Integration of Insecticides and Biological Control Tactics for Sweet Corn

F. R. Musser and A. M. Shelton

Abstract

Sweet corn 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. When not killed by broad-spectrum insecticides, natural enemies have been shown to provide partial control of sweet corn pests. The major natural enemies in New York sweet corn are two species of lady beetles and *Orius insidiosus*. New products that specifically target pests, while being relatively benign to other insects, could enable growers to have the benefits of natural enemies and still use insecticides as needed. In field trials we found that Avaunt and SpinTor are both less toxic to some natural enemies than the pyrethroid Warrior. Avaunt, however, was highly toxic to lady beetles, and SpinTor was slightly toxic to *O. insidiosus* at labeled field rates. Both of these new products were able to provide control of the primary pests equal to Warrior. Transgenic Bt sweet corn varieties provided excellent control of pests and showed no toxicity to the natural enemies monitored, while Dipel, a Bt foliar spray formulation, provided no significant pest control and was slightly toxic to lady beetles. The choice of insecticide material had a major impact on survival of both the pests and natural enemies in sweet corn, but the rate and frequency of application had only minor impacts. Thirteen commercial varieties were screened for resistance to pests and attractiveness to natural enemies. Significant differences occurred between varieties for populations of European corn borer, lady beetles, *O. insidiosus*, and aphids, indicating that there is potential to select varieties for host resistance and increased pest control by natural enemies.

Introduction

Sweet corn is attacked by a complex of insects, but the most persistent pests in North America are the lepidopteran species *Ostrinia nubilalis*, (European corn borer, (ECB)), *Spodoptera frugiperda* (fall armyworm (FAW)), and *Helicoverpa zea* (corn earworm (CEW)) (Flood et al. 1995). In New York state, ECB is the main pest throughout the season while the other Lepidoptera are primarily late-season pests. ECB are known to have numerous predators (Frye 1972, Hudon and LeRoux 1986, Andow 1990, Godfrey et al. 1991), and yet the contribution of these predators is largely overlooked as an insect control tactic because the extent of predation is unknown or unpredictable. Surveys in New York have historically found that the primary predator in the region is the coccinellid *Coleomegilla maculata* (Whitman 1975, Andow and Risch 1985, Hoffmann et al. 1997). However, the recent arrival of *Harmonia axyridis* (Multicolored Asian Lady Beetle) (Coderre et al. 1995, Wheeler and Stoops 1996) introduced a new predator into the sweet corn system. In 1998 the most numerous predator in sweet corn in western New York was *H. axyridis* (Shelton, unpubl.). As both *C. maculata* and *H. axyridis* are polyphagous, the impact of these predators on pest populations is difficult to predict. *C. maculata* has been recorded as a predator of aphids (Wright and Laing 1980), Lepidoptera and Coleoptera eggs and small larvae (Conrad 1959, Groden et al. 1990, Coll and Bottrell 1991,

Andow 1992), plant pollen (Smith 1961, Cottrell and Yeargan 1998), mites (Putnam 1964) and fungal spores (Putnam 1964). *H. axyridis* is mainly known as an aphid feeder, but other prey recorded include scales (Hukusima and Ohwaki 1972, McClure 1986), mites (Lucas et al. 1997), psyllids (Iablokoff-Khnzorian 1982), Lepidoptera larvae (Hironori and Katsuhiro 1997), Neuroptera eggs (Phoofolo and Obrycki 1998), pollen (Hukusima and Itoh 1976), spiders (Hironori and Katsuhiro 1997) and coccinellids ((Hironori and Katsuhiro 1997). In sweet corn most of these food sources are available at some time, making the extent of predation on pest species such as ECB eggs difficult to predict. Overall ECB egg predation has been recorded at levels generally ranging from 2-41% in the Northeast (Andow and Risch 1985, Hudon and LeRoux 1986, Coll and Bottrell 1992), To implement an integrated pest management program in sweet corn, the biological control potential resulting from the current natural enemy complex must be understood so it can be incorporated into insect control decisions.

The standard insect controls for the pest complex over the last several years have been broad-spectrum pyrethroids, primarily lambda cyhalothrin (Warrior), and they have provided good control of the primary and secondary pests. In 1998, Warrior was by far the most widely used insecticide in New York with 68% of the processing fields treated with Warrior an average of 1.7 times. Baythroid was second with 10% of the fields being treated an average of 1.1 times. In fresh market sweet corn, 60% of the fields were treated with Warrior an average of 1.4 times followed by Larvin at 51% of the fields an average of 1.0 times (Anonymous 1999). Since 1998 three new products have entered the market for controlling Lepidoptera in sweet corn. Spinosad (SpinTor), produced by Dow AgroSciences was registered in 1999 for control of lepidopteran pests. Studies on various crops have shown that it does not disrupt coccinellids, anthocorids, nabids, and 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, but not always as good as Warrior (Linduska et al. 1999, Straub 1999). The DuPont product, indoxacarb (Avaunt), was registered in 2000 and is also targeted at lepidopteran pests. Like SpinTor, testing against natural enemies has revealed that Avaunt is toxic to Lepidoptera (Hammes et al. 1998) but relatively non-toxic for anthocorids, nabids, chrysopids, and spiders (Hammes 2000). However there have also been studies showing that Avaunt is toxic to some natural enemies. Studebaker (1999) found that indoxacarb caused >60% mortality in *O. insidiosus*, compared with 100% and 19% mortality from Warrior and spinosad respectively. Tillman (1998) likewise found that indoxacarb was toxic to the anthocorid *Geocoris punctipes* at high rates, but was less toxic to all natural enemies than Warrior. Transgenic Bt sweet corn varieties were released on a limited basis in 1998. Transgenic varieties incorporate a toxin from the bacteria *Bacillus thuringiensis* (Bt) into the DNA of the plant. Numerous formulations of Bt have been used for many years as a foliar spray against many lepidopteran insects. There have been many studies on the impact of transgenic and foliar sprayed Bt on both pests and natural enemies. In general, Bt has been found to have 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). The impact on sweet corn pests, however, depends on the delivery system. Foliar sprays have provided inconsistent control inferior to the other insecticides available (Bartels and Hutchinson 1995, Bartels et al. 1995, Cagan et al. 1995, Straub 1999), while transgenic Bt corn and sweet corn have provided consistently excellent control of Lepidoptera (Williams et al. 1997, Lynch et al. 1999, Sorenson and Holloway 1999).

While the above studies together give an indication of the results a grower may have, generalizing results from related species may not give an accurate picture. Pietrantonio (1999) cautions against generalizing insecticide impacts within families and even within genera. Elzen (1998) confirmed that insects vary within a family by showing that the anthocorid *O. insidiosus* was more sensitive to insecticides than another anthocorid, *G. punctipes*. Another limitation of generalization is that one may not be able to see a niche for a product. As insecticides are used at a variety of rates and are often used numerous times on the same crop, a product that is relatively non-toxic in one scenario, may be highly toxic in another scenario. Before growers use these products, it is critical that the products be tested in a number of different scenarios to understand what the impact of a product will be on both pests and natural enemies. One of the concerns of using products which specifically target certain insects (e.g. Lepidoptera) is that secondary pests like aphids or sap beetles which were formerly controlled by the broad spectrum insecticide may become significant pests (Linduska et al. 1999). It is also possible that they will be sufficiently controlled by the conserved natural enemies (Peterson et al. 1996). To better assess the impact of these products on the pest and natural enemy complex present in sweet corn in New York, and to compare these products under the same circumstances, field tests were conducted in 2000 with the goal of developing an IPM program for sweet corn.

Materials and Methods

Monitoring: This trial was planted with plantings in late May, mid June, and late June in a completely randomized design with 3 replications in 10.7 x 12.2 m plots (76 cm row width). To monitor populations of insects, we counted the insects of interest weekly on 10 consecutive plants. At the same time two whole plants were cut and carefully placed in plastic bags and frozen. These plants were later examined in the laboratory, identifying and counting all insects found. Sticky card counts were from three 7.5 cm x 14 cm yellow cards, sticky on 1 side, that were placed in the field for 2 days. Pest damage to the crop was assessed by harvesting 25 random ears from each plot and counting all insects and damage found on the ears.

Field Cages: Field cages were utilized to understand which coccinellids were the most voracious eaters of ECB eggs. 2.5 x 2.5 x 2.5 m cages were placed over about 30 plants of sweet corn. The edges of the netting were buried in the ground. All coccinellids were removed from the cage manually. *H. axyridis* larvae, *C. maculata* adults, and *C. maculata* larvae were collected from corn fields for release inside the cage. One hundred ECB egg masses from a lab colony were pinned in each cage through the midrib of the ear leaf and the leaf directly above the ear leaf. Then 40 coccinellids of a single type were evenly distributed onto the caged corn. A control cage received the ECB egg masses but no coccinellids. After 2 days, all the pins were removed from the plants, recording those which no longer had ECB egg masses. This trial was conducted 5 times on two different corn plantings, with 1 replication (4 field cages) each time. Due to a scarcity of *H. axyridis* larvae late in the season, only 3 replications could be completed with this species.

Insecticide Trials: Two different field trials were conducted to examine the impact of insecticides and a transgenic Bt variety on beneficial and pest insects of sweet corn in 2000. Insecticide treatments were Avaunt (indoxacarb) at 1.5 and 3.0 oz/ac, Dipel (*Bacillus thuringiensis* ssp. kurstaki) at 1 and 2 pt/ac, SpinTor (spinosad) at 2.3 and 4.5 fl oz/ac, Warrior (lambda cyhalothrin) at 1.5 and 3.0 fl oz/ac and an unsprayed check. In the 'multiple spray' trial, the insecticide treatments were applied 4 times at 5 to 7 day intervals beginning at early silk to a non-transgenic variety 'Candy Corner'. The same insecticide treatments were applied a single time at early silk in the 'single spray' trial. In the 'single spray' trial, the transgenic variety 'Attribute 0966' and the isoline 'Prime Plus' were also compared using a variety x insecticide factorial in a randomized complete block design with 3 replications. Plots in both trials were 7 rows wide (76 cm row width) and 6.1 m long. The interior 5 rows were sprayed with a High-Boy sprayer applying 36 gal / acre. The 'multiple spray' trial was planted June 20 and the 'single spray' trial was planted July 1. To monitor populations of insects, we counted the insects of interest on 10 consecutive plants prior to spraying and 3 days after each application. The single spray trial was also monitored 13 days after spraying. At the same time as each field count, two whole plants were cut and carefully placed in plastic bags and frozen. These plants were later examined in the laboratory, identifying and counting all insects found. Pest damage to the crop was assessed by harvesting 25 random ears from the center 5 rows of each plot and counting all insects and damage found on the ears.

Variety Trial: Trials were planted May 31, 2000 with 3 replications of 6 'sugar enhanced' (se) varieties and 7 'shrunken' (sh) varieties. Plots were 6 rows wide and 6.1 m long. The se and sh

varieties were planted in separate blocks to minimize pollen mixing but in every other way the blocks were treated the same. Each week the plots were monitored by field counts, lab counts and sticky cards as in the monitoring trial. Pest damage to the crop was assessed by harvesting 25 random ears from each plot and counting all insects and damage found on the ears.

Data for all trials was analyzed using SAS statistical software, primarily utilizing the general linear model procedure (PROC GLM) and the frequency procedure (PROC FREQ). Significance was determined using $\alpha=.05$.

Results

Monitoring: For the third consecutive year, the only significant coccinellids present in sweet corn were *C. maculata* and *H. axyridis*. Besides coccinellids, the only other natural enemy found on more than 1% of plants was *Orius insidiosus*. The population dynamics of *C. maculata* and *H. axyridis* were very different. As seen in Figure 1, *C. maculata* adult populations peaked over the early reproductive stage of corn and were higher in May-planted corn than in June-planted corn. The adult population showed no numerical response to aphid populations, likely being driven instead by corn pollen. It does seem however that either oviposition or early larval survival was affected by aphid availability. In 1999 the larger aphid population was in the late season corn, but in 2000 it was in the early season corn. Their impact on *C. maculata* larvae was a higher population at these times than at times when there were fewer aphids. There is also a link between aphids and *H. axyridis* populations. Figure 1 shows that *H. axyridis* adult populations were largest in the late-planted corn and when aphid populations were high. Like *C. maculata*, *H. axyridis* larval population increase was closely linked to aphid populations, due to either an increase in oviposition or higher larval survival in the presence of aphids. Because *C. maculata* adults were more numerous in early season corn and *H. axyridis* adults were found more in the late season, the competition between these populations was minimal. However, when aphids became numerous early in the 2000 season, then was competition between the larvae of the two species. When an encounter was observed during monitoring, *H. axyridis* adults and larvae always ate *C. maculata* larvae, a finding consistent with the report of Cottrell and Yeargan (1998). Predation of adults of either species was not observed.
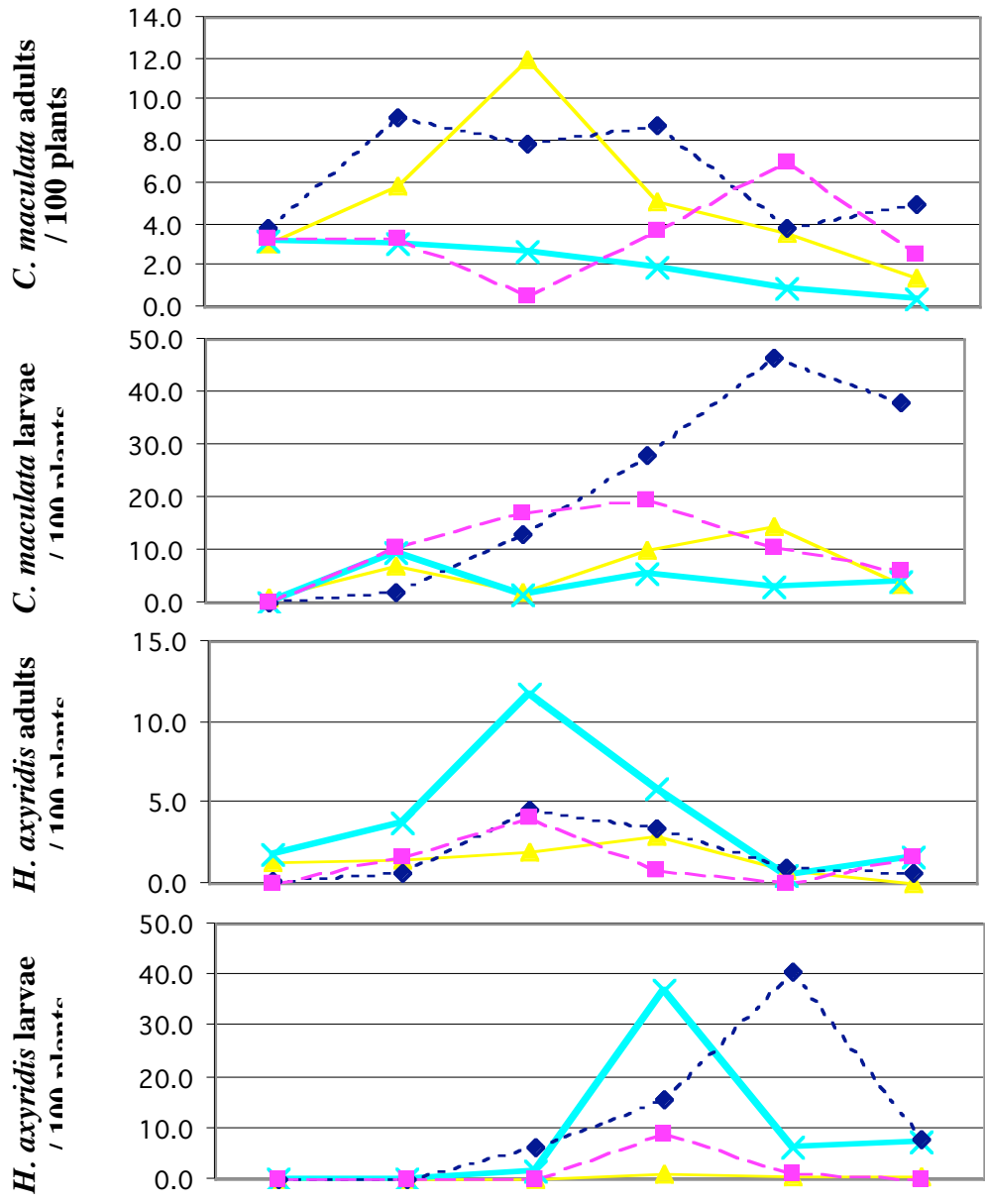
Field Cages: The results of the field cage trial shows that *C. maculata* adults, *C. maculata* larvae and *H. axyridis* larvae are all equally significant as ECB egg predators. On average, 32% fewer ECB egg masses were retrieved from these cages with coccinellids than from the control cages (p=.002). However, there were no significant differences in predation rate between the insect types. Aphid populations were low in these cages, so alternative food sources was mainly pollen and low levels of various insects. Given high aphid populations, the results may have been very different.

Insecticide Trials: The results of the 'multiple spray' trial (Table 1) show that rates applied made no significant difference in pest control for any product. Warrior, SpinTor and Avaunt each provided equal control against Lepidoptera. As expected, Warrior plots had very low populations of all natural enemies and the other insecticides had less drastic effects. Avaunt and Dipel plots had fewer coccinellids but no effect on *O. insidiosus*. SpinTor was not toxic to coccinellids, but had lower *O. insidiosus* nymph populations. Using half rates in general had no significant effect on Lepidoptera or aphids, but it is less costly and resulted in more *O. insidiosus* nymphs (p=.0281).
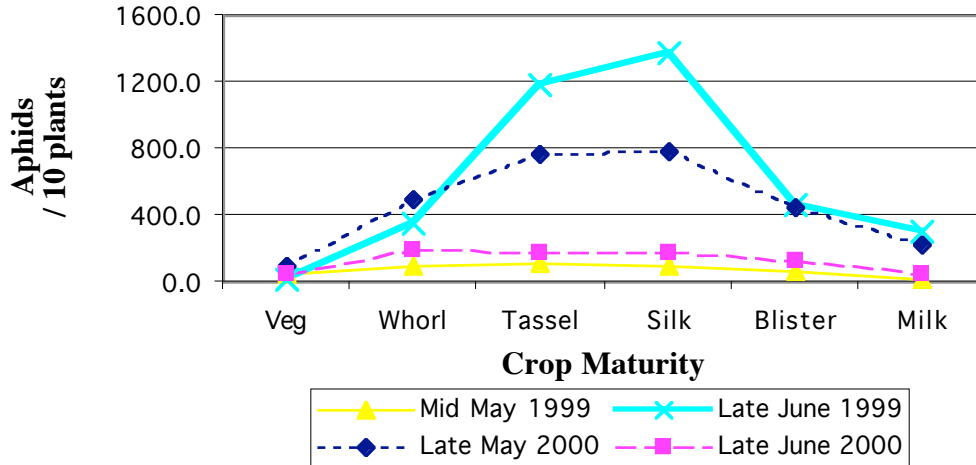
The results of the 'single spray' trial (Table 2) show that lepidopteran pest pressure was severe and that one spray was not commercially adequate for pest control, except for the Bt variety plots which had excellent control. While the Bt and non-Bt varieties were isolines, there were several differences in insect populations which may not be directly related to the Bt toxin. Both aphid and *O. insidiosus* adult populations were significantly different, with the Bt variety having higher populations both times. The importance of this is minimal as these same varieties did not show

these differences in the variety trial (Table 3). While all spray treatments suffered high Lepidoptera damage in the 'single spray' trial, there were significant differences between insecticides on pest and non-pest species. Plots receiving the full rates of Warrior, SpinTor, Avaunt and the half rate of SpinTor were significantly cleaner than the check. Coccinellid populations were most adversely affected by Warrior and Avaunt, while only Warrior caused significantly lower *O. insidiosus* populations. An analysis of the impact of lower rates across all the insecticides shows that lower rates resulted in more *O. insidiosus* nymphs (p=.0074), and aphids (p=.0335) as well as more ear damage by ECB (p=.0034) resulting in fewer clean ears (p=.0001).

Figure 1. Coccinellid and aphid populations over crop maturity for 4 different plantings.

Figure: Aphids / 10 plants vs. Crop Maturity (Veg, Whorl, Tassel, Silk, Blister, Milk) for Mid May 1999, Late June 1999, Late May 2000, Late June 2000.

Table 1. Natural enemy and pest populations after multiple insecticide applications.

Insecticides applied August 18, 25, 30 and Sept. 5, 2000. Aphid, coccinellid and *O. insidiosus* data collected Aug. 22, 29, Sept. 4, and 11. Table combines all dates. ECB, FAW, CEW and clean ear data collected on Sept. 14.

Treatment	Rate	Aphids[1]	Coccinellids[2]	*O. insidiosus*[3] adult	*O. insidiosus*[3] nymph	ECB Ears[4]	FAW CEW Ears	Clean Ears
	/ acre			Number per 10 plants				%
Warrior 1E	3.0 oz	54 ns	0.03 d	0.9 c	0.4 b	0.04 b	0.00 c	98.7 a
SpinTor 2SC	4.5 oz	119 ns	1.70 a	17.5 ab	2.1 b	0.09 b	0.00 c	97.3 a
SpinTor 2SC	2.3 oz	95 ns	1.38 ab	10.4 b	10.5 a	0.18 b	0.13 c	96.0 a
Warrior 1E	1.5 oz	58 ns	0.08 d	1.5 c	1.0 b	0.33 b	0.27 c	93.3 a
Avaunt 30WG	1.5 oz	92 ns	0.03 d	16.5 ab	10.7 a	0.36 b	0.13 c	93.3 a
Avaunt 30WG	3.0 oz	135 ns	0.00 d	12.5 ab	8.6 a	0.76 ab	0.00 c	92.0 a
Dipel ES	1.0 pt	91 ns	0.64 bc	19.6 a	11.4 a	2.53 a	0.93 ab	73.3 b
Check		69 ns	1.47 a	11.0 ab	14.9 a	3.00 a	0.53 bc	69.3 b
Dipel ES	2.0 pt	86 ns	0.50 c	14.5 ab	11.7 a	2.68 a	1.47 a	57.3 b

Means with the same letter in the same column are not significantly different (LSD test with $\alpha=.05$).

[1] by lab count method. Data was transformed by square root for statistical analysis. Transformed totals are presented.
[2] Coccinellid data is the total of *C. maculata* (16 adults, 78 larvae) and *H. axyridis* (8 adults, 10 larvae) by field count method. Data was transformed by logarithm for statistical analysis. Transformed totals are presented.
[3] by lab count method. Data was transformed by square root for statistical analysis. Transformed totals are presented.
[4] ECB data was transformed by square root for statistical analysis. Transformed totals are presented.

Table 2. **Natural enemy and pest populations after a single insecticide application.** Sprayed on Sept. 5, 2000. Aphid, coccinellid and *O. insidiosus* data collected on Sept. 8 and 18. Table combines both dates. ECB, FAW, CEW and clean ear data collected on Sept. 25.

Treatment	Rate	Aphids[1]	Coccinellids[2]	*O. insidiosus*[3] adult	*O. insidiosus*[3] nymph	ECB Ears[4]	FAW CEW Ears[4]	Clean Ears[5]
	/ acre			Number per 10 plants				%
Warrior 1E	3.0 oz	65 ns	0.00 d	6.4 c	1.1 d	2.54 bc	1.55 b	61.3 a
SpinTor 2SC	4.5 oz	127 ns	1.28 a	33.5 a	12.7 bc	1.81 c	1.59 b	57.3 ab
Avaunt 30WG	3.0 oz	132 ns	0.41 bc	41.0 a	11.8 bc	2.48 bc	2.73 ab	56.0 ab
SpinTor 2SC	2.3 oz	185 ns	0.53 abc	37.7 a	11.6 bc	3.81 ab	2.89 ab	46.7 abc

Warrior 1E	1.5 oz	140 ns	0.00 d	16.1 b	8.2 c	4.19 ab	2.42 ab	44.0 bcd
Avaunt 30WG	1.5 oz	175 ns	0.31 c	40.8 a	17.5 ab	4.36 ab	3.08 ab	32.0 cde
Check		136 ns	0.98 ab	40.4 a	18.5 ab	4.78 a	3.91 ab	30.7 de
Dipel ES	2 pt	142 ns	0.56 abc	47.7 a	14.0 abc	3.73 ab	4.71 a	30.7 de
Dipel ES	1 pt	155 ns	0.48 abc	37.6 a	24.4 a	4.35 ab	4.53 a	22.7 e
Attribute 0966 (Bt)	all	164 a	0.40 ns	38.9 a	11.9 ns	0.03 b	0.03 b	97.8 a
Prime Plus (check)	all	111 b	0.37 ns	25.2 b	12.5 ns	3.49 a	2.95 a	42.4 b

Means with the same letter in the same column are not significantly different (LSD test with α=.05). The insecticide factors were analyzed separately from the variety factors.

[1] from both varieties by lab count method. Data was transformed by logarithm for statistical analysis. Transformed totals are presented.

[2] is the total of *C. maculata* (37 adults, 57 larvae) and *H. axyridis* (3 adults, 7 larvae) from both varieties by field count method. Data was transformed by logarithm for statistical analysis. Transformed totals are presented.

[3] from both varieties by lab count method. Data was transformed by square root for statistical analysis. Transformed totals are presented.

[4] ECB, FAW and CEW damaged ears only from Prime Plus for spray evaluations. Data was transformed by square root for statistical analysis. Transformed totals are presented.

[5] Clean ear data only from Prime Plus for spray evaluations.

Variety Trial: The results, presented in Table 3, show that the two transgenic Bt varieties, Bonus Bt and Attribute 0966 were very effective in controlling the lepidopteran pests. These varieties appear to have no effect on the other insects monitored as there were no other significant differences between these Bt varieties and their respective non-Bt isolines, Bonus and Prime Plus. There was a moderate negative correlation between the tip cover length and tip damage in the SH varieties (R^2=.51), but only a weak negative correlation in the SE varieties (R^2=.20). There were no significant correlations found between natural enemy populations and pest damage.

Table 3. Average Natural Enemy and Pest Populations for SE and SH Varieties from weekly monitoring. Geneva, NY, 2000.

Variety (Days)	Tip Cover	*C. maculata*[1]	*H. axyridis*[1]	*O. insidiosus* nymphs[2]	Aphids[3]	ECB Ears	FAW/ CEW Ears	Clean[4]
SE Varieties	cm	Number per 10 plants (LS Means)						%
Bonus Bt (83)	6.1 bc	2.70 a	1.47 a	7.76 a	200.9 a	0.0 c	0.1 b	98.7 a
Temptation (72)	6.6 b	2.72 a	0.79 ab	2.79 b	63.6 d	3.2 b	0.4 b	70.8 b
Sprint (71)	4.1 d	1.13 b	0.36 b	5.59 ab	81.5 cd	5.3 ab	0.7 ab	50.4 c
Golden Millennium (85)	8.4 a	3.18 a	0.76 b	3.38 b	93.5 bcd	5.9 ab	0.5 b	45.3 c
Sensor (80)	4.6 d	2.06 ab	0.65 b	3.32 b	157.4 ab	6.5 a	0.4 b	44.4 c
Bonus (83)	5.3 cd	2.60 ab	0.96 ab	8.67 a	152.9 abc	6.2 a	1.3 a	43.9 c
SH Varieties								
Attribute 0966 (78)	4.8 bc	2.58 bc	1.01 b	5.36 ns	148.3 b	0.0 c	0.0 d	100.0 a
Zenith (81)	7.1 a	3.67 abc	3.02 a	5.21 ns	182.8 ab	3.3 b	0.1 cd	60.0 b
BiTime (78)	3.0 d	2.10 c	0.89 b	3.99 ns	121.5 b	5.1 ab	0.8 abc	53.3 b
Candy Corner (76)	5.3 ab	4.09 ab	0.93 b	6.62 ns	126.5 b	3.8 ab	1.4 ab	53.3 b
Cabaret (80)	4.1 bcd	4.40 a	2.32 ab	2.95 ns	276.3 a	5.0 ab	0.2 bcd	44.0 bc
Prime Plus (78)	3.3 cd	3.61 abc	1.01 b	5.26 ns	208.2 ab	6.1 ab	0.3 abcd	41.3 bc
Even Sweeter (82)	4.3 bcd	2.99 abc	1.31 ab	2.85 ns	170.5 ab	8.2 a	1.5 a	27.4 c

Means with the same letter in the same column for the same group of varieties are not significantly different (LSD test with α=.05).

[1]Coccinellid data from field counts.

[2]*O. insidiosus* nymph data from lab counts. Data was transformed by square root for statistical analysis. Transformed totals are presented.

[3]Aphid data from lab counts. Data was transformed by logarithm for statistical analysis. Transformed totals are presented.

[4]Data was transformed by square for statistical analysis. Transformed totals are presented.

Discussion

Harmonia axyridis and *Coleomegilla maculata* were the only significant coccinellids found in corn fields of western New York in 1999 and 2000. Adult populations are largely asynchronous, but larval populations are more synchronized. As a result, competition between these species is mostly among the larvae as oviposition and/or larval survival of both species is dependant on aphid populations. The most intense competition between the species for food is most likely to

occur when sweet corn is in the blister stage, 1-2 weeks before harvest as larval populations are at their peak, the larvae are mostly late instars with a large appetite, and the food sources of aphids and pollen are shrinking. Natural predation of sentinel ECB egg masses reached 62% in 1999, and a mid-season planting in 1998 had 95% predation (data not shown), so natural predation can be very significant. The results of our field cage study confirms that coccinellids are responsible for a significant part of this predation and our monitoring data indicates that the only other predator present in great enough quantity to influence overall predation rates is *Orius insidiosus*. The effect of the arrival of *H. axyridis* in New York appears to be an increase in pest predation in sweet corn, but more testing is needed to better understand the influence of alternative food sources.

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. Both of the field studies showed major differences between materials but little difference between the half and full rate of the materials. In both trials, only *O. insidiosus* nymphs had a higher survival in the half rate treatments, while pest control was compromised by the half rates when only applied a single time. The frequency of application also had little impact as there were no significant interactions between the insecticides and the number of times sprayed for any of the natural enemy populations within the multiple spray trial. The degree of pest control was quite different between the single spray and multiple spray trials, but this is not a fair comparison as these were in different trials with different varieties and different amounts of pest pressure.

The five products tested represent a wide range of control options. The best choice of insecticide will depend on the circumstances faced by the grower. At one end of the spectrum, Warrior provided good pest control and is relatively inexpensive, but it was also highly toxic to all other insects in the field. At the other end, Dipel did not provide any pest control and was somewhat toxic to coccinellids when used repeatedly. From an IPM perspective, the products SpinTor, Avaunt and Bt sweet corn are all good choices, each with different strengths and weaknesses. SpinTor and Avaunt provided good pest control and were toxic to some natural enemies. SpinTor was slightly toxic to *O. insidiosus*, while Avaunt was highly toxic to the coccinellids. Both of these natural enemies can provide significant control to primary and secondary pests (Andow and Risch 1985, Corey et al. 1988, Andow 1992, Coll and Bottrell 1992), so the selection of the best foliar spray will depend on the natural enemy populations in the field. Transgenic Bt sweet corn appears to be the most desirable choice from an IPM perspective when control is needed. This product gave outstanding control of the pests and showed no toxic effects to the natural enemies. Unfortunately, the decision to use this product needs to be made long before pest pressure can be predicted, the seed is currently quite expensive, and the current hysteria about genetically modified organisms (GMOs) dims the potential market acceptance of this product. When considering the economic and environmental impact of each of these products, there is no single product that is the best in all cases, so each situation will need to be evaluated on an ongoing basis. This research provides a scientific basis for comparing these products.

Host plant resistance is an underutilized tool in sweet corn insect resistance. Our screening test demonstrated that there is variability in commercially available lines. A major source of resistance is through transgenic technology, but the variance among the traditional varieties

demonstrates that more resistance can be bred into these varieties without sacrificing the other qualities demanded by the market. To bring about increased host plant resistance in varieties would be a long-range project involving numerous disciplines. However, host plant resistance should be incorporated into existing variety screens as this additional information is easily collected and can help growers choose varieties that are less likely to require chemical inputs.

The potential impact of choosing varieties and insecticides based on their ability to encourage natural enemies is still largely unknown. As the major natural enemies in sweet corn are quite mobile, localized effects are unlikely. Transgenic Bt varieties show potential for eliminating foliar insecticide applications, while other variety traits would reduce insecticide needs marginally. The benefits of preserved natural enemies should be a reduced need for multiple insecticide applications. While the need for the initial application may not change, the natural enemies should be able to control the few late-arriving pests that traditionally have required extra insecticide applications. The potential of these narrow-spectrum insecticides may best be realized in a fresh-market situation where sweet corn with different planting dates are grown in close proximity. The natural enemy populations could build up on each successive crop instead of needing to reestablish in each crop as currently occurs. Secondary pest populations would also have the opportunity to increase, so more research would be helpful before recommending these new products.

References

Andow, D. A. (1990). Characterization of predation on egg masses of *Ostrinia nubilalis* (Lepidoptera: Pyralidae). Ann. Entomol. Soc. Amer. 83: 482-486.

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.

Anon. (1999). Agricultural Chemical Usage: 1998 Vegetable Summary. USDA Nat. Ag. Stat. Service, Economic Research Service.

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.

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

Coderre, D., E. Lucas and I. Gagne. (1995). The occurrence of *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) in Canada. Can. Entomol. 127: 609-611.

Coll, M. and D. G. Bottrell. (1991). Microhabitat and resource selection of the European corn borer (Lepidoptera: Pyralidae) and its natural enemies in Maryland field corn. Environ. Entomol. 20: 526-533.

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.

Conrad, M. S. (1959). The Spotted Lady Beetle, *Coleomegilla maculata* (DeGeer), as a predator of European corn borer eggs. J. Econ. Entomol. 52: 843-847.

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.

Cottrell, T. E. and K. V. Yeargan. (1998). Effect of pollen on *Coleomegilla maculata* (Coleoptera: Coccinellidae) population density, predation, and cannibalism in sweet corn. Environ. Entomol. 27: 1402-1410.

Cottrell, T. E. and K. V. Yeargan. (1998). Intraguild predation between an introduced lady beetle, *Harmonia axyridis* (Coleoptera: Coccinellidae), and a native lady beetle, *Coleomegilla maculata* (Coleoptera: Coccinellidae). J. Kans. Entomol. Soc. 71: 159-163.

Duffie, W., M. J. Sullivan and S. G. Turnipseed. (1997). Survival of beneficial arthropods following the application of various insecticides. Beltwide Cotton Conference, New Orleans, LA, USA 2: 1120-1121.

Duffie, W. D., M. J. Sullivan and S. G. Turnipseed. (1998). Predator mortality in cotton from different insecticide classes. Beltwide Cotton Conference 2: 1111-1112.

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

Elzen, G. W., P. J. Elzen and E. G. King. (1998). Laboratory toxicity of insecticide residues to *Orius insidiosus, Geocoris punctipes, Hippodamia convergens*, and *Chrysoperla carnea*. Southwest. Entomol. 23: 335-342.

Flood, B., R. Foster and B. Hutchison. (1995). Sweet Corn. *In* "Vegetable Insect Management with emphasis on the Midwest". Willoughby, OH, Meister Publishing Company. 19-40.

Frye, R. D. (1972). Evaluation of insect predation on European corn borer in North Dakota. Environ. Entomol. 1: 535-536.

Godfrey, L. D., K. E. Godfrey, T. E. Hunt and S. M. Spomer. (1991). Natural enemies of European corn borer *Ostrinia nubilalis* (Hubner) (Lepidoptera: Pyralidae) larvae in irrigated and drought-stressed corn. J. Kans. Entomol. Soc. 64: 279-286.

Groden, E., F. A. Drummond, R. A. Casagrande and D. L. Haynes. (1990). *Coleomegilla maculata* (Coleoptera: Coccinellidae): Its predation upon Colorado Potato Beetle (Coleoptera Chrysomelidae) and its incidence in potatoes and surrounding crops. J. Econ. Entomol. 83: 1306-1315.

Hammes, G. G. (2000). A Five Year Summary of Beneficial Arthropod Studies with "Steward" (DPX MP 062). Beltwide Cotton Conference. 2: 940.

Hammes, G. G., D. Sherrod and D. Marsden. (1998). "Steward" (DPX MP-062), a novel new insecticide for cotton insect control. Beltwide Cotton Conference, San Diego, CA USA 2: 1275-1276.

Hironori, Y. and S. Katsuhiro. (1997). Cannibalism and interspecific predation in two predatory ladybirds in relation to prey abundance in the field. Entomophaga. 42: 153-163.

Hoffmann, M. P., M. S. Orfanedes, L. H. Pedersen, J. J. Kirkwyland, E. R. Hoebeke and R. Ayyappath. (1997). Survey of Lady Beetles (Coleoptera: Coccinellidae) in Sweet Corn Using Yellow Sticky Cards. J. Entomol. Sci. 32: 358-369.

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.

Hudon, M. and E. J. LeRoux. (1986). Biology and population dynamics of the European Corn Borer (*Ostrinia nubilalis*) with special reference to sweet corn in Quebec. III. Population dynamics and spatial distribution. Phytoprotection 67: 93-115.

Hukusima, S. and K. Itoh. (1976). Pollen and fungus as food for some coccinellid beetles. Res. Bull. Fac. Agric. Gifu U. 39: 31-37.

Hukusima, S. and T. Ohwaki. (1972). Further notes on feeding biology of *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae). Res. Bull. Fac. Agric. Gifu U. 33: 75-82.

Iablokoff-Khnzorian, S. M. (1982). Les coccinelles: Coleopteres- Coccinellidae. Boubee, Paris, Societe nouvelle des editions.

Linduska, J. J., G. P. Dively and M. Ross. (1999). Timing Insecticide Applications for Dusky Sap Beetle Control in Bt Sweet Corn. Poster at 1999 ESA meeting in Atlanta GA,

Linduska, J. J., M. Ross, D. Baumann and M. Lemuiex. (1999). Foliar sprays to control ear invading insects in sweet corn, 1998. Arth. Mngmt. 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). Bollettino Zool. Agraria Bach. 30: 153-164.

Lucas, E., D. Coderre and C. Vincent. (1997). Voracity and feeding preferences of two aphidophagous coccinellids on *Aphis citricola* and *Tetranychus urticae*. Entomol. Exp. Appl. 85: 151-159.

Lynch, R. E., B. R. Wiseman, D. Plaisted and D. Warnick. (1999). 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.

McClure, M. S. (1986). Role of predators in regulation of endemic populations of *Matsucoccus matsumurae* (Homoptera: Margarodidae) in Japan. Environ. Entomol. 15: 976-983.

Murray, D. A. H. and R. J. Lloyd. (1997). The effect of spinosad (Tracer) on arthropod pest and beneficial populations in Australian cotton. Beltwide Cotton Conference, New Orleans, LA USA, 2: 1087-1091.

Obrycki, J. J. and T. J. Kring. (1998). Predacious coccinellidae in biological control. Ann. 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. Beltwide Cotton Conference, Nashville, TN, USA, 2: 872-873.

Phoofolo, M. W. and J. J. Obrycki. (1998). Potential for intraguild predation and competition among predatory coccinellidae and chrysopidae. Entomol. Exp. Appl. 89: 47-55.

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.

Putnam, W. L. (1964). Occurrence and food of some coccinellids (Coleoptera) in Ontario peach orchards. Can. Entomol. 96: 1149-1155.

Smith, B. C. (1961). Results of rearing some coccinellid (Coleoptera: Coccinellidae) larvae on various pollens. Proc. Entomol. Soc. Ontario. 91: 270-271.

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. Arth. Mngmt. 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. Arth. Mngmt. Tests. 24: 133.

Studebaker, G. E. and T. J. Kring. (1999). Lethal and sub-lethal effects of selected insecticides on *Orius insidiosus*. Beltwide Cotton Conference, Orlando, FL USA, 2: 1203-1204.

Tillman, P. G., J. E. Mulrooney and W. Mitchell. (1998). Susceptibility of selected beneficial insects to DPX-MP062. Beltwide Cotton Conference, San Diego, CA, USA, 2: 1112-1114.

Wheeler, A. G., Jr. and C. A. Stoops. (1996). Status and spread of the Palearctic lady beetles *Hippodamia variegata* and *Propylea quatuordecimpunctata* (Coleoptera: Coccinellidae) in Pennsylvania, 1993-1995. Entomol. News. 107: 291-298.

Whitman, R. J. (1975). Natural Control of European Corn Borer in New York. Cornell.

Williams, W. P., J. B. Sagers, J. A. Hanten, F. M. Davis and P. M. Buckley. (1997). Transgenic corn evaluated for resistance to fall armyworm and southwestern corn borer. Crop Sci. 37: 957-962.

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