Assessing the Impact of Reduced Rates of Spinosad and Permethrin on the Lepidopteran Pest Complex, and Associated Parasitoids, in Minnesota Cabbage

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ABSTRACT Field studies were conducted in 1996 and 1997 to evaluate the effect of spinosad (Spintor™ 2SC, Dow AgroSciences, Indianapolis, IN) on the lepidopteran pest complex, and parasitism by several parasitoid species on fresh-market cabbage. In all studies, spinosad was compared to permethrin (Pounce® 3.2E, FMC Corp. Philadelphia, PA), a standard synthetic pyrethroid used in the Midwestern United States. Spinosad and permethrin were applied at full and reduced rates throughout each growing season. Percentage parasitism and Hill's *N*1 were calculated for each treatment. There was no consistent affect of any rate of spinosad or permethrin, for percent larval parasitism of imported cabbageworm, *Pieris* (=*Artogeia*) *rapae* (Linnaeus), or the cabbage looper, *Trichoplusia ni* (Hübner). However, spinosad applied at a reduced rate, allowed for significantly higher percent parasitism of diamondback moth, *Plutella xylostella* (Linnaeus), than permethrin. Hill's did not consistently differ among any spinosad or permethrin-treated plots. Both yield and marketability were not affected by reduced rates of spinosad or permethrin. In addition, all of the reduced-rates for spinosad or permethrin treatments yielded similar marketability ratings of fresh-market cabbage as did the full rates for each insecticide. Although most reduced-rate spinosad and permethrin treatments were effective against the pest complex, a 50% reduction of the highest labeled rate of spinosad provided the most consistent control overall, for each of the three pest species, and a high level of parasitism. Results from this study suggest that spinosad can be an integral component of a biologically-based IPM system for cabbage.

KEY WORDS : Biological control, integrated pest management, parasitoid, spinosad

INTRODUCTION

The cabbage looper, *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae), imported cabbageworm, *Pieris* (=*Artogeia*) *rapae* (Linnaeus) (Lepidoptera: Pieridae), and diamondback moth, *Plutella xylostella* (Linnaeus) (Lepidoptera: Plutellidae), are the three most common insect pests of cabbage in Minnesota (Hutchison *et al*., 2004). Although cabbage production in Minnesota is relatively low, with ca. 500 ha produced annually (Noetzel *et al*., 1985; Subramanyam *et al*., 1996), it is valued at over US $10,000 per ha (Eastman *et al*., 1995). Because of the high value of the crop, coupled with the low tolerance for insect damage, growers commonly make four to seven applications of insecticide throughout the season to produce high quality cabbage (Ciborowski *et al*., 2002). Growing concerns about pesticide residues on fresh and processed vegetables have motivated growers to seek alternatives to conventional pesticides. In the past, growers have

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relied heavily on the use of *Bacillus thuringiensis* (*Bt*) (Locke *et al.*, 1997) as well as conventional insecticides (Hutchison and Burkness, 1999). However, complete reliance on *Bt* has led to the development of *Bt* resistance in field populations of *P. xylostella* (Tabashnik *et al.*, 1990; Shelton *et al.*, 1993; Iqbal *et al.*, 1996), while conventional insecticides are disruptive to natural enemy populations (Croft, 1989). In addition, most *Bt* formulations have not provided consistent control of *T. ni*, the key economic pest of cabbage in Minnesota (Hutchison *et al.*, 1993).

The biological insecticide, spinosad (Spintor™ 2SC, Dow AgroSciences, Indianapolis, IN), has provided growers with a promising alternative to *Bt* and conventional pesticides (Sparks *et al.*, 1998; Liu *et al.*, 1999). Spinosad is a combination of metabolites spinosyn A and spinosyn D, that are tetracyclic-macrolide compounds produced by an actinomycete bacterium, *Saccharopolyspora spinosa* Mertz & Yao (Sparks *et al.*, 1998). Preliminary studies have shown spinosad to be effective on a wide range of insects, including economically important pests within the Lepidoptera, Coleoptera, Diptera, and Thysanoptera (Bret *et al.*, 1997; Thompson *et al.*, 2000). In addition, the introduction of spinosad also offered the promise of being less harmful to beneficial insects (Thompson *et al.*, 2000). From 1991-2003, over 20 parasitoid species were recovered from the lepidopteran pest complex in Minnesota cabbage (Hutchison *et al.*, 1993; Wold-Burkness *et al.*, 2005). Because cabbage harbors a diversity of natural enemies, including parasitoids and generalist predators (Oatman, 1966; Weires and Chiang, 1973), coupled with the increased efficacy of spinosad against *T. ni* (Bret *et al.*, 1997; Hines and Hutchison, 2001), we pursued research to assess the impact of spinosad on parasitoids of the lepidopteran pest complex. Sublethal effects of spinosad on natural enemies were recently reviewed (Williams *et al.*, 2003), and one study concluded that spinosad negatively affected *Diadegma insulare* (Cresson), an important parasitoid of *P. xylostella* (Hill and Foster, 2003). However, there continues to be limited information regarding the overall impact of spinosad on both field level control of the entire lepidopteran pest complex, as well as field level effects on overall parasitism by a diversity of species. Thus, the objectives of this study were to assess the potential for reduced rates of spinosad to provide enhanced levels of biological control compared to the synthetic pyrethroid, permethrin, and to assess the efficacy of reduced rates of spinosad for lepidopteran control.

MATERIALS AND METHODS

Cabbage, *Brassica oleracea* var. *capitata* L. 'Gourmet', was transplanted bare-root using a mechanical transplanter on 27 June, 1996 and 17 June, 1997 at the University of Minnesota Agricultural Experiment Station, near Rosemount, Minnesota. Plots consisted of four 7.6 m rows, 102 cm apart, with a plant spacing of 33 cm. Each plot was separated by 3.0 m borders. The plots were arranged in a randomized complete block design and replicated four times. Treatments were applied on a seven to 15 day schedule (1996 treatment dates: 26 July, 8 August, and 3 September; 1997 treatment dates: 15 July, 30 July, and 4 August). Ten treatments were included and consisted of the following: 1) 0.10 kg AI/ha spinosad (100% of the maximum labeled rate); 2) 0.091 kg AI/ha permethrin (100% of the maximum labeled rate) (Pounce® 3.2E, FMC Corp. Philadelphia, PA); 3) 0.075 kg AI/ha spinosad (75% of the maximum labeled rate); 4) 0.068 kg AI/ha permethrin (75% of the maximum labeled rate); 5) 0.050 kg AI/ha spinosad (50% of the maximum labeled rate); 6) 0.045 kg AI/ha permethrin (50% of the maximum labeled rate); 7) 0.025 kg AI/ha spinosad (25% of the maximum labeled rate); 8) 0.023 kg AI/ha permethrin (25% of the maximum labeled rate); 9 &10) untreated check plots. Bond sticker/extender was added to all treatments at a rate of 0.8 ml/l (0.10 fl oz/gal). A high-clearance Spirit sprayer with three TX-10 hollow-cone nozzles (one overhead and two drop nozzles per row) was used. The sprayer was calibrated to deliver 252.5 l/ha (27 gpa) at 380 kpa (55 psi) and 4.8 kph (3 mph). Weather data were collected throughout the growing season.

Treatment effects on the pest complex were measured by randomly sampling plants for *P. rapae*, *T. ni*, and *P. xylostella*. Numerical counts of eggs, larvae, and pupae of *P. rapae* and *T. ni* were recorded. Only larvae and pupae of *P. xylostella* were recorded. Whole plants were sampled twice each week (n=80 plants/week) from two rows of each plot in 1996 (from 12 July to 11 September) and 1997 (from 26 June to 2 September).

The impact of each treatment on the parasitoid complex was measured by collecting larvae and pupae of each lepidopteran host. At peak larval populations for each pest, late instar larvae and/or pupae were collected (maximum of 10 larvae and/or pupae per insect per plot) from the two previously unsampled rows. Larvae, with cabbage leaf tissue, and pupae were placed in 29 ml plastic cups (Bio-Serv, Frenchtown, New Jersey), held in a cooler, then transferred to the laboratory and held at ≈25°C for parasitoid emergence, following the methods of Wold-Burkness *et al*., (2005). All emerged parasitoids were identified and voucher specimens of each were placed in the Insect Collection of the Department of Entomology, University of Minnesota (*see also* Wold-Burkness *et al*., 2005).

At the time of harvest (11 September, 1996 and 2 September, 1997), 10 heads of cabbage were randomly selected from the two sampled rows of each plot (n=40 heads/treatment). Each head plus four-wrapper leaves closest to the head were weighed and evaluated for feeding damage and marketability. Marketability was quantified using the rating scale of Greene *et al*. (1969): 1=no apparent insect feeding; 2=minor insect feeding on wrapper or outer leaves, 0-1 per cent leaf area eaten; 3=moderate insect feeding on wrapper or outer leaves with no head damage, 2-5 per cent leaf area eaten; 4=moderate insect feeding on wrapper or outer leaves with minor feeding on head, 6-10 per cent leaf area eaten; 5=moderate to heavy feeding on wrapper and head leaves and a moderate number of feeding scars on head, 11-30 per cent of leaf area eaten; 6=considerable insect feeding on wrapper and head leaves with head having numerous feeding scars, over 30 per cent of leaf area eaten. Marketability ratings of < 3 are considered marketable (Hines and Hutchison, 2001).

Statistical Analysis

Host larval populations were summarized using insect-days, which combines insect numbers and time to express insect intensity and duration (Ruppel, 1983). Insect days were calculated for all larval instars of *P. rapae*, *T. ni*, and *P. xylostella*. Data were analyzed using a one-way ANOVA and Fisher's protected least significant difference (LSD) test (P = 0.05) (SAS Institute, 1999).

Marketability data were transformed using the RANK procedure (nonparametric) (SAS Institute, 1999) to account for the non-normal distribution of rating scale data. Conover and Iman (1981) have found that for non-normal populations the multiple comparisons procedure is more robust and has more power when rank-transformed data are used. Transformed data were analyzed with Fisher's protected LSD.

Total per cent parasitism and per cent parasitism by each species was estimated for each treatment. Data were transformed for proportions (ARCSIN), and analyzed using a one-way ANOVA and Fisher's protected LSD test (P = 0.05) (SAS Institute, 1999). In addition, we used Shannon's index (eq. 1), where H' is the average uncertainty per parasitoid species in a community made up of s* species with known proportional abundances (p_i), to determine Hill's $N1$ (eq. 2), which measures the number of abundant species for a given year (Ludwig and Reynolds, 1988; Wold *et al*., 2001), and analyzed those values with Fisher's protected LSD.

$$H' = -\sum_{i=1}^{s^*} (p_i \ln p_i) \quad (1)$$

$$N1 = e^{H'} \quad (2)$$

RESULTS

Oviposition by *T. ni* and *P. rapae* for different treatments using either insecticide was similar across all plots. Abundance of *P. rapae* eggs was not affected by treatment during either year (1996: P=0.166; F=1.64; df=8,3; LSD=4.03; 1997: P=0.169; F=1.63; df=8,3; LSD=0.537). In 1997, the densities of *T. ni* eggs were not affected by either insecticide (P=0.169; F=1.63; df=8,3; LSD=0.537). In 1996, however, density of *T. ni* eggs was significantly affected by treatment, in particular, spinosad applied at the highest rate (0.10 kg AI/ha) resulted in the fewest *T. ni* eggs

(=0.00±10.00d; P=0.007; F=3.59; df=8,3; LSD=0.235).

All treatments performed equally well in reducing the larval population of *T. ni* and *P. rapae*. With the exception of *T. ni* in 1997, analysis of insect-days, which integrates larval density over the entire season, showed no differences among the rates of spinosad and permethrin, but all treatments pro-

Table 1. Mean insect-days (±SEM) for *P. rapae*, *T. ni*, and *P. xylostella* larvae, Rosemount, MN

	T. ni		*P. rapae*		*P. xylostella*	
Treatment (kg AI/ha)	1996	1997	1996	1997	1996	1997
Spinosad 0.10	31.00 ± 3.70bc	101.00 ± 9.98c	113.00 ± 26.08cde	91.00 ± 26.24b	28.25 ± 5.61b	17.75 ± 6.98b
Spinosad 0.075	25.50 ± 10.31c	117.50 ± 13.67bc	173.50 ± 46.05bc	54.50 ± 12.45cde	39.00 ± 8.02b	11.63 ± 2.39b
Spinosad 0.050	32.00 ± 9.35bc	127.50 ± 7.50bc	169.00 ± 29.42bcd	82.50 ± 15.65cde	58.63 ± 17.50b	29.88 ± 20.86b
Spinosad 0.025	47.00 ± 12.48b	156.50 ± 24.70c	197.50 ± 33.47b	69.00 ± 9.81bcd	43.88 ± 0.85b	29.25 ± 5.01b
Permethrin 0.091	16.00 ± 3.56c	50.50 ± 11.30d	83.00 ± 12.40e	24.50 ± 8.66e	27.25 ± 7.23b	10.50 ± 4.62b
Permethrin 0.068	26.00 ± 3.74c	118.00 ± 19.54bc	100.00 ± 24.58de	28.00 ± 4.24e	25.63 ± 7.34b	12.38 ± 2.46b
Permethrin 0.045	34.00 ± 3.56bc	93.00 ± 5.80cd	104.00 ± 24.73cde	43.50 ± 10.47de	38.50 ± 4.14b	17.25 ± 8.04b
Permethrin 0.023	51.00 ± 9.00b	98.50 ± 21.36cd	115.00 ± 23.63cde	31.50 ± 7.80e	42.50 ± 13.97b	18.38 ± 8.26b
Untreated check	111.50 ± 16.90a	316.25 ± 23.40a	670.00 ± 72.95a	167.25 ± 24.37a	332.06 ± 48.87a	136.56 ± 38.16a
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.001	<0.001
F	16.90	20.82	54.15	13.85	34.87	7.33
Df	8,3	8,3	8,3	8,3	8,3	8,3
LSD	20.12	48.08	72.82	35.25	48.72	43.148

Means within a column followed by the same letter are not significantly different (*P*>0.05); Fisher's protected least significant difference test (LSD).

Table 2. Impact of reduced rates of spinosad and permethrin on cabbage marketability and yield per one cabbage head, Rosemount, MN

Treatment	1996			1997		
(kg AI/ha)	Marketability Rating[1]	Weight (kg)	Contaminants[2]	Marketability Rating[1]	Weight (kg)	Contaminants[2]
Spinosad 0.10	2.18 ± 0.12cd (13.50)	2.01 ± 0.25	0.00 ± 0.00b	2.42 ± 0.25bc (22.38)	2.28 ± 0.04a	0.18 ± 0.09abc
Spinosad 0.075	2.65 ± 0.44bcd (18.50)	1.73 ± 0.05	0.05 ± 0.03b	2.40 ± 0.07bc (21.88)	2.31 ± 0.03a	0.08 ± 0.08bc
Spinosad 0.050	3.08 ± 0.22ab (26.25)	1.70 ± 0.10	0.03 ± 0.03b	2.48 ± 0.17bc (22.88)	2.28 ± 0.14ba	0.13 ± 0.06abc
Spinosad 0.025	3.00 ± 0.31abc (24.75)	1.81 ± 0.07	0.00 ± 0.00b	2.78 ± 0.32ab (26.13)	2.44 ± 0.10ab	0.25 ± 0.06ab
Permethrin 0.091	1.80 ± 0.28d (8.25)	2.05 ± 0.21	0.03 ± 0.03b	1.45 ± 0.16e (7.13)	2.51 ± 0.04a	0.00 ± 0.00c
Permethrin 0.068	2.10 ± 0.21d (10.88)	1.93 ± 0.14	0.03 ± 0.03b	1.58 ± 0.17de (9.50)	2.49 ± 0.05a	0.00 ± 0.00c
Permethrin 0.045	2.30 ± 0.23bcd (15.36)	1.94 ± 0.10	0.08 ± 0.05b	1.30 ± 0.07e (4.88)	2.46 ± 0.08a	0.03 ± 0.03c
Permethrin 0.023	2.28 ± 0.25cd (14.50)	1.74 ± 0.08	0.05 ± 0.05b	2.08 ± 0.25cd (17.38)	2.48 ± 0.05a	0.03 ± 0.03c
Untreated check	4.63 ± 0.08a (34.50)	1.83 ± 0.06	0.55 ± 0.11a	3.90 ± 0.24a (34.38)	2.25 ± 0.07a	0.35 ± 0.20a
P	0.002	0.548	0.001	<0.001	0.093	0.028
F	4.52	0.88	11.36	11.19	1.98	2.70
Df	8,3	8,3	8,3	8,3	8,3	8,3
LSD	(11.579)	0.394 NS[3]	0.134	(8.465)	0.218	0.2455

Marketable heads were transformed using the arcsine transformation, head marketability ratings were transformed using a RANK procedure, and contaminant counts were transformed using the square root transformation to obtain mean separations Fisher's protected least significant difference test (LSD); both untransformed means and transformed means, in Parenthesis, are presented; LSD values for transformed means, in Parenthesis.

[1]Marketability rating based on Greene *et al.*, 1969.

[2] Number of larvae and/or pupae of one or more pest species.

[3] Not significant

vided significant larval control compared to the untreated control plots (Table 1). Both yield and the number of insect contaminants were similar across most treatments in 1996 and 1997 (Table 2). However, in 1996, plots treated with 0.050 kg and 0.025 kg AI/ha of spinosad had a significantly worse marketability rating in comparison to the full rate of spinosad (Table 2). Despite the differences in ratings, all treatments, with the exception of the untreated check, were considered highly marketable, because marketability ratings of 1-3 are acceptable. In 1997, all treatments, with the exception of spinosad applied at 0.025 kg AI/ha, had marketability ratings that were significantly lower than the untreated check plots, and all treatments were considered highly marketable (Table 2).

A total of eight parasitoid species were recovered from *T. ni*, including *Compsilura concinnata* (Meigen), *Voria ruralis* (Fallen) (Diptera: Tachinidae), *Itoplectis conquisitor* (Say), *Stenichneumon culpator cincticornis* (Cresson), *Iseropus stercorator orgyiae* Ashmead, *Gambrus ultimus* (Cresson), *Vulgichneumon brevicinctor* (Say) (Hymenoptera: Ichneumonidae), and *Copidosoma floridanum* (Ashmead) (Hymenoptera: Encyrtidae). Five parasitoids were recovered from *P. rapae* and include, *Phryxe pecosensis* (Townsend), *C. concinnata* (Diptera: Tachinidae), *Cotesia glomerata* (Linnaeus) (Hymenoptera: Braconidae), *Pteromalus puparum* (Linnaeus) (Hymenoptera: Eulophidae), and *I. conquisitor*. *P. xylostella* parasitoids include *Diadegma insulare* (Cresson), *Diadromus* sp. (Hymenoptera: Ichneumonidae), *Microplitis plutellae* Muesebeck (Hymenoptera: Braconidae), and *Tetrastichus* sp. (Hymenoptera; Eulophidae).

In 1996, total percent parasitism and percent parasitism by species did not differ significantly among treatments for *T. ni*, and total percent parasitism across all treatments was low (Table 3). In particular, spinosad applied at 0.10 and 0.025 kg AI/ha, and permethrin applied at 0.091 and 0.045 kg AI/ha resulted in zero per cent parasitism of *T. ni* (Table 3). Although *C. floridanum* and *C. concinnata* were the most abundant parasitoids, *C. floridanum* was only present in the untreated plots and plots treated with 0.050 kg AI/ha of spinosad. Total percent parasitism of *P. rapae* did not differ among treatments (Table 4). *P. pecosensis* and *P. puparum* were the most abundant parasitoids, and were present in all plots,

Table 3. Overall parasitism and the relative contributors of each parasitoid species to the overall parasitism rate of the cabbage looper, *T. ni*, in each treatment, Rosemount, MN, 1996

Treatment (kg AI/ha)	Total percent parasitism	Species of parasitoids recovered from *T. ni* (%)				
		C. floridanum	*C. concinnata*	*S.c. cinctornis*	*I. orgyiae*	*V. ruralis*
Spinosad 0.10	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Spinosad 0.075	4.0 ± 4.0	0.0 ± 0.0b	4.0 ± 4.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Spinosad 0.050	4.0 ± 3.0	1.0 ± 1.0b	0.0 ± 0.0	0.0 ± 0.0	3.0 ± 3.0	0.0 ± 0.0
Spinosad 0.025	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Permethrin 0.091	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Permethrin 0.068	7.0 ± 6.0	0.0 ± 0.0b	0.0 ± 0.0	6.0 ± 6.0	0.0 ± 0.0	1.0 ± 1.0
Permethrin 0.045	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0	0.0 ± 0.0	0.0a ± 0.0	0.0 ± 0.0
Permethrin 0.023	3.0 ± 2.0	0.0 ± ±0.0b	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 2.0	1.0 ± 1.3
Untreated check	8.0 ± 2.0	4.00 ± 1.00a	3.0 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.6
P	0.327	<0.001	0.334	0.445	0.552	0.619
F	1.18	5.01	1.17	1.00	0.86	0.78
Df	8,3	8,3	8,3	8,3	8,3	8,3
LSD	8.09	1.86	4.07	5.89	3.10	1.68
	NS[1]		NS	NS	NS	NS

Means within a column followed by the same letter are not significantly different (P>0.05); Fisher's protected least significant difference test (LSD). Data were transformed by arcsin; untransformed means are presented.

[1] Not significant

Table 4. Overall parasitism and the relative contributors of each parasitoid species to the overall parasitism rate of the imported cabbage worm, *P. rapae* in each treatment, Rosemount, MN, 1996

		Species of parasitoids recovered from *P. rapae* (%)				
Treatment (kg AI/ha)	Total percent parasitism	*P. pecosensis*	*C. concinnata*	*I. conquisitor*	*C. glomerata*	*P. puparum*
Spinosad 0.10	4.0 ± 2.0	2.0 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 2.0
Spinosad 0.075	12.0 ± 4.0	11.0 ± 3.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 1.0
Spinosad 0.050	9.0 ± 2.0	5.0 ± 2.0	1.0 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	3.0 ± 2.0
Spinosad 0.025	5.0 ± 3.0	3.0 ± 2.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	3.0 ± 2.0
Permethrin 0.091	6.0 ± 3.0	5.0 ± 2.0	0.0 ± 0.0	1.0 ± 1.0	0.0 ± 0.0	0.0 ± 0.0
Permethrin 0.068	12.0 ± 5.0	11.0 ± 5.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 1.0
Permethrin 0.045	13.0 ± 6.0	10.0 ± 5.0	1.0 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.0
Permethrin 0.023	13.0 ± 5.0	5.0 ± 3.0	1.0 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	8.0 ± 4.0
Untreated check	19.0 ± 4.0	9.0 ± 2.0	2.0 ± 1.0	1.0 ± 1.0	1.0 ± 1.0	7.0 ± 2.0
P	0.267	0.148	0.389	0.505	0.441	0.078
F	1.27	1.56	1.07	0.92	1.00	1.84
Df	8,3	8,3	8,3	8,3	8,3	8,3
LSD	11.71	8.40	2.05	0.98	0.55	5.36
	NS[1]	NS	NS	NS	NS	NS

Means not significantly different (P>0.05); Fisher's protected least significant difference test (LSD). Data were transformed by arcsin; untransformed means are presented.
[1] Not significant

with the exception of *P. puparum* in plots treated with 0.091 kg AI/ha of permethrin (Table 4). *C. glomerata* was only recovered from the untreated check plots. Total percent parasitism of *P. xylostella* was significantly higher in plots treated with 0.05 and 0.025 kg AI/ha of spinosad (Table 5). In addition, we did not observe any parasitism in any permethrin-treated plots, or plots treated with 0.10 kg AI/ha of spinosad (Table 5). *D. insulare* was the most abundant species recovered from

Table 5. Overall parasitism and the relative contributors of each parasitoid species to the overall parasitism rate of the diamondback moth, *P. xylostella*, Rosemount, MN, 1996

		Species of parasitoids recovered from *P. xylostella* (%)			
Treatment (kg AI/ha)	Total percent parasitism	*D. insulare*	*Diadromus sp.*	*Tetrastichus sp.*	*M. pluttelae*
Spinosad 0.10	0.0 ± 0.0d	0.0 ± 0.0d	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Spinosad 0.075	8.0 ± 8.0cd	8.0 ± 8.0cd	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Spinosad 0.050	22.0 ± 12.0bc	22.0 ± 22.0bc	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Spinosad 0.025	38.0 ± 14.0b	38.0 ± 14.0b	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Permethrin 0.091	0.0 ± 0.0d	0.0 ± 0.0d	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Permethrin 0.068	0.0 ± 0.0d	0.0 ± 0.0d	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Permethrin 0.045	0.0 ± 0.0d	0.0 ± 0.0d	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Permethrin 0.023	0.0 ± 0.0d	0.0 ± 0.0d	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Untreated check	81.0 ± 5.0a	76.0 ± 5.0a	2.0 ± 2.0	2.0 ± 1.0a	0.47 ± 0.47
P	<0.001	<0.001	0.441	<0.001	0.441
F	10.59	9.29	1.00	5.20	1.00
Df	8,3	8,3	8,3	8,3	8,3
LSD	19.53	19.67	1.95	0.82	0.44
			NS[1]		NS

Means within a column followed by the same letter are not significantly different (P>0.05); Fisher's protected least significant difference test (LSD). Data were transformed by arcsin; untransformed means are presented.
[1] Not significant

Table 6. Overall parasitism and the relative contributors of each parasitoid species to the overall parasitism rate of the cabbage looper, *T. ni*, in each treatment, Rosemount, MN, 1997

		Species of parasitoids recovered from *T. ni* (%)						
Treatment (kg AI/ha)	Total percent parasitism	*C. floridanum*	*C. concinnata*	*S.c. cinctornis*	*V. brevicinctor*	*I. conquisitor*	*G. ultimus*	*I. stercorator*
Spinosad 0.10	17.0 ± 6.0d	4.0 ± 3.0	12.0 ± 5.0d	1.0 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Spinosad 0.075	48.0 ± 10.0ab	0.0 ± 0.0	38.0 ± 9.0abc	11.0 ± 5.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Spinosad 0.050	22.0 ± 4.0d	6.0 ± 4.0	12.0 ± 4.0d	3.0 ± 2.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Spinosad 0.025	26.0 ± 6.0d	5.0 ± 3.0	13.0 ± 5.0d	2.0 ± 2.0	5.0 ± 4.0	1.0 ± 1.0	0.0 ± 0.0b	0.0 ± 0.0
Permethrin 0.091	26.0 ± 10.0bcd	0.0 ± 0.0	18.0 ± 9.0bcd	8.0 ± 6.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Permethrin 0.068	57.0 ± 11.0a	0.0 ± 0.0	51.0 ± 12.0a	6.0 ± 6.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Permethrin 0.045	48.0 ± 9.0abc	3.0 ± 2.0	42.0 ± 9.0ab	2.0 ± 2.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Permethrin 0.023	27.0 ± 6.0cd	3.0 ± 2.0	17.0 ± 5.0cd	5.0 ± 2.0	2.0 ± 2.0	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Untreated check	31.0 ± 3.0bcd	3.0 ± 2.0	11.0 ± 2.0d	8.0 ± 3.0	5.0 ± 2.0	3.0 ± 2.0	2.0 ± 1.0a	0.4 ± 0.4
P	0.001	0.4029	<0.001	0.598	0.137	0.232	0.038	0.45
F	3.53	1.05	4.22	0.81	1.59	1.34	2.15	1.00
F	3.53	1.05	4.22	0.81	1.59	1.34	2.15	1.00
LSD	21.65	6.22	20.30	10.40	4.68	2.14	1.20	0.39
		NS[1]		NS	NS	NS		NS

Means within a column followed by the same letter are not significantly different (*P*>0.05); Fisher's protected least significant difference test (LSD). Data were transformed by arcsin; untransformed means are presented.
[1] Not Significant

Table 7. Overall parasitism and the relative contributors of each parasitoid species to the overall parasitism rate of the imported cabbage worm, *P. rapae*, Rosemount, MN, 1997

		Species of parasitoids recovered from *P. rapae* (%)			
Treatment (kg AI/ha)	Total percent parasitism	*P. pecosensis*	*C. concinnata*	*C. glomerata*	*P. puparum*
Spinosad 0.10	30.0 ± 10.0	10.0 ± 6.0a	16.0 ± 8.0	3.0 ± 3.0bcd	0.0 ± 0.0
Spinosad 0.075	37.0 ± 8.0	3.0 ± 3.0ab	31.0 ± 7.0	3.0 ± 3.0bcd	2.0 ± 2.0
Spinosad 0.050	43.0 ± 9.0	3.0 ± 2.0ab	27.0 ± 9.0	12.0 ± 5.0ab	1.0 ± 1.0
Spinosad 0.025	58.0 ± 6.0	2.0 ± 2.0ab	43.0 ± 6.0	11.0 ± .0abc	2.0 ± 2.0
Permethrin 0.091	31.0 ± 16.0	6.0 ± 6.0b	21.0 ± 14.0	0.0 ± 0.0d	4.0 ± 4.0
Permethrin 0.068	25.0 ± 16.0	0.0 ± 0.0b	13.0 ± 13.0	0.0 ± 0.0d	13.0 ± 13.0
Permethrin 0.045	44.0 ± 18.0	0.0 ± 0.0b	31.0 ± 16.0	0.0 ± 0.0d	13.0 ± 13.0
Permethrin 0.023	18.0 ± 9.0	4.0 ± 4.0ab	14.0 ± 9.0	0.0 ± 0.0d	0.0 ± 0.0
Untreated check	50.0 ± 5.0	3.0 ± 2.0ab	27.0 ± .0a	12.0 ± 6.0a	8.0 ± 3.0
P	0.633	0.57	0.744	0.008	0.661
F	0.77	0.84	0.64	2.89	0.73
Df	8,3	8,3	8,3	8,3	8,3
LSD	33.40	10.03	29.01	9.20	17.28
	NS[1]		NS		NS

Means within a column followed by the same letter are not significantly different (*P*>0.05); Fisher's protected least significant difference test (LSD). Data were transformed by arcsin; untransformed means are presented.
[1] Not Significant

Table 8. Overall parasitism and the relative contributors of each parasitoid species to the overall parasitism rate of the diamondback moth, *P. xylostella*, Rosemount, MN, 1997

	Species of parasitoids recovered from *P. xylostella* (%)		
Treatment (kg AI/ha)	Total percent parasitism	*D. insulare*	*Diadromus sp.*
Spinosad 0.10	25.0 ± 16.0bc	25.0 ± 16.0bc	0.0 ± 0.0b
Spinosad 0.075	25.0 ± 16.0bc	25.0 ± 16.0bc	0.0 ± 0.0b
Spinosad 0.050	13.0 ± 13.0bc	13.0 ± 13.0bc	0.0 ± 0.0b
Spinosad 0.025	46.0 ± 18.0ab	46.0 ± 18.0ab	0.0 ± 0.0b
Permethrin 0.091	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0b
Permethrin 0.068	25.0 ± 16.0bc	25.0 ± 16.0bc	0.0 ± 0.0b
Permethrin 0.045	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0b
Permethrin 0.023	0.0 ± 0.0c	0.0 ± 0.0c	0.0 ± 0.0b
Untreated check	84.0 ± 4.0a	83.0 ± 3.0a	2.0 ± 1.0a
P	0.002	0.003	0.032
F	3.43	3.27	2.30
Df	8,3	8,3	8,3
LSD	33.71	33.72	1.01

Means within a column followed by the same letter are not significantly different ($P>0.05$); Fisher's protected least significant difference test (LSD). Data were transformed by arcsin; untransformed means are presented.

P. xylostella and was present in plots treated with 0.075, 0.050 and 0.025 kg AI/ha of spinosad, and untreated plots (Table 5). *Diadromus* sp., *Tetrastichus* sp., and *M. pluttelae* were only present in untreated plots.

In 1997 total percent parasitism of *T. ni* was significantly higher in cabbage plots treated with 0.075 kg AI/ha of spinosad and permethrin applied at 0.068 kg AI/ha (Table 6). The most abundant parasitoids recovered from *T. ni* were *S. c. cinctornis* and *C. concinnata*, which were both present in all treatments (Table 6). *G. ultimus* and *I. stercorator* were only present in untreated plots (Table 6). Total percent parasitism and percent parasitism by species of *P. rapae* did not differ among treatments (Table 7). *C. concinnata* was the most abundant parasitoid species recovered from *P. rapae* and was present in all treatments. *C. glomerata* was recovered from all spinosad-treated and untreated plots, however, was not recovered from any permethrin-treated plots (Table 7). Similar to 1996, total percent parasitism of *P. xylostella* in 1997 was significantly higher in cabbage treated with 0.025 kg AI/ha of spinosad compared to higher rates of spinosad, and all rates of permethrin (Table 8). No parasitism of *P. xylostella* occurred in plots treated with 0.091, 0.045, and 0.023 kg AI/ha of permethrin. *D. insulare* was again the dominant parasitoid recovered from *P. xylostella*. *Diadromus sp.* was only recovered from untreated plots (Table 8).

The number of parasitoid species and number of abundant parasitoid species recovered from *T. ni* during 1996 did not differ significantly between treatments; however, significantly more abundant species were observed in the untreated plots (Table 9). As with *T. ni*, the number of parasitoid species and number of abundant parasitoid species that emerged from *P. rapae* did not differ significantly between treatments, but the number of species was significantly greater in the untreated plots (Table 9). The number of abundant parasitoid species recovered from *P. xylostella* did not differ among treatments (Table 9). However, the number of different species observed was significantly greater in plots treated with 0.050 and 0.025 kg AI/ha of spinosad (Table 9). In addition, significantly more abundant species were observed in the untreated check plots.

In 1997 there were no differences among treatments in the number of abundant species recovered from *T. ni*; however, the number of different species was significantly less in plots treated with 0.10 kg AI/ha of spinosad and 0.091 and

Table 9. Diversity of parasitoid species recovered from parasitized *T. ni*, *P. rapae*, and *P. xylostella*, Rosemount, MN, 1996

Treatment	*T. ni*		*P. rapae*		*P. xylostella*	
(kg AI/ha)	Sum[1]	Hill's *N*1[2]	Sum[1]	Hill's *N*1[2]	Sum[1]	Hill's *N*1[2]
Spinosad 0.10	0.00 ± 0.00b (63.67)	1.00 ± 0.00b	0.33 ± 0.19b (63.67)	1.08 ± 0.08	0.00 ± 0.00d (70.50)	1.00 ± 0.00b
Spinosad 0.075	0.13 ± 0.13b (86.83)	1.00 ± 0.00b	0.67 ± 0.19b (86.83)	1.07 ± 0.07	0.08 ± 0.08cd (77.67)	1.00 ± 0.00b
Spinosad 0.050	0.25 ± 0.16b (90.63)	1.00 ± 0.00b	0.75 ± 0.22b (90.63)	1.17 ± 0.11	0.25 ± 0.13bc (92.00)	1.00 ± 0.00b
Spinosad 0.025	0.00 ± 0.00b (63.67)	1.00 ± 0.00b	0.33 ± 0.19b (63.67)	1.08 ± 0.08	0.42 ± 0.15b (106.33)	1.00 ± 0.00b
Permethrin 0.091	0.00 ± 0.00b (69.46)	1.00 ± 0.00b	0.42 ± 0.19b (69.46)	1.08 ± 0.08	0.00 ± 0.00d (70.50)	1.00 ± 0.00b
Permethrin 0.068	0.25 ± 0.16b (75.25)	1.00 ± 0.00b	0.50 ± 0.19b (75.25)	1.07 ± 0.07	0.00 ± 0.00d (70.50)	1.00 ± 0.00b
Permethrin 0.045	0.00 ± 0.00b (67.46)	1.00 ± 0.00b	0.42 ± 0.23b (67.46)	1.13 ± 0.09	0.00 ± 0.00d (70.50)	1.00 ± 0.00b
Permethrin 0.023	0.25 ± 0.16b (82.83)	1.00 ± 0.00b	0.67 ± 0.26b (82.83)	1.21 ± 0.11	0.00 ± 0.00d (70.50)	1.00 ± 0.00b
Untreated check	0.56 ± 18a (130.96)	1.12 ± 0.08a	1.13 ± 0.17a (130.96)	1.36 ± 0.11	1.25 ± 0.09a (166.50)	1.15 ± 0.06a
P	<0.001	0.032	0.004	0.4019	<0.001	<0.001
F	4.21	2.30	3.03	1.05	25.66	9.28
Df	8,3	8,3	8,3	8,3	8,3	8,3
LSD	(25.945)	0.0735	(34.07)	0.259 NS[3]	(17.691)	0.046

Means within a column followed by the same letter are not significantly different (*P*>0.05); Fisher's protected least significant difference test (LSD). Data were transformed by arcsin; untransformed means are presented.

[1] Refers to number of species observed in a given year.

[2] Average number of abundant species observed per year (Ludwig and Reynolds 1988).

[3] Not significant

Table 10. Diversity of parasitoid species recovered from parasitized *T. ni*, *P. rapae*, and *P. xylostella*, Rosemount, MN, 1997

Treatment	*T. ni*		*P. rapae*		*P. xylostella*	
(kg AI/ha)	Sum[1]	Hill's *N*1[2]	Sum[1]	Hill's *N*1[2]	Sum[1]	Hill's *N*1[2]
Spinosad 0.10	0.58 ± 0.23c (82.88)	1.16 ± 0.11	0.88 ± 0.30cd (97.31)	1.19 ± 0.13cd	0.25 ± 0.16bc (92.00)	1.00 ± 0.00b
Spinosad 0.075	1.25 ± 0.18ab (129.21)	1.30 ± 0.13	1.25 ± 0.25bc (120.38)	1.33 ± 0.16bcd	0.25 ± 0.16bc (92.00)	1.00 ± 0.00b
Spinosad 0.050	1.00 ± 0.21abc (112.50)	1.24 ± 0.13	1.50 ± 0.33abc (128.56)	1.48 ± 0.19bc	0.13 ± 0.13c (81.25)	1.00 ± 0.00b
Spinosad 0.025	1.00 ± 0.21abc (112.50)	1.23 ± 0.12	1.75 ± 0.25ab (142.94)	1.63 ± 0.23ab	0.50 ± 0.19b (113.50)	1.00 ± 0.00b
Permethrin 0.091	0.50 ± 0.19c (79.08)	1.08 ± 0.08	0.50 ± 0.27d (74.25)	1.11 ± 0.11d	0.00 ± 0.00c (70.50)	1.00 ± 0.00b
Permethrin 0.068	0.83 ± 0.11bc (107.58)	1.00 ± 0.00	0.25 ± 0.16d (59.88)	1.00 ± 0.00d	0.25 ± 0.16bc (92.00)	1.00 ± 0.00b
Permethrin 0.045	1.17 ± 0.17ab (125.42)	1.22 ± 0.12	0.50 ± 0.19d 77.25)	1.00 ± 0.00d	0.00 ± 0.00c (70.50)	1.00 ± 0.00b
Permethrin 0.023	1.25 ± 0.25ab (123.79)	1.35 ± 0.16	0.63 ± 0.38d (76.75)	1.00 ± 0.00d	0.00 ± 0.00c (70.50)	1.00 ± 0.00b
Untreated check	1.46 ± 0.19a (142.58)	1.51 ± 0.16	2.13 ± 0.20a (162.81)	1.96 ± 0.18a	1.13 ± 0.09a (161.50)	1.07 ± 0.05a
P	0.004	0.175	<0.001	<0.001	<0.001	0.0347
F	3.07	1.45	6.46	5.37	7.92	2.26
Df	8,3	8,3	8,3	8,3	8,3	8,3
LSD	(33.506)	0.345 NS[3]	(39.68)	0.409	(29.228)	0.0453

Means within a column followed by the same letter are not significantly different (*P*>0.05); Fisher's protected least significant difference test (LSD). Data were transformed by arcsin; untransformed means are presented.

[1] Refers to number of species observed in a given year.

[2] Average number of abundant species observed per year (Ludwig and Reynolds, 1988).

[3] Not significant

0.068 kg AI/ha of permethrin (Table 10). The number of different parasitoid species and number of abundant parasitoid species recovered from *P. rapae* was significantly greater in plots treated with 0.025 and 0.05 kg AI/ha of spinosad (Table 10). In addition, significantly more abundant species were observed in the untreated check plots. Although the number of abundant parasitoid species recovered from *P. xylostella* did not differ among treatments, significantly more parasitoid species were recovered from plots treated with 0.025 kg AI/ha of spinosad (Table 10). The number of abundant species was significantly greater in the untreated check plots.

Weather data collected were similar throughout the summer months of both years of this study (average monthly rainfall = 8.94 cm-14.30 cm; mean daily temperature = 20.1ºC-21.5ºC).

DISCUSSION

Spinosad, at a range of reduced rates, effectively reduced *T. ni*, *P. rapae*, and *P. xylostella* populations in 1996 and 1997. Based on the analysis of insect days (Table 1), and the high marketability rating (Table 2), spinosad provided control comparable to permethrin. In general, percent parasitism of *T. ni* and *P. rapae* was similar across all treatments. We did not observe any immediate impact from Spinosad on the diversity of parasitoids recovered from *T. ni* in 1996 and 1997 (Tables 9 and 10). *C. floridanum* and *C. concinnata* were often the most abundant species recovered from parasitized *T. ni*. *C. floridanum* is a polyembronic egg-larval parasitoid that attacks several lepidopteran species, and has a high reproductive ability and developmental synchrony with *T. ni*. (Strand, 1989). *C. concinnata*, a generalist parasitoid that parasitizes over 200 different species (Arnaud, 1978) was first introduced in the United States in 1906 as a control of the gypsy moth, *Lymantria dispar* (Linnaeus) (Lepidoptera: Lymantriidae) (Culver, 1919). During the years of 1937, 1971-1977 and 1983, the Minnesota Department of Agriculture released *C. concinnata*, most likely to help suppress populations of the fall cankerworm, *Alsophila pometaria* (Harris), which was a major defoliator in Minnesota (J. Luhman, MDA, personal communication).

In 1996, the dominant parasitoid of *P. rapae* was *P. pecosensis* (9.0% Table 4). Noetzel (1956) found *Phryxe* sp. in his collections, but Weires and Chiang (1973) did not document parasitism by *Phryxe* sp. Parasitism by *Phryxe* sp. is also known to occur in Wisconsin (Mahr *et al.*, 1993). In contrast to 1996, the percentage of parasitism by *P. pecosensis* in untreated plots declined dramatically in 1997 to 3.0 per cent, and *C. concinnata* became the dominant parasitoid (2.0% in 1996 and 27.0% in 1997). The dramatic increase in the number of *C. concinnata* collected from 1996 to 1997 indicates that *C. concinnata* may have a significant impact on economically important insect pest species, particularly in cole crops (Tables 4 and 7). The increased parasitism by *C. concinnata* illustrates an unexpected, additional level of biological control for *T. ni*, caused by the release of an exotic biological control agent for a different pest. Additional larval collections are necessary to determine the impact of *C. concinnata* parasitism on both *T. ni* and *P. rapae* (Wold-Burkness *et al.*, 2005).

D. insulare was more adversely affected by permethrin than spinosad. In a recent study, Hill and Foster (2003) illustrated similar results, where they found parasitism by *D. insulare* to be greater in spinosad-treated cabbage compared to permethrin-treated cabbage. Idris and Grafius (1993) also reported *D. insulare* to be highly susceptible to permethrin and other synthetic insecticides. While the high sensitivity of *D. insulare* to synthetic insecticides does not appear uncommon, it is interesting for the fact that several hymenopteran parasitoids are more tolerant to pyrethroids (Croft and Whalon, 1982; Powell *et al*. 1986).

Worldwide, *P. xylostella* is the most destructive and costly insect pest of cole crops (Talekar and Shelton, 1993). In our study, however, *P. xylostella* was the least abundant of the three lepidopteran pests of cabbage, which is likely due to the high parasitism rate that occurred in our plots (81.0% and 84.0% in untreated plots, Tables 5 and 8, respectively). As in previous Minnesota surveys (Wold-Burkness *et al.*, 2005), *D. insulare* was the dominant parasitoid of *P. xylostella* during both years of this study, and was rarely found in permethrin treated plots. The untreated plots allowed for high levels of parasitism by *D. insulare*, which successfully controlled *P. xylostella* in these plots. Mahr *et al*. (1993) also found in the Upper Midwestern U.S. that *D. insulare* is effective in controlling *P. xylostella*, particularly during late-season. A recent Minnesota analysis of *P. xylostella* parasitism, from 1991-2003, indicated that *D. insulare* provided an average of 73.7 per cent parasitism in cabbage not treated with insecticides (Wold-Burkness *et al*., 2005).

Although the results with spinosad and *D. insulare* are promising, recent evidence points to the possibility that spinosad may have sublethal effects on parasitoids, including reproductive capacity and foraging abilities (Williams *et al*., 2003). In their review, Williams *et al*. (2003) found that 78 per cent of laboratory studies, and 86 per cent of field studies reported that spinosad has a moderately harmful to harmful effect on hymenopteran parasitoids, based on the IOBC (international organization for biological and integrated control of noxious animals and plants) toxicity rating (Hassan, 1992). Specifically, Hill and Foster (2000) found that the topical LC_{50} value following exposure to dried residues was 0.3 ppm for *D. insulare*, while *D. insulare* exposed to a field recommended rate of 120 mg AI/liter, showed a delayed, yet high toxicity of 100 per cent of the population dying after 8 hours. Pietrantonio and Benedict (1999) found spinosad to be toxic to adults of *Cotesia plutellae* (Kurdjumov), a parasitic wasp of *P. xylostella*. In addition to direct mortality, Suh *et al*. (2000) found that adult longevity of the egg parasitoid *Trichogramma exiguum* Pinto and Platner (Hymenoptera: Trichogrammatidae) was shortened, while Consoli *et al*. (2001) found parasitism activity of *T. exiguum* was decreased by 90 per cent.

In summary, reduced rates of spinosad and permethrin provided excellent control of *T. ni*, *P. rapae*, and *P. xylostella* in cabbage. Parasitism of *T. ni* and *P. rapae* was higher in plots treated with reduced rates of either product. However, *P. xylostella* parasitism was consistently higher only in reduced-rate spinosad treatments. There were no significant differences among reduced rates for yield or marketability, for either spinosad or permethrin. Although both products provided adequate control, we found that spinosad applied at 50 per cent of the highest labeled rate provided acceptable, consistent control of all lepidopteran pests, allowed for an overall increase in parasitism of all pests, and produced highly marketable cabbage. Based on these results, reduced rates of spinosad can be used to decrease costs, while also having fewer detrimental impacts on natural enemy populations, compared to permethrin. Spinosad should be a valuable component of a biologically-based integrated pest management system for cabbage in the Upper Midwestern U.S. (Hines and Hutchison, 2001; Hutchison *et al*., 2004). Additional research, however, is needed to further study indirect, or sublethal effects that spinosad may have on the most common parasitoid species attacking each of the Lepidopteran pests in cabbage systems.

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