Indoxacarb	multiple	Full	4.0bcd	0.0a	96.0bcd
Spinosad	single	Half	1.0abc	0.0a	99.0abc
Spinosad	single	Full	1.5abc	0.0a	98.6abc
Spinosad	multiple	Half	1.0abc	0.0a	99.0abc
Spinosad	multiple	Full	2.9abcd	0.0a	97.1abcd
Untreated			20.9e	2.0b	76.5e

Means with the same letter in the same column are not significantly different (LSD test with $\alpha = 0.05$). Data transformed by arcsine of square root for statistical analysis. Back-transformed totals presented.
[a] Ears without lepidopteran pests.
[b] Fall armyworm (*S. frugiperda*) plus corn earworm (*H. zea*).

Table 3. Impact of transgenic Bt sweet corn and insecticides applied to nontransgenic sweet corn on aphid populations 3 and 14 d (at harvest) after application in the early planting, 2001. Geneva, NY

Treatment	Spray frequency	Rate	No./plant 3 d after application[a]	% ears infested (>50 aphids) at harvest[b]
Bt corn	—	—	686cde	14.2abcd
Cyhalothrin	single	Half	156ab	18.5bcde
Cyhalothrin	single	Full	282abc	31.5e
Cyhalothrin	multiple	Half	157ab	24.3de
Cyhalothrin	multiple	Full	92a	21.5bcde
Indoxacarb	single	Half	955de	22.6cde
Indoxacarb	single	Full	1369e	13.7abcd
Indoxacarb	multiple	Half	546cde	17.8bcde
Indoxacarb	multiple	Full	1012de	9.3abc
Spinosad	single	Half	428bcd	4.7a
Spinosad	single	Full	921de	21.7bcde
Spinosad	multiple	Half	680cde	8.7ab
Spinosad	multiple	Full	591cde	14.7abcd
Untreated			844cde	12.0abcd

Means with the same letter in the same column are not significantly different (LSD test with $\alpha = 0.05$).
[a] 6 August. Data transformed by logarithm for statistical analysis. Back-transformed totals presented.
[b] 17 August. Data transformed by arcsine of square root for statistical analysis. Back-transformed totals presented.

higher rates increased control only in the lambda cyhalothrin treatments when pooled over both spray frequencies (data not shown).

Corn leaf aphids, *Rhopalosiphum maidis* (Fitch), were abundant, providing an opportunity to evaluate the impact of these insecticides against a nonlepidopteran pest. The two aphid readings (Table 3), one presented as the number of aphids per plant and the other as the percentage of ears with >50 aphids, differed greatly even though there were only 11 d between the data collection dates. In the reading 3 d after insecticides were applied, treatment differences were significant ($F = 4.30$; df = 13,39; $P = 0.0002$) with the four lambda cyhalothrin treatments having the fewest aphids. In contrasts between the insecticides over all rates and frequencies, lambda cyhalothrin was the only treatment with significantly lower aphid populations than the untreated check ($t = 3.78$; df = 18; $P = 0.0005$). Eleven days later at harvest, the results were reversed with lambda cyhalothrin treatments being four of the six most infested treatments. In contrasts between the insecticides, lambda cyhalothrin was again the only product significantly different from the untreated check ($t = 2.05$; df = 18; $P = 0.0469$), but this time it had higher infestation rates than the untreated check.

2001 Late Planting. There were significant differences between insecticide treatments in producing undamaged ears ($F = 12.85$; df = 16,38; $P < 0.0001$), but not all treatments were better than the untreated check (Table 4). Indoxacarb treatments had fewer undamaged ears than comparable spinosad or lambda cyhalothrin treatments, although the differences were not always statistically significant. When all uses of insecticides were analyzed together, lambda cyhalothrin ($t = 6.33$; df = 29; $P < 0.0001$) and spinosad ($t = 5.31$; df = 29; $P < 0.0001$) treatments had fewer damaged ears than indoxacarb treatments, but there was

Table 4. Impact of transgenic Bt sweet corn and insecticides applied to nontransgenic sweet corn on Lepidoptera populations in sweet corn ears at harvest in the late planting, 2001. Geneva, NY

Treatment	Spray frequency	Rate	% ears infested		% undamaged[a]
			O. nubilalis	FAW + CEW[b]	
Bt corn	—	—	0.0a	0.0a	100.0a
Cyhalothrin	single	Half	21.5cd	9.4cde	69.7de
Cyhalothrin	single	Full	34.8def	4.3bcd	62.1ef
Cyhalothrin	multiple	Half	3.7b	0.3ab	95.6b
Cyhalothrin	multiple	Full	14.9c	2.3abc	83.0cd
Indoxacarb	single	Half	53.3f	19.7e	34.3g
Indoxacarb	single	Full	45.0f	4.0bcd	48.9fg
Indoxacarb	multiple	Half	39.9ef	13.3de	50.0fg
Indoxacarb	multiple	Full	25.8cde	8.0cde	66.2def
Spinosad	single	Half	23.8cde	2.9abc	72.7cde
Spinosad	single	Full	35.2def	1.9abc	61.8ef
Spinosad	multiple	Half	14.0c	5.2bcd	78.8cde
Spinosad	multiple	Full	13.7bc	0.3ab	86.3bc
Untreated			52.1f	9.0cde	49.0fg

Means with the same letter in the same column are not significantly different (LSD test with $\alpha = 0.05$). Data transformed by arcsine square root for statistical analysis. Back-transformed totals presented.
[a] Ears without lepidopteran pests.
[b] Fall armyworm (*S. frugiperda*) plus corn earworm (*H. zea*).

Table 5. Impact of transgenic Bt sweet corn and insecticides applied to nontransgenic sweet corn on predator populations in 2000. Geneva, NY

Treatment	Rate	Single Spray Trial[a]				Multiple Sprays Trial[b]			
		Coccinellids[c]/100 plants		*O. insidiosus*[d]/100 plants		Coccinellids[c]/100 plants		*O. insidiosus*[d]/100 plants	
		adults	larvae	adults	nymphs	adults	larvae	adults	nymphs
Insecticide Factors									
Bt spray	Half	0.6bc	6.0abc	376a	244a	2.6ab	6.4bc	196a	114a
Bt spray	Full	4.1ab	3.8bcd	477a	140abc	2.6ab	4.6c	145ab	117a
Cyhalothrin	Half	0.0c	0.0d	161b	82c	1.2b	0.6d	15c	10b
Cyhalothrin	Full	0.0c	0.0d	64c	11d	0.6b	0.0d	9c	4b
Indoxacarb	Half	3.3abc	2.3cd	408a	175ab	0.0b	0.6d	165ab	107a
Indoxacarb	Full	2.6abc	3.3cd	410a	118bc	0.0b	0.0d	125ab	86a
Spinosad	Half	2.6abc	3.8bcd	377a	116bc	4.6a	10.7ab	104b	105a
Spinosad	Full	5.1a	9.9a	335a	127bc	1.9ab	15.9a	175ab	21b
Untreated		5.9a	8.7ab	404a	185ab	1.9ab	15.9a	110ab	149a
Variety Factors									
Bt corn	all	2.4ns	4.2ns	389a	119ns	—	—	—	—
Non-Bt	all	2.7ns	3.5ns	252b	125ns	—	—	—	—

Means with the same letter in the same column are not significantly different (LSD test with $\alpha = 0.05$). The insecticide factors were analyzed separately from the variety factors. There were no significant variety by insecticide interactions.
[a] Mean populations from data collected 3 and 13 d after insecticide application.
[b] Mean populations from data collected 3 d after each of 4 insecticide applications.
[c] Total of *C. maculata* and *H. axyridis*. Data were transformed by logarithm for statistical analysis. Back-transformed totals presented.
[d] Data were transformed by square root for statistical analysis. Back-transformed totals presented.

no difference between lambda cyhalothrin and spinosad ($t = 1.05$; df = 30; $P = 0.3010$). The percentage of undamaged ears was raised by increasing the frequency of application ($F = 28.81$; df = 1,41; $P < 0.0001$) and the spray by frequency interaction was not significant ($F = 1.22$; df = 2,41; $P = 0.3063$). Higher rates, however, did not increase the percentage of undamaged ears for all insecticides ($F = 0.01$; df = 1,41; $P = 0.9290$), but there was a significant spray by rate interaction ($F = 4.78$; df = 2,41; $P = 0.0136$) as higher rates tended to reduce damage in the indoxacarb treatments but increase damage in the lambda cyhalothrin treatments. Higher rates provided more consistent benefits when analyzing the *S. frugiperda* plus *H. zea* control. For these pests, the full rate provided significantly better control than the half rate ($F = 6.17$; df = 1,41; $P = 0.0172$) and the spray by rate interaction was not significant ($F = 1.78$; df = 2,41; $P = 0.1806$).

Impact on Predators

Single Spray, 2000. Coccinellid populations were low, so *C. maculata* and *H. axyridis* populations are combined for the analysis in this trial. The treatments had a significant effect on all the major predators (coccinellid adults $F = 1.85$; df = 20,87; $P = 0.0268$; coccinellid larvae $F = 3.54$; df = 20,87; $P < 0.0001$; *O. insidiosus* adults $F = 10.33$; df = 12,95; $P < 0.0001$; *O. insidiosus* nymphs $F = 4.58$; df = 12,95; $P < 0.0001$) (Table 5). Use of lambda cyhalothrin at both half and full rates resulted in lower populations of all predators than the unsprayed check, while the other treatments reduced one or no predator populations. Indoxacarb at both rates had fewer coccinellid larvae than the untreated check, but had no effect on coccinellid adult or *O. insidiosus* populations. Using half rates in general resulted in more *O. insidiosus* nymphs than using full rates ($t = 2.74$; df = 94; $P = 0.0074$), but rate differences had no significant effect on the other predator populations (coccinellid adults $t = 1.41$; df = 94; $P = 0.1631$; coccinellid larvae $t = 0.91$; df = 94; $P = 0.3652$; *O. insidiosus* adults $t = 0.93$; df = 94; $P = 0.3550$). *Orius insidiosus* adult populations were significantly higher in the transgenic Bt corn than in the non-Bt corn ($F = 20.47$; df = 1,95; $P < 0.0001$), indicating no toxicity from the transgenic Bt toxin, and, perhaps, a preference by *O. insidiosus* for ears and silks free from lepidopteran feeding. There were no significant variety by insecticide interactions (coccinellid adults $F = 0.98$; df = 8,87; $P = 0.4543$; coccinellid larvae $F = 0.94$; df = 8,87; $P = 0.4918$; *O. insidiosus* adults $F = 0.76$; df = 8,87; $P = 0.6385$; *O. insidiosus* nymphs $F = 1.09$; df = 8,87; $P = 0.3797$).

Multiple Sprays, 2000. As in the single spray trial, *C. maculata* and *H. axyridis* populations were combined for analysis. Treatment effects were significant for each of the four populations (coccinellid adults $F = 2.10$; df = 11,96; $P = 0.0270$; coccinellid larvae $F = 4.20$; df = 35,72; $P < 0.0001$; *O. insidiosus* adults $F = 5.50$; df = 35,72; $P < 0.0001$; *O. insidiosus* nymphs $F = 3.33$; df = 35,72; $P < 0.0001$) (Table 5). *Orius insidiosus* adult populations were lowest on the last two sampling dates ($F = 30.68$; df = 3,72; $P < 0.0001$) while coccinellid larval populations were lowest on the last sampling date ($F = 7.28$; df = 3,72; $P = 0.0002$). Sampling date was not significant for the *O. insidiosus* nymph ($F = 0.28$; df = 3,72; $P = 0.8382$) and coccinellid adult ($F = 1.29$; df = 3,72; $P = 0.2840$) populations. Because no population had a significant treatment by date interaction (coccinellid adults $F = 0.52$; df = 24,72; $P = 0.9615$; coccinellid larvae $F = 1.11$; df = 24,72; $P = 0.3556$; *O. insidiosus* adults $F = 1.12$; df = 24,72; $P = 0.3485$; *O. insidiosus* nymphs $F = 1.39$; df =

Table 6. Impact of transgenic Bt sweet corn and insecticides applied to nontransgenic sweet corn on predator populations in early and late planted sweet corn in 2001. Geneva, NY

Treatment	Spray frequency	Rate	*O. insidiosus*[a]/100 plants			*C. maculata*[a]/100 plants		*H. axyridis*[b]/100 plants	
			adults						
			early[c]	late[d]	nymphs late	adults late	larvae both[e]	adults early	larvae early
Bt corn			21abcde	388a	216a	14.8a	16.8ab	8.2a	51.8a
Cyhalothrin	single	half	6de	0f	1ef	0.0c	0.1f	0.9bc	0.9e
Cyhalothrin	single	full	7cde	30e	3ef	0.0c	0.0f	4.1abc	0.0e
Cyhalothrin	multiple	half	0e	2ef	0f	0.0c	0.0f	0.0c	0.0e
Cyhalothrin	multiple	full	1e	7ef	3ef	0.0c	0.0f	0.0c	0.0e
Indoxacarb	single	half	61abc	293ab	96b	0.3bc	3.8c	1.5bc	8.0cde
Indoxacarb	single	full	83a	193bcd	107ab	0.3bc	2.6cd	8.9a	19.0bc
Indoxacarb	multiple	half	27abcde	208bcd	13ef	0.1c	1.8cde	3.0abc	2.5de
Indoxacarb	multiple	full	17abcde	296ab	26cde	1.1bc	0.2def	6.2ab	11.0bcd
Spinosad	single	half	70ab	194bcd	76bcd	3.9b	14.8ab	9.1a	21.6bc
Spinosad	single	full	77ab	264abc	145ab	1.8bc	12.7ab	4.1abc	24.8ab
Spinosad	multiple	half	13bcde	289ab	81bc	1.8bc	11.0b	4.1abc	24.4abc
Spinosad	multiple	full	21abcde	137d	18def	1.4bc	11.0b	5.7ab	29.5ab
Untreated			52abcd	147cd	178ab	3.6b	22.3a	9.3a	50.8a

Only populations that had significant differences between treatments are shown. Means with the same letter in the same column are not significantly different (LSD test with $\alpha = 0.05$).

[a] Data were transformed by square root for statistical analysis. Back-transformed totals presented.

[b] Data were transformed by logarithm for statistical analysis. Back-transformed totals presented.

[c] Early-planted corn was planted 18 May. Data from monitoring on 30 July and 6 Aug.

[d] Late-planted corn was planted on 27 June. Data from monitoring on 28 Aug., 4 Sept. and 11 Sept.

[e] Combined data from both early and late-planted corn.

24,72; $P = 0.1423$) and to gain power in detecting treatment differences, the data are presented as the mean population density over the four sampling dates. No treatment resulted in coccinellid adult populations that were significantly different from the unsprayed check, although no coccinellid adults were found in either of the indoxacarb treatments. Both rates of lambda cyhalothrin significantly reduced all the other predator populations, while both rates of indoxacarb and Bt spray reduced the coccinellid larval population but not the *O. insidiosus* populations. The rate applied was a significant factor for the *O. insidiosus* nymph population only ($t = 2.23$; df = 94; $P = 0.0281$), with the higher rate resulting in fewer nymphs. In no case was there a significant insecticide by rate interaction (coccinellid adults $F = 0.73$; df = 3,96; $P = 0.5338$; coccinellid larvae $F = 0.88$; df = 3,96; $P = 0.4548$; *O. insidiosus* adults $F = 1.51$; df = 3,96; $P = 0.2169$; *O. insidiosus* nymphs $F = 2.14$; df = 3,96; $P = 0.0997$).

2001. The insecticide treatments had a significant effect on all six of the predator populations (*C. maculata* adults $F = 2.01$; df = 45,176; $P = 0.0007$; *C. maculata* larvae $F = 5.71$; df = 45,176; $P < 0.0001$; *H. axyridis* adults $F = 3.01$; df = 45,176; $P < 0.0001$; *H. axyridis* larvae $F = 8.44$; df = 45,176; $P < 0.0001$; *O. insidiosus* adults $F = 8.15$; df = 45,175; $P < 0.0001$; *O. insidiosus* nymphs $F = 3.37$; df = 45,175; $P < 0.0001$). However, not all populations showed significant effects in both plantings. Table 6 shows the population data when there were significant treatment differences. Data from both plantings are combined for *C. maculata* larvae as the treatment by planting date interaction was not significant for this population ($F = 0.96$; df = 13,176; $P = 0.4888$). Bt corn had as many or more of each predator population as the untreated check, indicating that there was no negative lethal effect on the major predators from the Bt corn. Of the seven predator populations reported in Table 6, the various spinosad treatments resulted in significant decreases when compared with the untreated check in zero to two populations, indoxacarb treatments decreased two to four populations, and lambda cyhalothrin treatments decreased five to seven populations. Multiple applications resulted in lower *O. insidiosus* adult populations in the early planting ($F = 10.52$; df = 1,96; $P = 0.0016$) and lower *O. insidiosus* nymph populations in the late planting ($F = 12.39$; df = 1,93; $P = 0.0008$), but had no impact on any of the coccinellid populations. There was no impact on any predators from applying a half rate rather than the full rate of the insecticide.

When all the coccinellid populations and *O. insidiosus* populations are combined, the overall impact of each product on coccinellids becomes clearer (Table 7). As neither rate nor frequency were significant factors, all frequencies and rates were combined for each insecticide. There were significant interactions between the early and late planting and between the two readings on each planting, but the overall trend is very consistent. Bt corn always had as many or more coccinellids than the untreated check. Spinosad treated corn mostly had populations that were statistically equal to the untreated check. Coccinellid populations in indoxacarb treatments were always lower than the untreated check, but *O. insidiosus* populations were equal to the check. Lambda cyhalothrin always had lower coccinellid and *O. insidiosus* populations than the check and these were generally lower than all other treatments as well.

Table 7. Impact of transgenic Bt sweet corn and insecticides (pooled rates and frequencies) applied to nontransgenic sweet corn on predator populations during silk and blister stages of early and late planted corn in 2001. Geneva, NY

Treatment	Total Coccinellids[a]/100 plants				*O. insidiosus*[b]/100 plants	
	Silk-Early[c]	Blister-Early	Silk-Late	Blister-Late	Early[d]	Late
Bt corn	48.3a	292.3a	49.0a	22.5ab	34.5ab	658.6a
Cyhalothrin	0.4c	6.7d	0.9c	0.0d	10.4b	10.1c
Indoxacarb	14.1b	45.7c	3.6c	4.9c	97.6a	328.1b
Spinosad	31.5a	122.1b	34.0ab	11.2b	81.8a	314.8b
Untreated	57.5a	209.3ab	19.9b	26.0a	131.2a	375.6b

Means with the same letter in the same column are not significantly different (LSD test with $\alpha = 0.05$).
[a] Total of *C. maculata, H. axyridis* adults and larvae and other coccinellids. Data were transformed by logarithm for statistical analysis. Back-transformed data presented.
[b] Total of *O. insidiosus* adult and nymph populations from readings during silk and blister stage corn. Data were transformed by square root for statistical analysis. Back-transformed data presented.
[c] Corn maturity and time of planting.
[d] *O. insidiosus* populations not separated by maturity as this factor was not significant for either planting date (Early planting $F = 1.84$; df = 1,96; $P = 0.1780$; Late planting $F = 1.38$; df = 1,93; $P = 0.2427$).

Differential Toxicity to Coccinellids. This test was used to document whether there was any difference in the toxicity of any of the products to *C. maculata* compared with *H. axyridis.* Both coccinellid populations were numerous enough to conduct this analysis only in the early planting of 2001. As larvae of both species are more susceptible to insecticides than the adults, *C. maculata* adults were compared with *H. axyridis* adults and *C. maculata* larvae were compared with *H. axyridis* larvae. There was no evidence of differential toxicity to the two coccinellids. The overall contrast of adults was insignificant ($F = 0.78$; df = 33,78; $P = 0.7867$) and no treatment factors or interactions were significant. While the overall contrast for larvae was significant ($F = 1.79$; df = 33,78; $P = 0.0185$), the source of the significance was the sampling date ($F = 10.97$; df = 1,78; $P = 0.0014$) and a treatment by date interaction ($F = 2.01$; df = 13,78; $P = 0.0305$). When each date was analyzed separately, the treatment factor was not significant (First date $F = 1.30$; df = 13,39; $P = 0.2570$; Second date $F = 1.34$; df = 13,39; $P = 0.2302$).

Impact on *O. nubilalis* Egg Predation

As expected based on the predator population data, the largest decreases in *O. nubilalis* egg predation rates were in the indoxacarb and lambda cyhalothrin treatments (Fig. 1). The differences in predation rates among insecticidal materials were significant for each date (27 August $F = 7.45$; df = 4,24; $P = 0.0005$; 4 September $F = 3.64$; df = 4,45; $P = 0.0118$; 11 September $F = 5.93$; df = 4,45; $P = 0.0006$), but the rate applied (27 August $F = 0.00$; df = 1,24; $P = 0.9978$; 4 September $F = 1.78$; df = 1,45; $P = 0.1886$; 13 September $F = 0.15$; df = 1,45; $P = 0.7016$) and the frequency of application (4 September $F = 0.00$; df = 1,45; $P = 0.9529$; 13 September $F = 0.30$; df = 1,45; $P = 0.5878$) were not significant factors on any date. The only treatments to result in significantly lower predation rates than the untreated check on any date were indoxacarb and lambda cyhalothrin.

Discussion

The impact of an insect control practice is a function of the material used, the rate applied, and the frequency with which it is applied. The field studies reported here revealed major differences among materials in their impact on both pests and predators. However, the impact from differences in rates and application frequencies were smaller and less consistent. *Orius insidiosus* nymphs were the only predators to show a rate response with higher survival at lower rates in both of the 2000 trials. Higher rates gave better protection than half rates against *O. nubilalis* in the 2000 single spray trial and against *S. frugiperda* plus

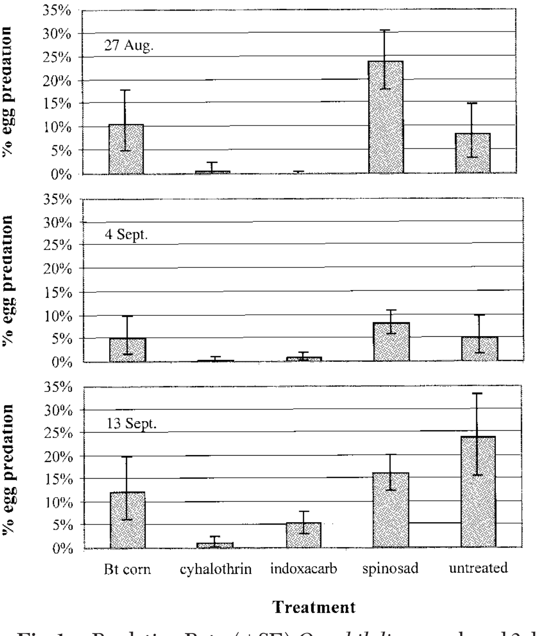

Fig. 1. Predation Rate (±SE) *O. nubilalis* eggs placed 2 d in transgenic Bt sweet corn or nontransgenic sweet corn sprayed with insecticides. Data are from three dates from first silk (27 August) to blister stage (13 September) in 2001. Geneva, NY.

H. zea in 2001. More frequent applications provided better control of all the lepidopteran pests, while the impact on the predators was minor, with only the *O. insidiosus* adult and nymph populations being reduced from more frequent applications.

The five products tested provide a wide range of control options. The current standard, lambda cyhalothrin, provided good lepidopteran pest control but was also highly toxic to all predators. Lambda cyhalothrin was also the only product that provided short-term aphid control. As aphids can serve as an aggregating factor for coccinellids (Wright and Laing 1980), the lower aphid populations in the lambda cyhalothrin treatments could be part of the reason for lower coccinellid populations observed in these treatments. However, this seems unlikely to be a major factor because these treatments still had ≈100–200 aphids per plant in the early planting of 2001 (Table 3). Laboratory studies without the confounding aphid factor have also shown lambda cyhalothrin to be highly toxic to predators (Tillman et al. 1998, Tillman and Mulrooney 2000). When biological control by predators is eliminated, secondary pest outbreaks, as observed in 2001 with aphids, could be a problem. From an integrated pest management (IPM) perspective, spinosad, indoxacarb and Bt sweet corn are all better choices than lambda cyhalothrin as each provides chemical control against lepidopteran pests, while allowing some predator populations to continue providing biological control. Indoxacarb provided some pest control but generally was inferior to Bt corn, lambda cyhalothrin and spinosad. It had low toxicity to *O. insidiosus* and was sometimes less toxic to coccinellids than lambda cyhalothrin, but was much more toxic to the coccinellids than spinosad or Bt corn. Spinosad provided pest control equal to lambda cyhalothrin and showed low toxicity to all the predators. The only vulnerable populations to spinosad were *O. insidiosus* nymphs and larvae of *C. maculata* and *H. axyridis.* Spinosad was the most selective of the foliar insecticides tested and, therefore, would be the best choice among the foliar sprays. However, from an IPM perspective, transgenic Bt sweet corn may be the most desirable choice when pest control is needed. This product gave outstanding control of the lepidopteran pests and showed no lethal or sublethal effects on the predators. In contrast, the Bt spray did not provide any pest control, confirming research that showed superior pest control from transgenic Bt corn compared with foliar-applied Bt sprays (Clark et al. 2000). The only pest management concern with Bt corn that is unique to its delivery method is that the pest control toxin is continuously present in the plant at a high level, a situation that warrants resistance management techniques and a thorough comparison of ecological impacts to other management options (Shelton et al. 2002).

One component needed for IPM practices to be used routinely by growers is the availability of products that can be used in ways that are familiar to growers without sacrificing pest control. This research has demonstrated that some of the new products available in sweet corn effectively achieve this goal, opening the door to truly integrated biological and chemical pest control in sweet corn, and making future advances in conservation, augmentation and classical biological control more feasible.

Acknowledgments

We thank R. Scott Boyd, Jr., Paul Smereka, Madhurima Musser, William T. Wilsey, and Sarah Millis for their assistance with data collection. We also thank Brian Nault for supplying the European corn borer eggs. Partial funding for this project was provided by the Paul Chapman Fellowship from the Department of Entomology at NYSAES, the New York State Integrated Management Program and the New York State Vegetable Research Council/Association.

References Cited

Andow, D. A. 1992. Fate of eggs of first-generation *Ostrinia nubilalis* (Lepidoptera: Pyralidae) in three conservation tillage systems. Environ. Entomol. 21: 388–393.

Andow, D. A., and S. J. Risch. 1985. Predation in diversified agroecosystems: relations between a coccinellid predator *Coleomegilla maculata* and its food. J. Appl. Ecol. 22: 357–372.

Bartels, D. W., and W. D. Hutchinson. 1995. On-farm efficacy of aerially applied *Bacillus thuringiensis* for European corn borer (Lepidoptera: Pyralidae) in corn earworm (Lepidoptera: Noctuidae) control in sweet corn. J. Econ. Entomol. 88: 380–386.

Bartels, D. W., W. D. Hutchison, V. A. Fritz, and G. R. Klacan. 1995. Effect of *Bacillus thuringiensis* application interval on European corn borer (Lepidoptera: Pyralidae) control in sweet corn. J. Entomol. Sci. 30: 374–389.

Boyd, M. L., and D. J. Boethel. 1998. Susceptibility of predaceous hemipteran species to selected insecticides on soybean in Louisiana. J. Econ. Entomol. 91: 401–409.

Burkness, E. C., W. D. Hutchison, P. C. Bolin, D. W. Bartels, D. F. Warnock, and D. W. Davis. 2001. Field efficacy of sweet corn hybrids expressing a *Bacillus thuringiensis* toxin for management of *Ostrinia nubilalis* (Lepidoptera: Crambidae) and *Helicoverpa zea* (Lepidoptera: Noctuidae). J. Econ. Entomol. 94: 197–203.

Cagan, L., J. Tancik, P. Bokor, and V. Uhlik. 1995. Control of the European corn borer on maize. Acta Fytotechnica. 50: 53–55.

(CCE) Cornell Cooperative Extension. 2002. Integrated crop and pest management guidelines for commercial vegetable production. http://www.nysaes.cornell.edu/recommends/.

Clark, T. L., J. E. Foster, S. T. Kamble, and E. Heinrichs. 2000. Comparison of Bt (*Bacillus thuringiensis* Berliner) maize and conventional measures for control of the European corn borer (Lepidoptera: Crambidae). J. Entomol. Sci. 35: 118–128.

Coll, M., and D. G. Bottrell. 1992. Mortality of European corn borer larvae by natural enemies in different corn microhabitats. Biol. Control. 2: 95–103.

Corey, D., S. Kambhampati, and G. Wilde. 1988. Electrophoretic analysis of *Orius insidiosus* (Hemiptera: Anthocoridae) feeding habits in field corn. J. Kans. Entomol. Soc. 71: 11–17.

Duffie, W., M. J. Sullivan, and S. G. Turnipseed. 1997. Survival of beneficial arthropods following the application of various insecticides. 2: 1120–1121. *In* Proceedings, Beltwide Cotton Conferences, 6–10 January, 1997, New Orleans, LA, USA. National Cotton Council of America, Memphis, TN.

Duffie, W. D., M. J. Sullivan, and S. G. Turnipseed. 1998. Predator mortality in cotton from different insecticide classes. 2: 1111–1112. *In* Proceedings, Beltwide Cotton Conferences, 5–9 January, 1998, San Diego, CA, USA. National Cotton Council of America, Memphis, TN.

Elzen, G. W., and P. J. Elzen. 1999. Lethal and sublethal effects of selected insecticides on *Geocoris punctipes.* Southwest. Entomol 24: 199–205.

Flood, B., R. Foster, and B. Hutchison. 1995. Sweet corn, 19–40. *In* R. Foster and B. Flood [eds.], Vegetable Insect Management with emphasis on the Midwest, Meister Publishing Company, Willoughby, OH.

Hammes, G. G. 2000. A five year summary of beneficial arthropod studies with "Steward" (DPX MP 062). 2: 940. *In* Proceedings, Beltwide Cotton Conferences, 4–8 January, 2000, San Antonio, TX, USA. National Cotton Council of America, Memphis, TN.

Hammes, G. G., D. Sherrod, and D. Marsden. 1998. "Steward" (DPX MP-062), a novel new insecticide for cotton insect control. 2: 1275–1276. *In* Proceedings, Beltwide Cotton Conferences, 5–9 January, 1998, San Diego, CA, USA. National Cotton Council of America, Memphis, TN.

Horn, D. J. 1983. Selective mortality of parasitoids and predators of *Myzus persicae* on collards treated with malathion, carbaryl, or *Bacillus thuringiensis.* Entomol. Exp. Appl. 34: 208–211.

Linduska, J. J., M. Ross, D. Baumann, and M. Lemuiex. 1999. Foliar sprays to control ear invading insects in sweet corn, 1998. Arthropod Mgt. Tests. 24: 127.

Lozzia, G. C., C. Furlanis, B. Manachini, and I. E. Rigamonti. 1998. Effects of Bt corn on *Rhopalosiphum padi* L. (Rhynchota Aphididae) and on its predator *Chrysoperla carnea* Stephen (Neuroptera Chrysopidae). Boll. Zool. Agrar. Bachic. 30: 153–164.

Lynch, R. E., B. R. Wiseman, D. Plaisted, and D. Warnick. 1999a. Evaluation of transgenic sweet corn hybrids expressing CryIA(b) toxin for resistance to corn earworm and fall armyworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 92: 246–252.

Lynch, R. E., B. R. Wiseman, H. Sumner, D. Plaisted, and D. Warnick. 1999b. Management of corn earworm and fall armyworm (Lepidoptera: Noctuidae) injury on a sweet corn hybrid expressing a cryIA(b) gene. J. Econ. Entomol. 92: 1217–1222.

Murray, D.A.H., and R. J. Lloyd. 1997. The effect of spinosad (Tracer) on arthropod pest and beneficial populations in Australian cotton. 2: 1087–1091. *In* Proceedings, Beltwide Cotton Conferences, 6–10 January, 1997, New Orleans, LA, USA. National Cotton Council of America, Memphis, TN.

(NYASS) New York Agricultural Statistics Service. 2001. New York agricultural statistics 2000–2001. Albany, NY.

Obrycki, J. J., and T. J. Kring. 1998. Predacious coccinellidae in biological control. Annu. Rev. Entomol. 43: 295–321.

Peterson, L. G., D. J. Porteous, R. M. Huckaba, B. A. Nead, R. L. Gantz, J. M. Richardson, and G. D. Thompson. 1996. Beneficial insects, their role in cotton pest management systems founded on naturalyte insect control. 2: 872–873. *In* Proceedings, Beltwide Cotton Conferences, 9–12 January, 1996, Nashville, TN, USA. National Cotton Council of America, Memphis, TN.

Pietrantonio, P. V., and J. H. Benedict. 1999. Effect of new cotton insecticide chemistries, tebufenozide, spinosad and chlorfenapyr, on *Orius insidiosus* and two *Cotesia* species. Southwest. Entomol. 24: 21–29.

Pilcher, C. D., J. J. Obrycki, M. E. Rice, and L. C. Lewis. 1997. Preimaginal development, survival, and field abundance of insect predators on transgenic *Bacillus thuringiensis* corn. Environ. Entomol. 26: 446–454.

SAS Institute. 1999. SAS/STAT user's guide, Version 8. SAS Institute, Cary, NC.

Shelton, A. M. 1986. Management of Lepidoptera on processing sweet corn in western New York. J. Econ. Entomol. 79: 1658–1661.

Shelton, A. M., and W. T. Wilsey. 1997. Control of lepidopterous insects on corn with foliar applications, 1996. Arthropod Mgt. Tests. 22: 124.

Shelton, A. M., and W. T. Wilsey. 1998. Control of corn Lepidoptera with foliar applications, 1997. Arthropod Mgt. Tests. 23: 100–101.

Shelton, A. M., J. Z. Zhao, and R. T. Roush. 2002. Economic, ecological, food safety and social consequences of the deployment of Bt transgenic plants. Annu. Rev. Entomol. 47: 845–881.

Sorenson, K. A., and C. W. Holloway. 1999. Corn earworm and European corn borer control with Bt treated corn, Brunswick and Sampson Co., NC, 1998. Arthropod Mgt. Tests. 24: 429–430.

Straub, R. W. 1999. Insect control on late-season sweet corn with foliar sprays of conventional and reduced-risk insecticides, 1998. Arthropod Mgt. Tests. 24: 133.

Studebaker, G. E., and T. J. Kring. 1999. Lethal and sublethal effects of selected insecticides on *Orius insidiosus.* 2: 1203–1204. *In* Proceedings, Beltwide Cotton Conferences, 3–7 January, 1999, Orlando, FL, USA. National Cotton Council of America, Memphis, TN.

Tillman, P. G., and J. E. Mulrooney. 2000. Effect of selected insecticides on the natural enemies *Coleomegilla maculata* and *Hippodamia convergens (Coleoptera: Coccinellidae), Geocoris punctipes* (Hemiptera: Lygaeidae), and *Bracon mellitor, Cardiochiles nigriceps,* and *Cotesia marginiventris* (Hymenoptera: Braconidae) in cotton. J. Econ. Entomol. 93: 1638–1643.

Tillman, P. G., J. E. Mulrooney, and W. Mitchell. 1998. Susceptibility of selected beneficial insects to DPX-MP062. 2: 1112–1114. *In* Proceedings, Beltwide Cotton Conferences, 5–9 January, 1998, San Diego, CA, USA. National Cotton Council of America, Memphis, TN.

[USDA—NASS] U.S. Department of Agriculture National Agricultural Statistics Service. 2001. Agricultural chemical usage: 2000 vegetable summary.

Wright, D. J., and R.H.J. Verkerk. 1995. Integration of chemical and biological control for arthropods: evaluation in a multitrophic context. Pestic. Sci. 44: 207–218.

Wright, E. J., and J. E. Laing. 1980. Numerical response of coccinellids to aphids in corn in southern Ontario. Can. Entomol. 112: 977–988.

Zeleny, J., J. Vostrel, Z. Ruzicka, and P. K. Kalushkov. 1988. Impact of various pesticides on aphidophagous coccinellids, pp. 327–332. *In* E. Niemczyk and A.F.G. Dixon [eds.], Proceedings, Ecology and Effectiveness of Aphidophaga, 31 August-5 September, 1987, Teresin, Poland. SPB Academic Publishing, The Hague, Netherlands.

Received for publication 25 March 2002; accepted 17 September 2002.