Select Nontarget Arthropod Abundance in Transgenic and Nontransgenic Field Crops in Ohio

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ABSTRACT Nontarget arthropod populations were monitored in both transgenic and nontransgenic corn and soybean fields in western and central Ohio. A total of 24 fields, 12 corn and 12 soybean, were inspected weekly from late June through mid August. Half of the cornfields were *Bacillus thuringiensis* (Bt) hybrids and half of the soybean fields were Roundup Ready (RR). Sweep net samples in soybean fields and unbaited Pherocon AM yellow sticky traps in both soybean and cornfields were used to collect nontarget arthropods. Soil samples were also taken from all 24 fields to compare soil mite populations. A select group of 15 readily identifiable arthropods composed mainly of beneficial insects commonly found in field crops, were recorded in weekly sweep net and sticky trap samples for later analysis. Sweep net data from soybean fields revealed no significant differences in nontarget arthropods. Yellow sticky trap data from soybean and corn fields found significantly more green lacewing adults (*Chrysopa* spp.) in six pooled non-RR soybean fields, significantly more rove beetles in one non-Bt cornfield, and significantly more *Orius* spp. in one Bt cornfield. There were also significantly more soil inhabiting mites at one non-RR soybean field. Based on the abundance of these arthropod populations in paired transgenic and nontransgenic fields, few negative effects on the 15 nontarget arthropods selected can be directly associated with transgenic soybean and corn crops in Ohio.

KEY WORDS *Chrysopa*, *Orius*, rove beetle, *Bacillus thuringiensis*, mites

OHIO FARMERS PLANTED 1.37 million ha of field corn and 1.86 million ha of soybean in 2001, including ≈96,315 ha of *Bacillus thuringiensis* (Bt) corn and 1.19 million ha of Roundup Ready (RR) soybeans. Transgenic acreage for both of these commodities in Ohio has increased one and 16%, respectively, from the 2000 planting statistics (National Agricultural Statistic Service 2001). While many farmers see clear production advantages in using transgenic corn and soybean hybrids for increased yield, stalk quality, insect and weed control, their utility in agriculture as pest management tools is debated between Government, industry, and public interests.

Since the earliest releases of "insect protected" transgenic field crops in the mid 1990s, researchers have been aware of possible nontarget and unintended ecological effects. Schuler et al. (1999) explain how vital risk assessment is when releasing transgenic plants to the field, insisting that monitoring of beneficial insects be set up once crop production reaches commercial scale. In Bt cotton, beneficial arthropod populations in transgenic fields appear not to differ significantly nor to negligibly effect those in surrounding nontransgenic fields (Van-Tol and Lentz 1998, Flint et al. 1995). Sims (1995) also found risks to non-Lepidopteran beneficial insects from Bt proteins in cotton negligible. Expression of Bt endotoxins in cotton have reduced the number of cotton bollworms *Helicoverpa armigera* (*Hubner*) and the number of cotton bollworm parasitoids (Cui and Xia 1999). The reduction of insecticides on Bt cotton has led to parasitic wasp populations capable of keeping aphid outbreaks to sub-economic levels and increasing secondary boll damaging pests such as plant bugs, *Lygus lineolaris* (*Palisot*) in North Carolina cotton fields in the late 1990s (Bacheler et al. 1999).

There are similar findings in field corn, where beneficial arthropod populations show little variation between Bt and non-Bt fields (Lozzia 1999, Pilcher et al. 1997, Cannon, 2000). Additional studies indicate tritrophic responses of *Chrysopa carnea* Stephens larval development and longevity to aphids fed Bt corn did not differ from *C. carnea* larvae fed aphids raised on

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non-Bt corn (Manachini et al. 1999, Lozzia et al. 1998). Conversely, Hilbeck et al. (1998a) found increased mortality on *C. carnea* larvae fed an artificial diet spiked with Bt protein (Cry1Ab) compared with an untreated control diet. Although *C. carnea* mortality increased overall when fed *Ostrinia nubilalis* (Hubner) or *Spodoptera littoralis* (Boisduval) larvae reared on Bt diet, there was no significant increase over the same prey fed a non-Bt diet (Hilbeck et al.1998b). Green peach aphids, *Myzus persicae* (Sulzer) fed on snowdrop lectin-transformed potato plants led to lower fecundity and decreased longevity of *Adalia bipunctata* (L.) adults (Birch et al. 1999).

The addition of herbicide resistance to insect protected transgenic corn, primarily glufosinate (Liberty, Syngenta, Basel, Switzerland) resistance, did not alter the beneficial arthropod populations between the herbicide treated Bt cornfield and the non-Bt corn buffer area (Volkmar et al. 1999). Transformation of glyphosate (Roundup, Monsanto, St. Louis, MO) resistance into soybeans was primarily for weed control and not intended to directly affect arthropods found in soybeans. The effect of glyphosate herbicide applied to transgenic RR soybeans has come under scrutiny, apparently having less effect on insect populations in general than did the corresponding level of weed control achieved by the herbicide (Buckelew et al. 2000). Searle et al. (1990) indicated the use of glyphosate was toxic to the gorse spider mite, *Tetranychus lintearius* (Dufour). Glyphosate applied in a laboratory setting was found to increase mortality of several soil mites and isopods, but field studies were inconclusive (Eijsackers 1985). In contrast, Ahn et al. (1997) found paraquat dichloride combined with glyphosate ineffective against all stages of twospotted spider mite, *Tetranychus urticae* Koch.

Regardless of the nature of the plant transformation, that is, for insect protection or for herbicide resistance, the purpose of this study is to evaluate the impact of transgenic field crops on select nontarget arthropod populations relative to Ohio.

Materials and Methods

Thirteen transgenic fields (6 Bt corn, 1 non-Bt RR corn, 6 RR soybean) and eleven nontransgenic fields (5 conventional hybrid corn and 6 conventional soybean) were selected for this study. There were a total of 11 paired transgenic and nontransgenic sites; five paired cornfields and six paired soybean fields. After the study had begun it was discovered that one pair of cornfields in Champaign county, OH actually consisted of a non-Bt RR and a Bt hybrid. The pairing was kept because of the fact no glyphosate herbicide was applied to either field.

Soybean fields were sampled using both a sweep net and unbaited Pherocon AM yellow sticky traps (Trécé Inc., Salinas, CA). Weekly sweep net sampling began 23 June and discontinued 16 August after pod set. Uniform sweep samples were difficult to take after this date because of the fullness of the soybean canopy. For the first 2 wk of sampling, three locations in each field were swept for arthropods at 30, 61, and 91 m from the field edge. Two sweep net samples (10 pendulum sweeps per sample) were taken at each location, each sample separated by at least 30 m. From the third week through the end of the study, only two locations 30 and 91 m from the field edge were swept; each location consisting of a pair of samples taken 30 m apart. The number of sweep net samples was reduced from 6 to 4 at each site to correspond with the position of the sticky traps placed in the field later in the survey. Any arthropods caught in the sweep net samples were placed in Ziploc bags and then refrigerated for later identification.

Two unbaited Pherocon AM yellow sticky traps were deployed 7 July in the same soybean fields monitored with sweep nets. The traps were attached to posts above canopy level at ≈30 and 91 m from the field edge. Traps were collected and replaced with fresh ones every week. The collected traps were refrigerated or frozen until a later date when they were inspected for select nontarget arthropods. Soybean sticky trap sampling was discontinued 25 August.

Sampling in cornfields began 7 July and relied only upon the use of unbaited Pherocon AM yellow sticky traps, which were attached to the corn stalk near the ear zone. Placement of the first trap within the field was at least 24 rows (18.2 m) into the field, with the second trap placed an additional 40 rows (30 m) toward the interior of the field. Both sticky traps were changed weekly in each field. The collected traps were refrigerated or frozen until a later date when they were inspected for select nontarget arthropods. Field corn sticky trap sampling was discontinued 25 August.

Three soil samples were also taken from each of the 12 soybean and corn fields in the survey before any fall tillage had occurred to see if differences could be detected in soil mite populations. The first soil sample was taken 15 m from the edge of the field with subsequent samples taken at 24 and 34 m into the field. A shovel was used to remove each sample containing the top 10–15 cm of the soil profile. Each sample was split into two 1000 cc sub-samples, placed into Ziploc bags and then refrigerated for temporary storage. Within a week of the sample being taken from the field, a composite sub sample from each of the three areas of each field was brought into the laboratory for mite extraction. A 500 cc soil sample was placed into a Berlese funnel with a 15 watt light bulb placed above the funnel and a collection jar filled with alcohol beneath the funnel neck. After 7 continuous days of extraction, the collection jars were sealed for later separation of mites. The soil extraction samples from soybean and cornfields were used to note mite abundance in different fields, not necessarily differentiate species.

Amid the diversity of arthropods captured in soybean and corn fields, only fifteen nontargets were selected because of their known abundance and importance in field crops and relative ease of identification when captured by either sweep net or yellow sticky trap. Specimens of interest included spiders,

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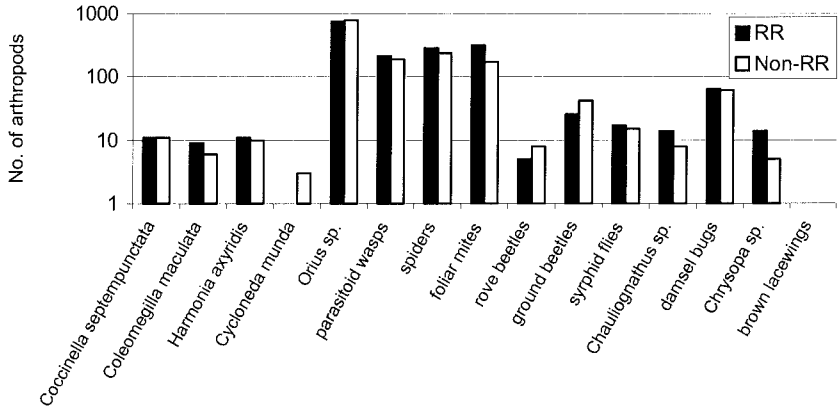

Fig. 1. A log scale of the total number of selected nontarget arthropods collected with sweep nets at six paired transgenic and nontransgenic soybean fields. *P* values for each arthropod exceed 0.05 for all RR versus non-RR comparisons. All insects are adults except for the damsel bugs and *Chrysopa* spp., which also contain immatures. No brown lacewings were collected.

foliar mites, parasitic wasps plus 12 other insects; 5 identified to family level, 3 to generic level, and 4 to species.

Differences between transgenic and nontransgenic nontarget arthropod data were statistically analyzed by technique (sweep net, sticky trap, soil extraction) and by crop (soybean and corn) at each site. Site data were combined to look for trends in transgenic versus nontransgenic arthropod abundance. Statistical analyses of data were performed using a nonparametric Mann-Whitney median test for paired sites and one way analysis of variance (ANOVA) for pooled data (Minitab v. 13.2, 2000).

Results

Sweep net samples between the six paired transgenic and nontransgenic soybean field sites revealed no statistically significant differences for any of the 15 nontarget arthropods; *Coccinella septempunctata* L., *Coleomegilla maculata* Timberlake, *Harmonia axyridis* Pallas, *Cycloneda munda* Say, *Orius* spp., parasitoid wasps, spiders, foliar mites, rove beetles, ground beetles, syrphid flies, *Chauliognathus* spp., damsel bugs, *Chrysopa* spp., or brown lacewings ($P > 0.05$). Pooling the six paired transgenic and nontransgenic soybean site data revealed no study wide statistical difference for any of the 15 nontarget arthropods ($P > 0.05$, Fig. 1).

Pherocon AM yellow sticky trap data between the six paired transgenic and nontransgenic soybean fields revealed no statistically significant differences for any of the 15 nontarget arthropods outlined in the soybean sweep net protocol ($P > 0.05$). Pooling the 6 paired transgenic and nontransgenic soybean sites revealed a study wide statistical increase of *Chrysopa* spp. adults in nontransgenic fields ($P = 0.041$). None of the other 14 nontarget arthropods analyzed differed significantly ($P > 0.05$, Fig. 2).

Pherocon AM yellow sticky trap data between transgenic and nontransgenic cornfields revealed an increase of *Orius* spp. in a transgenic field in Hancock

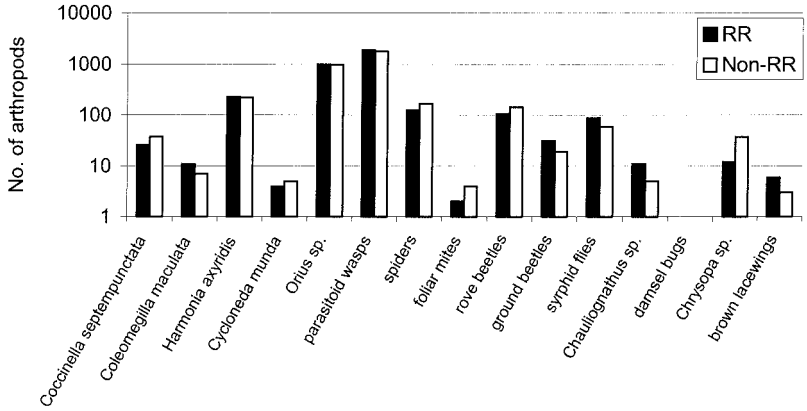

Fig. 2. A log scale of the total number of selected nontarget arthropods collected using unbaited Pherocon AM yellow sticky traps at six paired transgenic and nontransgenic soybean fields. *P* values for each arthropod exceed 0.05 for all RR versus non-RR comparisons except for *Chrysopa* spp. ($P = 0.041$). All insects are adults. No damsel bugs were collected.

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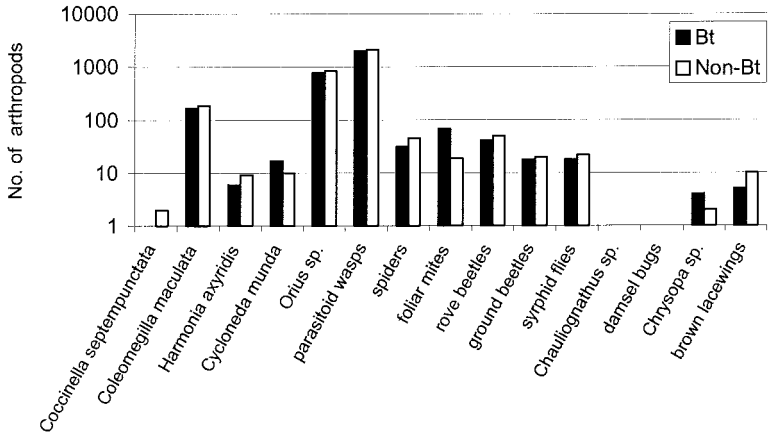

Fig. 3. A log scale of the total number of selected nontarget arthropods collected using unbaited Pherocon AM yellow sticky traps at six paired transgenic and nontransgenic cornfields. *P* values for each arthropod exceed 0.05 for all *Bacillus thuringiensis* (Bt) versus non-Bt comparisons. All insects are adults. No damsel bugs or *Chauliognathus* spp. were collected.

county, OH ($P = 0.0048$) and an increase of rove beetles in a nontransgenic field in Champaign county, OH ($P = 0.037$). Comparisons of the remaining thirteen arthropods revealed no other statistically significant differences ($P > 0.05$). It is interesting to note that captures of *Coccinella septempunctata* were very low in comparison to other Coccinellidae beetles (1 in Bt, 2 in non-Bt) and that no damsel bugs or *Chauliognathus* spp. were captured. Pooling site data from the 6 paired transgenic and nontransgenic cornfields revealed no statistically significant differences between the fields for the 15 nontarget arthropods ($P > 0.05$, Fig. 3).

The total number of soil inhabiting mites extracted from each pair of transgenic and nontransgenic soybean fields revealed a statistical difference at the Champaign county site, with more mites found in the nontransgenic field ($F = 11.66$; df = 1,4; $P = 0.027$). There was nearly a statistical difference between mite populations in soybean fields in Miami county ($F = 6.53$; df = 1,4; $P = 0.063$). The total number of soil mites extracted from each pair of transgenic and nontransgenic cornfields revealed no statistical differences ($P > 0.05$). Pooling all mites extracted from soil samples nearly revealed a significant difference in total mites between transgenic and nontransgenic soybean and corn fields ($F = 2.61$; df = 3,68; $P = 0.059$, Table 1).

Pesticide use among the twelve paired transgenic and nontransgenic sites were scrutinized to see if any trends appeared (Table 2). At 3 of the 6 paired sites where RR soybeans were compared with non-RR soybeans, both fields used glyphosate herbicide as part of their preplant weed control program. In the RR fields, a post emergence application of glyphosate was also made to the soybeans to control emerged weeds. This included the fields at Champaign county, where differences in soil mite populations were observed. The remaining three paired soybean sites used a total of 10 different herbicides in their weed control program. With the high variation of herbicides used in soybeans and the lack of insecticides on any of these soybean fields, no clear pesticide based explanation exists for the significant increase of *Chrysopa* spp. in nontransgenic fields.

Discussion

The purpose of this study was to assess the impact of transgenic corn and soybeans on nontarget arthropod populations. Out of the 15 nontarget arthropods selected for this study, there are only a few instances where any statistical differences between transgenic and nontransgenic field crops could be detected. Obrycki et al. (2001) generated a summary of 16 laboratory and field studies that dealt with nontarget, that is, natural enemy effects, because of exposure to Bt corn. Of those 16 studies, 3 showed negative effects, 2 showed positive effects, and the remainder showed neutral effects on specific natural enemies. Our study reflected similar trends, with most interactions between arthropods and transgenic crops benign. In specific instances transgenic crops were associated with significantly lower *Chrysopa* spp., rove beetle, and soil mite populations but not *Orius* spp. populations, which were higher in transgenic fields. There

Table 1. The total number of soil inhabiting mites extracted from *B. thuringiensis* (Bt) and non-Bt transgenic cornfields, Roundup Ready® (RR) and non-RR soybean fields listed by county

County	Bt corn	Non-Bt corn	RR soybeans	Non-RR soybeans
Champaign[a]	207	116	75	242
Clark	196	201	321	377
Darke	77	71	229	105
Miami[b]	295	181	486	259
Van Wert	70	53	96	131
Wood	16	22	99	79
Mean	123	92	187	170

[a] Paired soybean fields significantly different ($F = 11.66$; df 1,4; $P = 0.027$).

[b] Paired soybean fields nearly significantly different ($F = 6.53$; df = 1,4; $P = 0.063$).

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Table 2. ***B. thuringiensis*** **(Bt) corn, non-Bt corn, Roundup Ready® (RR) soybeans, and non-RR soybean field survey locations and pesticide records. Transgenic fields are paired in the table according to their pairing in the study**

County location	Field description	Acreage	Pesticide used
Champaign	RR Soybean	35	Roundup (41% glyphosate)
Champaign	Non-RR soybean	55	Backdraft (2.8% Imazaquin, 14.1% glypohosate) 2,4 D Ester Select (12.6% Clethodim) Roundup (41% glyphosate) Firstrate (84% Cloransulam-methyl)
Clark	RR soybean	19.4	Roundup (41% glyphosate)
Clark	Non-RR soybean	59.1	Pinnacle (25% Thifensulfuron methyl) Fusion (24.15% Fluazifop-P-butyl, 6.76% Fenoxaprop-p-ethyl) Reflex (22.8% Fomesafen sodium) Basagran (44% Bentazon) Firstrate (84% Cloransulam-methyl)
Darke	RR soybean	17	Roundup (41% glyphosate)
Darke	Non-RR soybean	16.5	Roundup (41% glyphosate) Synchrony (31.8% Chlorimuron ethyl, 10.2% Thifensulfuron methyl)
Miami	RR soybean	35	Roundup (41% glyphosate)
Miami	Non-RR soybean	37	Synchrony (31.8% Chlorimuron ethyl, 10.2% Thifensulfuron methyl) Select (12.6% Clethodim)
Van Wert	RR soybean	57	Roundup (41% glyphosate)
Van Wert	Non-RR soybean	82	Canopy XL (46.9% Sulfentrazone, 9.4% Chlorimuron ethyl) Sencor (50% Metribuzin) Command (44.4% Clomozone)
Wood	RR soybean	14	2,4, D Ester, Roundup (41% glyphosate)
Wood	Non-RR soybean	26	Touchdown (48.6% Glyphosate-trimesium) 2,4,D Ester Raptor (12.1% Imazamox) Firstrate (84% Cloransulam-methyl)
Champaign	Bt corn	40	Pounce (38.4% Permethrin) Bicep (35.6% Metolachlor, 28.9% Atrazine)
Champaign	Non-Bt RR corn	35	Harness Xtra (46.3% Acetochlor, 18.3% Atrazine)
Clark[a]	Bt corn/non-Bt corn	50.5	Lorsban 15G (15% Chlorpyrifos) Princep (41.9% Simazine) Bicep (35.6% Metolachlor, 28.9% Atrazine) Accent (51.7% Clopyralid, triethylamine salt, 19.1% Flumetsulam, 6.5% Nicosulfuron, 6.5% Rimsulfuron) Spirit (42.8 Primisulfuron-methyl, 14.2% Prosulfuron)
Darke	Bt corn	30	Harness Xtra (46.3% Acetochlor, 18.3% Atrazine)
Darke	Non-Bt corn	17.5	Bicep (35.6% Metolachlor, 28.9% Atrazine)
Hancock	Bt corn	40	Northstar (43.9% Dicamba, 7.5% Primisulfuron-methyl)
Hancock	Non-Bt corn	13	Northstar (43.9% Dicamba, 7.5% Primisulfuron-methyl)
Miami	Bt corn	18	Bicep (35.6% Metolachlor, 28.9% Atrazine)
Miami	Non-Bt corn	10	Bicep (35.6% Metolachlor, 28.9% Atrazine)
Van Wert	Bt corn	13	Bicep II Magnum (33% Atrazine, 26.1% Metolachlor) Atrazine
Van Wert	Non-Bt corn	50	Bicep II Magnum (33% Atrazine, 26.1% Metolachlor) Atrazine Distinct (55% Dicamba, 21.4% Diflufenzopyr-sodium)

[a] One large field split planted half to Bt, half to non-Bt corn.

may be generalist or specialist predators or parasitoids that our collection methods failed to detect, therefore we cannot comment on how those populations might be influenced by transgenic crops.

Weed populations in these fields are a major consideration affecting arthropod populations in soybean fields and can contribute greatly to the variation of certain species, such as insidious flower bugs (*Orius* sp.) and damsel bugs (Buckelew et al. 2000). Informal notes on weed species and abundance were taken on fields surveyed, but no clear relationship between weed density and arthropod abundance could be established.

Although there were no statistically significant differences in the data collected between sticky traps in paired transgenic and nontransgenic soybean fields at the same site, populations of *Chrysopa* spp. adults pooled across all soybean fields in the study were significantly higher in nontransgenic soybean fields. With the introduction of soybean aphid (*Aphis glycines* Matsumura) in late 2000 to soybean fields in Ohio, an increase in the number of generalist aphid

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predators should be expected. If the soybean aphid develops a preference for either transgenic or nontransgenic soybeans or is negatively affected by post applications of glyphosate or other herbicides, a corresponding shift in the predator and parasitoid populations may be seen in those fields.

Although both fields were treated with different herbicides, permethrin was applied to the Bt cornfield in Champaign county in the spring to control black cutworm, *Agrotis ipsilon* (Hufnagel). A statistically greater number of rove beetles were captured on sticky traps in the paired non-Bt untreated field. This suggests the increased capture of rove beetles in the non-Bt field may be an artifact of the insecticide application rather than some factor related to the transgenic nature of the hybrid. Curiously, the non-Bt corn hybrid planted in Champaign county was also RR, but did not receive any glyphosate herbicide. Another pair of Bt and non-Bt cornfields in Clark county were both treated with chlorpyrifos at planting, but no unequal effects were observed on nontarget arthropods in sticky traps, sweep net, or soil extraction samples. Both Bt and non-Bt cornfields in Hancock county were treated with the exact same herbicide and no insecticide, yet there was an increase in the number of *Orius* spp. in the transgenic field. A difference in the aphid populations between any of these fields was not noted. The remaining cornfields in the study were not treated with an insecticide.

With the reduction of *Ostrinia nubilalis* larval hosts because of the lethal effects of Bt, it might be reasonable to expect a decline of specific parasitoids (Pilcher 1999). There were over 2,000 parasitoid wasps collected in nontransgenic cornfields, ≈100 more than in transgenic cornfields. It was surprising to find only minimal numerical differences between parasitoid populations of Bt and conventional corn hybrids in this study.

The focus of this work was on select arthropods above the soil line with the exception of mites extracted from soil samples. It is important to investigate any transgenic affects on micro-invertebrates, earthworms, nematodes, bacteria, protozoa, fungi, or other similar taxa in the soil, but we did not address their abundance or distribution in this survey. Saxena and Stotzky (2001) did not comment on the effects of Bt corn exudates on soil mite communities, however, they found no evidence that such exudates harm earthworms, nematodes, bacteria, protozoa, or fungi. Although not soil dependent, a laboratory study by Lozzia et al. (2000) found no significant differences between time of development, survival rates, and the number of eggs laid between spider mites (*Tetranychus urticae*) fed Bt and non-Bt corn plants.

The basic function of Bt corn hybrids is to suppress Lepidopteran pest populations. The primary function of glyphosate resistant soybean and corn hybrids is weed control. There is some evidence to suggest both transgenic soybean and corn hybrids can affect soil or canopy fauna either directly or indirectly through altered plant chemistry, prey abundance, or changed cultural practices (Hoy et al. 1998, Hammond and Stinner 1999). Based on the data collected from sweep net, sticky trap, and soil extractions in this study, few negative impacts on nontarget arthropods can be directly associated with the production of transgenic soybean or corn crops in Ohio.

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References Cited

Ahn, Y. J., J. R. Cho, Y. J. Kim, J. K. Yoo, and J. O. Lee. 1997. Toxicity of the herbicide glufosinate-ammonium to *Tetranychus urticae* (Acari: Tetranychidae) under laboratory and field conditions. Pestic. Sci. 51: 455–461.

Bacheler, J. S. 1999. Pest fluctuations and trends in North Carolina cotton, pp. 1028–1031. *In* P. Dugger and D. Richter [eds.], Proceedings, Beltwide Cotton Conference, 3–7 January 1999, Orlando, FL. National Cotton Council of America, Memphis, TN.

Birch, A.N.E., I. E. Geoghegan, M.E.N. Majerus, J. W. McNichol, C. A. Hackett, A.M.R. Gatehouse, and J. A. Gatehouse. 1999. Tri-trophic interactions involving pest aphids, predatory 2-spot ladybirds and transgenic potatoes expressing snowdrop lectin for aphid resistance. Molec. Breed. 5: 75–83.

Buckelew, L., L. Pedigo, H. Mero, M. Owen, and G. Tylka. 2000. Effects of weed management systems on canopy insects in herbicide resistant soybeans. J. Econ. Entomol. 93: 1437–1443.

Cannon, R. J. 2000. Bt transgenic crops: risks and benefits. Integrated Pest Manag. Rev. 5: 151–173.

Cui, J. J., and J. Y. Xia. 1999. Effect of transgenic Bt cotton on the population dynamics of natural enemies. Acta Goss. Sin. 11: 84–91.

Eijsackers, J. 1985. Effects of glyphosate on the soil fauna, pp. 151–158. *In* E. Grossard and D. Atkinson [eds.], The Herbicide Glyphosate. Buttersworth, London, UK.

Flint, H. M., T. J. Henneberry, F. D. Wilson, E. Holguin, N. Parks, and R. E. Buehler. 1995. The effects of transgenic cotton, *Gossypium hirsutum* L., containing *Bacillus thuringiensis* toxin genes for the control of the pink bollworm, *Pectinophora gossypiella* (Saunders) and other arthropods. Southwest Entomol. 20: 281–292.

Hammond, R. B. and B. R. Stinner. 1999. Impact of tillage systems on pest management, pp. 693–712. *In* J. R. Ruberson [ed.], Handbook of Pest Management. Marcel Dekker, New York

Hilbeck, A., W. J. Moar, M. Pusztai-Carey, A. Filippini, and F. Bigler. 1998a. Toxicity of *Bacillus thuringiensis* Cry1Ab toxin to the predator *Chrysoperla carnea* (Neuroptera:Chrysopidae). Environ. Entomol. 27: 1255–1263.

Hilbeck, A., M. Baumgartner, P. M. Fried, and F. Bigler. 1998b. Effects of transgenic *Bacillus thuringiensis* cornfed prey on mortality and development time of immature *Chrysoperla carnea* (Neuroptera: Chrysopidae). Environ. Entomol. 27: 480–487.

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Hoy, C., J. Feldman, F. Gould, G. Kennedy, G. Reed, and J. Wyman. 1998. Naturally occurring biological controls in genetically engineered crops, pp. 185–205. *In* P. Barbosa [ed.], Conservation Biological Control. Academic, San Diego, CA.

Lozzia, G., C. Furlanis, C. Manachini, B., 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.

Lozzia, G. C. 1999. Biodiversity and structure of ground beetle assemblages (Coleoptera Carabidae) in Bt corn and its effects on non target insects. Boll. Zool. Agrar. Bachic. 31: 37–50.

Lozzia, G. C., I. E. Rigamonti, B. Manachini, and R. Rocchetti. 2000. Laboratory studies on the effects of transgenic corn on the spider mite (*Tetranychus urticae*) Koch. Boll. Zool. Agrar. Bachic. 32: 35–47.

Minitab statistical software. 2000. Version 13.2, State College, PA.

Manachini, B., M. Agosti, I. Rigamonti, and M. Trevisan. 1999. Environmental impact of Bt-corn on non target entomofauna: synthesis of field and laboratory studies, pp. 873–882. *In* A. M. Del-Re, C. Brown, E. Capri, G. Errera, and S. P. Evans, [eds.], Proceedings, XI Symposium Pesticide Chemistry, 11–15 September, 1999, Cremona, Italy. La Goliardica Pavese s. r. l., Pavia, Italy.

[NASS]National Agricultural Statistics Service. 2001. Crop Production Acreage supplement. Agricultural Statistics Board, U.S. Department of Agriculture. June 29, pp. 26–27.

Obrycki, J. J., J. E. Losey, O. R. Taylor, and L.C.H. Jesse. 2001. Transgenic insecticidal corn: beyond insecticidal toxicity to ecological complexity. BioScience 51: 353–361.

Pilcher, C. D. 1999. Phenological, physiological, and ecological influences of transgenic Bt corn on European corn borer management. Ph.D. dissertation. Iowa State University, Ames, IA.

Pilcher, C. D., J. J. Obyrcki, 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.

Saxena, D., and G. Stotzky. 2001. *Bacillus thuringiensis* (Bt) toxin released from root exudates and biomass of Bt corn has no apparent effect on earthworms, nematodes, protozoa, bacteria, and fungi in soil. Soil Biol. Biochem. 33: 1225–1230.

Schuler, T., G. Poppy, B. Kerry, and I. Denholm. 1999. Potential side effects of insect-resistant transgenic plants on arthropod natural enemies. Trends Biotechnol. 17: 210–216.

Searle, G. G., D. R. Penman, and R. B. Chapman. 1990. The toxicity of herbicides to the gorse spider mite *Tetranychus lintearius,* pp. 178–181. Proceedings, Forty Third New Zealand Weed and Pest Control Conference, Entomology Department, Lincoln University, Canterbury, New Zealand.

Sims, S. R. 1995. *Bacillus thuringiensis* var. kurstaki (CryIA (C)) protein expressed in transgenic cotton: effects on beneficial and other non-target insects. Southwest Entomol. 20: 493–500.

Van-Tol, N. B., and G. L. Lentz. 1998. Influence of Bt cotton on beneficial arthropod populations, pp. 1052–1054. Proceedings, Beltwide Cotton Conference, 5–9 January 1998, San Diego, CA. National Cotton Council of America, Memphis, TN.

Volkmar, C., T. Wetzel, M. L. Hussein, D. Jany, and L. Richter. 1999. Ecological studies accompanying the cultivation of transgenic maize plants in Friemar (Free State of Thuringia) from 1994 to 1996. Arch. Phytopathol. Plant Prot. 32: 291–335.

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