Insecticide Management Strategies for Control of Swede Midge (Diptera: Cecidomyiidae) on Cole Crops

REBECCA H. HALLETT,[1,2] MAO CHEN,[3] MARK K. SEARS,[1] AND ANTHONY M. SHELTON[3]

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ABSTRACT Insecticide field trials were conducted in Ontario, Canada, and New York state to identify insecticides effective against the swede midge, *Contarinia nasturtii* Kieffer (Diptera: Cecidomyiidae), a new invasive pest in North America. Field trials indicated that foliar applications of λ-cyhalothrin, permethrin, acetamiprid, chlorpyrifos, and dimethoate could provide control of *C. nasturtii*. Foliar insecticide applications were effective in keeping damage within marketable limits in all cabbage and some broccoli trials during the early phase of regional colonization by *C. nasturtii* (2001–2002). However by 2005–2006, treatments were rarely able to maintain damage levels within marketable limits. Low efficacy suggested the possibility of insecticide resistance in Canadian *C. nasturtii* populations, but laboratory assays revealed no evidence for resistance. Thus, eventual control failures on a season-long basis were apparently due to very high populations during later phases of colonization in Ontario. Early season applications (e.g., seed treatments, greenhouse plug tray drenches and/or band sprays) of neonicotinoid insecticides proved effective for 3–5 wk after transplanting in New York. These early season treatments would require supplemental control with foliar insecticides, but would reduce the number of foliar applications required and thus reduce insecticide usage. Our results suggest that acceptable control with foliar insecticides will be difficult where *C. nasturtii* populations are high, because of multiple and overlapping generations, and difficulty in achieving adequate spray coverage. An integrated pest management program that uses cultural control methods and host plant resistance, with judicious use of insecticides, is needed for sustainable management of this newly invasive pest.

KEY WORDS *Contarinia nasturtii*, cabbage gall midge, cabbage crowngall fly, pyrethroids, neonicotinoids

The swede midge, *Contarinia nasturtii* Kieffer (Diptera: Cecidomyiidae), was first discovered in North America in 2000 in southern Ontario, Canada, and it has been subsequently found in the Canadian provinces of Quebec, Nova Scotia, and Saskatchewan, as well as in the U.S. states of New York, Massachusetts, and New Jersey (Hallett and Heal 2001; CFIA 2006, 2008; Kikkert et al. 2006) and most recently in Connecticut (http://www.hort.uconn.edu/ipm/general/biocntrl/swedemidge.htm).

Female *C. nasturtii* lay eggs in clutches of two to 50 on meristematic tissue of plants in the family Brassicaceae (Barnes 1946). Adults are short-lived (1–4 d), and females may lay up to 100 eggs during this time (Readshaw 1966). Larval feeding results in swelling, twisting and distortion of tissue. In young cole crops (e.g., broccoli, cabbage, cauliflower) larvae are typically found near the meristem and between compressed petioles where they are protected by young leaves (unpublished data). Larvae also may be found feeding within folds on leaves and within swollen petioles, and among developing florets in broccoli and cauliflower heads. The larval stage lasts 7–21 d depending on climatic conditions (Readshaw 1966). Mature larvae drop to the soil for pupation.

In Ontario, there seem to be two emergence phenotypes of *C. nasturtii*, each with four generations per year (Hallett et al. 2009). The first spring flights of adults occur in mid to late May, and the last adult flights in late September to early October. Effective timing of insecticide applications for control of *C. nasturtii is* difficult due to the short adult life span and concealed nature of larval feeding (Taylor 1912, Smith 1951, Frey et al. 2004).

The objectives of this research program were to evaluate efficacy of various insecticides and application methods in the field for control of *C. nasturtii* in cole crops. Furthermore, when efficacy was less than anticipated, we wished to determine whether this was due to insecticide resistance or some other factor.

Materials and Methods

Insecticide Efficacy Field Trials in Ontario, Canada. Thirteen field experiments were conducted on two farms infested with *C. nasturtii* near the towns of

[1] School of Environmental Sciences, University of Guelph, Guelph, ON, Canada N1G 2W1.
[2] Corresponding author, e-mail: rhallett@uoguelph.ca.
[3] Department of Entomology, New York Agricultural Experimental Station, Cornell University, Geneva, NY 14456.

Stouffville and Markham (2001, 2002, 2005, and 2006), and at the University of Guelph's Elora Research Station (2006), Elora. In 2001 and 2002, *C. nasturtii* populations were monitored with yellow sticky cards, and Stouffville and Markham were considered to be sites of very high and moderate infestation, respectively (Hallett 2007). In 2005 and 2006, after the pheromone had been identified (Hillbur et al. 2005), midge populations were monitored using brown delta traps (2005) or white Jackson traps (2006) each baited with a *C. nasturtii* sex pheromone polyethylene cap lure (PheroNet, Alnarp, Sweden) (Hallett et al. 2007). Three traps were placed around the perimeter of each field and traps were checked three times per week for *C. nasturtii* males. Based on average pheromone trap captures over three seasons (2004–2006; data not shown), Stouffville, Markham, and Elora were considered to be sites of very high (≈30 males per trap per day), high (≈10 males per trap per day), and moderate (≈5 males per trap per day) *C. nasturtii* populations, respectively.

All broccoli (*Brassica oleracea* variety *botrytis*) trials were conducted with 'Eureka'. In 2001 and 2002, 'Balbro' was used for cabbage (*Brassica oleracea* variety *capitata*) trials, but 'Blue Dynasty', a cabbage cultivar resistant to cabbage yellows (*Fusarium oxysporum conglutinans*), was used in 2005 and 2006. All seeds were obtained from Stokes Seed Ltd. (St. Catherines, ON, Canada), and were seeded in 128-cell plug trays with Promix (Premier Horticulture Ltd., Dorval, QC, Canada) in a greenhouse and transplanted to the field at 5 wk after seeding. Plants were transplanted into four row plots, 5 m in length, with a row spacing of 90 cm and in-row plant spacing of 45 cm. Plots were separated by a 3-m spray lane (N–S) and a 3-m alley (E–W). Each experiment had a randomized complete block design, where replicates were blocks. All treatments were replicated five times in each experiment in 2001 and 2002 and four times in 2005 and 2006.

All insecticides tested, as well as rates and formulations, are listed in Table 1. To control cabbage maggot, *Delia radicum* (L.), azinphos-methyl (Guthion 50 WP; Makteshim Agan, Raleigh, NC) at 57.5 mg (AI) per plant (5.75 g product/10 liters water) was added to the planting water for all treatments including the control, unless "untreated control" is indicated. As a nonsystemic soil-applied insecticide, azinphos-methyl was unlikely to affect control of swede midge (EXTOXNET 1996). In 2001 and 2002, foliar insecticide applications were made using a Solo backpack sprayer with a flat spray nozzle #33 (Solo, Newport News, VA), pressurized by a hand pump to 172 kPa, and using water equivalent to 350 liters/ha. In 2005 and 2006, foliar insecticide applications were made using a CO_2-pressurized precision plot sprayer at 275 KPa in water equivalent to 200 liters/ha.

Unless otherwise indicated, *C. nasturtii* damage was assessed on a weekly basis from the first insecticide application, using a four point scale (Hallett 2007), where 0 is no damage, 1 is mild twisting of stem or leaves and/or mild swelling of petioles, 2 is severe twisting of stem and/or crumpling of leaves and/or swelling of florets, and 3 is death of apical meristem and/or multiple compensatory shoots. Broccoli or cabbage with a damage rating of 0 or one at harvest would be considered marketable. Damage ratings were conducted on plants randomly selected from the middle two rows of each plot. In 2001 and 2002, six plants per plot were rated; this was increased to 10 plants per plot in 2005 and 2006. Observers were given standardized training and visual aids to help ensure consistency of ratings among years. In most instances, larval counts were not conducted as these would have required unsustainable levels of destructive sampling throughout the season. However, destructive sampling of plants in other fields at each site confirmed the presence of *C. nasturtii* infestation.

Efficacy of Pyrethroid, Organophosphate, and Spinosyn Insecticides Applied as Foliar Sprays. In 2001, a broccoli trial was conducted at Markham and Stouffville to examine efficacy of foliar-applied pyrethroids (Table 2). Markham and Stouffville trials were planted on 13 and 6 June, respectively, and concluded on 2 August. Three applications of foliar insecticides were made at Markham (25 June; 10 and 31 July) and at Stouffville (26 June; 10 and 31 July).

In 2002, two broccoli trials were conducted at Markham and one at Stouffville (Table 3) to examine the efficacy of foliar-applied insecticides that were registered in Ontario for control of other cole crop pests (OMAF 2002). Markham and Stouffville trials were planted on 21 and 19 June, respectively, and concluded on 13 August. Due to space constraints at Markham, the spinosad treatments were evaluated in a separate experiment situated 32 m from the pyrethroid experiment. All treatments were evaluated in the same experiment at Stouffville. Imidacloprid was included only at Stouffville. Three applications of foliar insecticides were made at Stouffville (28 June; 12 and 30 July) and two at Markham (28 June and 12 July). All foliar insecticide applications were made as in 2001.

The 2001 cabbage trial consisted of the same nine treatments as for broccoli in 2001, plus acephate (Table 4). The other experimental procedures were made at the same timings as for the broccoli trial, except that this trial was concluded on 1 and 7 August at Stouffville and Markham, respectively.

In 2002, the same treatments were examined on cabbage as in 2001, except that an untreated control was not included because of high cabbage maggot populations and the absence of differences between the azinphos-methyl-treated and untreated controls in 2001 (Table 5). All foliar insecticide applications were made as in 2001, except that the trial was discontinued at Markham after 25 July due to a severe outbreak of cabbage yellows, which resulted in the death of most plants in most plots.

Efficacy of Organophosphate, Carbamate, and Neonicotinoid Insecticides Applied As Foliar Sprays. In 2005, broccoli and cabbage trials were conducted at Stouffville to examine efficacy of foliar-applied insecticides at Canadian and American registered rates. The trials were planted on 9 June, and treatments were

Table 1. Insecticides used in field trials in Ontario and New York in 2001, 2002, 2005, and 2006

Active ingredient and treatment name	Product name	Company	Rate	Application method	Insecticide class
Deltamethrin	Decis 5 EC	Bayer CropScience, Calgary AB	10 g (AI)/ha	Foliar spray	Pyrethroid
λ-Cyhalothrin Matador Low	Matador 120 EC	Syngenta Crop Protection, Guelph, ON	5 g (AI)/ha	Foliar spray	Pyrethroid
λ-Cyhalothrin Matador CDN	Matador 120 EC	Syngenta Crop Protection, Guelph, ON	10 g (AI)/ha	Foliar spray	Pyrethroid
λ-Cyhalothrin Matador US	Matador 120 EC	Syngenta Crop Protection, Guelph, ON	33.6 g (AI)/ha	Foliar spray	Pyrethroid
λ-Cyhalothrin Warrior Low	Warrior T	Syngenta Crop Protection, Guelph, ON	5 g (AI)/ha	Foliar spray	Pyrethroid
λ-Cyhalothrin Warrior High	Warrior T	Syngenta Crop Protection, Guelph, ON	10 g (AI)/ha	Foliar spray	Pyrethroid
λ-Cyhalothrin Warrior US	Warrior	Syngenta Crop Protection, Greensboro, NC	33.6 g (AI)/ha	Foliar spray	Pyrethroid
Permethrin Low	Pounce 384 EC	FMC Corp., Philadelphia, PA	34.6 g (AI)/ha	Foliar spray	Pyrethroid
Permethrin High	Pounce 384 EC	FMC Corp., Philadelphia, PA	69.1 g (AI)/ha	Foliar spray	Pyrethroid
Spinosad Low	Success 480 SC	Dow AgroSciences, Calgary, AB	101 g (AI)/ha	Foliar spray	Spinosyn
Spinosad High	Success 480 SC	Dow AgroSciences, Calgary, AB	167 g (AI)/ha	Foliar spray	Spinosyn
Spinosad Low + surfactant (siloxylated polyether)	Success 480 SC + Sylgard 309	Dow AgroSciences, Calgary, AB	101 g (AI)/ha	Foliar spray	Spinosyn
Spinosad High + surfactant (siloxylated polyether)	Success 480 SC + Sylgard 309	Dow AgroSciences, Calgary, AB	167 g (AI)/ha	Foliar spray	Spinosyn
Spinosad CDN	Entrust 80 W	Dow Agrosciences, Indianapolis, IN	80 g (AI)/ha	Foliar spray	Spinosyn
Spinosad US	Entrust 80 W	Dow Agrosciences, Indianapolis, IN	179.2 g (AI)/ha	Foliar spray	Spinosyn
Acetamiprid CDN	Assail 70 WP	DuPont Crop Protection, Mississauga, ON	60.2 g (AI)/ha	Foliar spray	Neonicotinoid
Acetamiprid US	Assail 70 WP or 30SG	DuPont Crop Protection, Mississauga, ON; Cerexagri, Inc., King of Prussia, PA	84 g (AI)/ha	Foliar spray	Neonicotinoid
Acetamiprid High	Tristar 70 WSP	Nippon Soda/Engage Agro Corp., Guelph, ON	84 g (AI)/ha	Greenhouse drench	Neonicotinoid
Acetamiprid	Assail 70 WP	Bayer CropScience, Calgary, AB	60.2 g (AI)/ha	Band spray	Neonicotinoid
Imidacloprid	Admire 240 F	Bayer CropScience, Calgary, AB	48 g (AI)/ha	Foliar spray	Neonicotinoid
Imidacloprid High	Provado 1.6F	Bayer CropScience, Kansas City, MO	52.6 g (AI)/ha	Foliar spray	Neonicotinoid
Imidacloprid High	Intercept 60 WP	Bayer CropScience, Calgary, AB	25 g (AI)/100 plants	Greenhouse drench	Neonicotinoid
Imidacloprid	Admire 240 F	Bayer CropScience, Calgary, AB	175.2 g (AI)/ha	Band spray	Neonicotinoid
Clothianidin Low	Poncho	Bayer CropScience, Kansas City, MO	0.4 g (AI)/100 g seed	Seed treatment	Neonicotinoid
Clothianidin Int	Poncho	Bayer CropScience, Kansas City, MO	4.5 g (AI)/100 g seed	Seed treatment	Neonicotinoid
Clothianidin High	Poncho	Bayer CropScience, Kansas City, MO	6.86 g (AI)/100 g seed	Seed treatment	Neonicotinoid
Thiamethoxam Low	Cruiser SF	Syngenta Crop Protection, Greensboro, NC	0.4 g (AI)/100 g seed	Seed treatment	Neonicotinoid
Thiamethoxam Int	Cruiser SF	Syngenta Crop Protection, Greensboro, NC	4.5 g (AI)/100 g seed	Seed treatment	Neonicotinoid
Thiamethoxam High	Cruiser SF	Syngenta Crop Protection, Greensboro, NC	6.86 g (AI)/100 g seed	Seed treatment	Neonicotinoid
Thiamethoxam	Actara 25 WG	Syngenta Crop Protection, Guelph, ON	0.68 mg (AI)/ha	Band spray	Neonicotinoid
Acephate	Orthene 75 SP	Arvesta Corp., San Francisco, CA	118.5 g (AI)/ha	Foliar spray	Organophosphate
Chlorpyrifos	Lorsban 4E or 75WG	Dow AgroSciences, Calgary, AB or Indianapolis, IN	1118 g (AI)/ha	Foliar spray	Organophosphate
Dimethoate	Dimethoate 400	BASF Canada, Toronto, ON	560.4 g (AI)/ha	Foliar spray	Organophosphate
Methomyl	Lannate L or LV	DuPont Crop Protection, Mississauga, ON or Newark, DE	1008 g (AI)/ha	Foliar spray	Carbamate
Oxamyl	Vydate L	DuPont Crop Protection, Mississauga, ON	560 g (AI)/ha	Foliar spray	Carbamate
Metaflumizone	—	BASF Canada, Toronto, ON	240 g (AI)/ha	Foliar spray	Semicarbizone
Cyromazine	Citation 75WP	Syngenta Crop Protection, Inc., Guelph, ON	141 g (AI)/ha	Foliar spray	Insect growth regulator
Novaluron Low	Rimon 10EC	Chemtura Canada, Elmira, ON	65 g (AI)/ha	Foliar spray	Insect growth regulator
Novaluron High	Rimon 10EC	Chemtura Canada, Elmira, ON	90 g (AI)/ha	Foliar spray	Insect growth regulator
Commercial standard[a]					
λ-Cyhalothrin	Matador 120EC	Syngenta Crop Protection, Guelph, ON	10 g (AI)/ha	Foliar spray	Pyrethroid
Acetamiprid	Assail 70WP	DuPont Crop Protection, Mississauga, ON	60.2 g (AI)/ha	Foliar spray	Neonicotinoid

CDN and US indicate registered rates in Canada and the United States, respectively. Low, intermediate (Int), and high are used to differentiate between treatments of the same product that differed in application rates.

[a] Weekly applications roughly alternating between λ-cyhalothrin and acetamiprid, total of three and five applications, respectively.

Table 2. Mean damage ratings in 2001 trials at Markham and Stouffville for broccoli treated with pyrethroid insecticides to prevent damage by *C. nasturtii*

Location and treatments	Mean damage rating (± SE)[a]						
	27 June	4 July	12 July	18 July	25 July	2 Aug.	
Broccoli-Markham[b]							
Control	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.2	1.1 ± 0.2	ab
Untreated control	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.2	1.1 ± 0.3	a
Deltamethrin	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.8 ± 0.2	abc
λ-Cyhalothrin Matador Low	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.6 ± 0.2	abc
λ-Cyhalothrin Matador CDN	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.2 ± 0.1	c
λ-Cyhalothrin Warrior Low	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.5 ± 0.2	abc
λ-Cyhalothrin Warrior High	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.3 ± 0.1	bc
Permethrin Low	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.4 ± 0.1	bc
Permethrin High	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.3 ± 0.1	c
Broccoli-Stouffville[c]							
Control	0.1 ± 0.1	0.8 ± 0.1	1.1 ± 0.2	1.5 ± 0.2	2.0 ± 0.2	2.7 ± 0.1	a
Untreated control	0.1 ± 0.1	0.8 ± 0.1	1.4 ± 0.2	1.9 ± 0.2	2.0 ± 0.2	2.3 ± 0.2	a
Deltamethrin	0.0 ± 0.0	0.4 ± 0.1	0.8 ± 0.2	1.1 ± 0.2	2.1 ± 0.2	2.2 ± 0.2	abc
λ-Cyhalothrin Matador Low	0.0 ± 0.0	0.7 ± 0.1	1.0 ± 0.2	1.4 ± 0.2	1.8 ± 0.2	2.4 ± 0.2	ab
λ-Cyhalothrin Matador CDN	0.0 ± 0.0	0.4 ± 0.1	0.5 ± 0.1	1.0 ± 0.2	0.9 ± 0.2	1.3 ± 0.2	bc
λ-Cyhalothrin Warrior Low	0.1 ± 0.1	0.7 ± 0.1	0.6 ± 0.2	1.3 ± 0.2	2.4 ± 0.2	2.3 ± 0.2	a
λ-Cyhalothrin Warrior High	0.0 ± 0.0	0.5 ± 0.1	0.4 ± 0.1	0.7 ± 0.2	1.0 ± 0.2	1.3 ± 0.2	c
Permethrin Low	0.1 ± 0.1	0.5 ± 0.1	0.6 ± 0.1	1.2 ± 0.2	1.5 ± 0.2	1.9 ± 0.2	abc
Permethrin High	0.0 ± 0.0	0.6 ± 0.1	0.7 ± 0.2	0.8 ± 0.2	2.0 ± 0.2	2.5 ± 0.2	abc

Three insecticide applications were made at Markham (25 June; 10 and 31 July) and Stouffville (26 June; 10 and 31 July). The means separations indicated represent the differences between treatments over the course of the season in damage ratings, and not differences between the actual means presented in the table. Treatments within an experiment followed by the same letter are not statistically different, by multiple means comparisons using Tukey's adjustment for LS Means, with $\alpha = 0.05$.

[a] 0, no damage; 1, mild twisting of stem or leaves and/or mild swelling of petioles; 2, severe twisting of stem and/or crumpling of leaves and/or swelling of florets; 3, death of apical meristem and/or multiple compensatory shoots.

[b] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 3.98$; df = 8,1525; $P = 0.0001$; day, $F = 79.89$; df = 5,1525; $P < 0.0001$; treatment × day, $F = 3.28$; df = 40,1525; $P < 0.0001$.

[c] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 5.23$, df = 8,1526; $P < 0.0001$; day, $F = 198.12$; df = 5,1526; $P < 0.0001$; treatment × day, $F = 2.61$; df = 40,1526; $P < 0.0001$.

the same in both broccoli and cabbage trials at each site (Table 6). In total, eight weekly insecticide applications were made from 4 d after transplanting until 5 and 8 August (cabbage and broccoli, respectively). Damage ratings were conducted at three intervals ≈25 d apart (i.e., 4 and 2 July; 18 August) on 10 plants per plot. In addition, four plants from the outside rows of each plot were destructively sampled on 4 and 29 July. Plants from a given plot were placed in a plastic bag and held in cold storage (≈10°C) until plants could be dissected and examined for larvae. All larvae found on plants and inside the bags were counted.

Efficacy of Experimental Insecticides Applied as Foliar Sprays. In 2005, a broccoli trial was conducted at Markham to examine the efficacy of foliar applications of unregistered or experimental products (Table 7). A commercial standard also was included for comparison (Table 1). With the registration of λ-cyhalothrin (Matador) and acetamiprid (Assail) in Canada for use against *C. nasturtii* in cole crops (see Discussion), approximately alternating applications of these products were adopted as the commercial standard in Ontario (OMAF 2004). The trial was planted on 22 June and concluded on 12 August. Six insecticide applications were made at weekly intervals from 23 June to 3 August.

Use Patterns of Novaluron Applied as Foliar Sprays. In 2006, broccoli and cabbage trials were conducted at Markham and Elora to examine use patterns of novaluron (i.e., whole versus partial season applications) and efficacy of several experimental products compared with the commercial standard. Elora and Markham trials were planted on 13 and 20 June, respectively.

In broccoli, efficacy of novaluron in protecting developing broccoli heads from swede midge damage was evaluated (Table 8). Insecticide treatments were made at weekly intervals from 14 June to 10 August and 21 June to 17 August at Elora and Markham, respectively; with the exception of partial season treatments of the commercial standard, which were made until early head formation (buttoning) was observed (25 and 31 July, Elora and Markham, respectively), and the commercial standard plus novaluron treatments, in which the commercial standard was applied until buttoning and then novaluron applied thereafter (from 3 and 8 August, Elora and Markham, respectively).

In cabbage, efficacy of novaluron in protecting cabbage plants from swede midge damage before head formation was evaluated (Table 9). Insecticide treatments were made at weekly intervals from 15 June to 11 August and 22 June to 18 August at Elora and Markham, respectively. Partial season treatments of novaluron and the commercial standard were made from 2 d after transplanting (15 and 22 June, Elora and Markham, respectively) until early head formation (cupping), with no further insecticide applications made after this time. The last precupping treatments

Table 3. Mean damage ratings in 2002 trials at Markham and Stouffville for broccoli treated with pyrethroid, and spinosyn insecticides to prevent damage by *C. nasturtii*

Exp. and treatments	Mean damage rating (± SE)[a]							
	5 July	12 July	19 July	25 July	2 Aug.	8 Aug.	13 Aug.	
Broccoli-Markham[b]								
Untreated control	0.1 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.6 ± 0.2	1.1 ± 0.2	1.3 ± 0.2	a
Deltamethrin	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.3 ± 0.1	0.1 ± 0.1	0.6 ± 0.2	b
λ-Cyhalothrin Matador Low	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.5 ± 0.1	b
λ-Cyhalothrin Matador CDN	0.1 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.5 ± 0.2	0.3 ± 0.1	0.7 ± 0.2	b
λ-Cyhalothrin Warrior Low	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.6 ± 0.1	b
λ-Cyhalothrin Warrior High	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.8 ± 0.1	0.8 ± 0.2	ab
Permethrin Low	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.5 ± 0.1	0.3 ± 0.1	0.6 ± 0.2	b
Permethrin High	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.2 ± 0.1	0.5 ± 0.2	b
Broccoli-Markham[c]								
Untreated control	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.5 ± 0.1	a
Spinosad Low	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.6 ± 0.1	0.6 ± 0.1	a
Spinosad High	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.4 ± 0.1	0.3 ± 0.1	a
Spinosad Low + surfactant	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	a
Spinosad High + surfactant	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.4 ± 0.1	0.5 ± 0.2	a
	2 July	12 July	19 July	25 July	1 Aug.	8 Aug.	13 Aug.	
Broccoli-Stouffville[d]								
Control	0.0 ± 0.0	1.3 ± 0.2	1.9 ± 0.2	2.3 ± 0.2	2.4 ± 0.1	2.7 ± 0.1	2.7 ± 0.1	a
Deltamethrin	0.0 ± 0.0	1.0 ± 0.2	1.3 ± 0.2	2.1 ± 0.2	1.8 ± 0.2	1.4 ± 0.3	2.5 ± 0.1	a
λ-Cyhalothrin Matador Low	0.0 ± 0.0	0.9 ± 0.2	1.1 ± 0.2	1.7 ± 0.3	1.5 ± 0.2	1.6 ± 0.2	1.7 ± 0.2	a
λ-Cyhalothrin Matador CDN	0.0 ± 0.0	0.9 ± 0.2	1.5 ± 0.2	1.4 ± 0.3	1.4 ± 0.2	1.7 ± 0.2	1.3 ± 0.2	a
λ-Cyhalothrin Warrior Low	0.0 ± 0.0	1.2 ± 0.2	2.2 ± 0.2	1.6 ± 0.3	2.2 ± 0.2	2.3 ± 0.2	2.3 ± 0.1	a
λ-Cyhalothrin Warrior High	0.0 ± 0.0	0.6 ± 0.2	1.3 ± 0.2	1.3 ± 0.3	1.7 ± 0.2	1.6 ± 0.3	1.9 ± 0.2	a
Permethrin Low	0.0 ± 0.0	1.1 ± 0.2	1.9 ± 0.2	2.0 ± 0.2	1.9 ± 0.2	2.3 ± 0.2	2.7 ± 0.1	a
Permethrin High	0.0 ± 0.0	0.7 ± 0.2	1.4 ± 0.3	1.5 ± 0.3	1.9 ± 0.2	1.5 ± 0.3	2.0 ± 0.2	a
Imidacloprid	0.1 ± 0.1	1.3 ± 0.2	1.9 ± 0.2	1.9 ± 0.2	2.0 ± 0.2	2.3 ± 0.2	2.5 ± 0.2	a
Spinosad Low	0.1 ± 0.1	1.3 ± 0.2	2.0 ± 0.2	2.0 ± 0.3	2.3 ± 0.2	2.3 ± 0.2	2.5 ± 0.1	a
Spinosad High	0.0 ± 0.0	1.2 ± 0.2	2.0 ± 0.2	1.7 ± 0.3	2.0 ± 0.2	2.3 ± 0.2	2.5 ± 0.2	a
Spinosad Low + surfactant	0.0 ± 0.0	0.6 ± 0.1	1.5 ± 0.2	1.4 ± 0.3	2.0 ± 0.2	2.1 ± 0.2	2.6 ± 0.1	a
Spinosad High + surfactant	0.2 ± 0.1	1.1 ± 0.2	1.8 ± 0.2	1.9 ± 0.2	1.9 ± 0.2	2.1 ± 0.2	2.6 ± 0.1	a

Two insecticide applications were made at Markham (28 June and 12 July) and three at Stouffville (28 June; 12 and 30 July).

[a] 0, no damage; 1, mild twisting of stem or leaves and/or mild swelling of petioles; 2, severe twisting of stem and/or crumpling of leaves and/or swelling of florets; 3, death of apical meristem and/or multiple compensatory shoots.

[b] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 4.43$; df = 7,1620; $P < 0.0001$; day, $F = 47.32$; df = 6,1620; $P < 0.0001$; treatment × day, $F = 2.06$; df = 42,1620; $P < 0.0001$.

[c] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 0.94$; df = 4,20; $P = 0.46$; day, $F = 0.88$; df = 6,120; $P = 0.51$; treatment × day, $F = 0.99$; df = 24,120; $P = 0.49$.

[d] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 2.17$; df = 12,3006; $P = 0.011$; day, $F = 359.45$; df = 7,3006; $P < 0.0001$; treatment × day, $F = 1.67$; df = 84,3006; $P = 0.0001$. The means separations indicated represent the differences between treatments over the course of the season in damage ratings, and not differences between the actual means presented in the table. Treatments within an experiment followed by the same letter are not statistically different, by multiple means comparisons using Tukey's adjustment for LS Means, with $\alpha = 0.05$.

were made on 19 and 24 July at Elora and Markham, respectively.

Efficacy of Seed Treatments, Greenhouse Drenches, and Band Spray Treatments. In 2006, short term broccoli and cabbage trials were conducted at Stouffville to evaluate the efficacy of early season insecticide treatments (i.e., seed treatments, greenhouse plug tray drenches, and band sprays). Five wk old seedlings were transplanted to field plots on 15 June and the trial was concluded on 21 July. Treatments were the same in both broccoli and cabbage trials (Table 10). Seed treatments were applied by A. Taylor at Cornell/New York Agricultural Experimental Station (NYSAES) by using a film-coating treatment similar to that described for cabbage maggot control (Jyoti et al. 2003). Greenhouse drenches were applied to seedlings in transplant plug trays in 200 ml of water per tray either 1 or 9 d before transplanting, for acetamiprid and imidacloprid, respectively. Band sprays were applied 1 d after transplanting using the CO_2 pressurized precision plot sprayer but with nozzles oriented so as to produce a 10-cm-wide band that was applied over the top of each row in water equivalent to 2,000 liters/ha. The foliar control was applied five times at weekly intervals from 1 d after transplanting, with the last application made on 14 July.

Insecticide Efficacy Field Trial in New York State. Broccoli 'Paragon' seeds (including those with seed treatments) were planted in 128-cell trays on 25 May 2006 and maintained in Cornell/NYSAES greenhouses. Seedlings were transplanted on 3 July by hand (50 cm between plants and 120 cm between rows) in a field in Niagara County, NY, where *C. nasturtii* infestation had been confirmed (Kikkert et al. 2006). Each plot contained 15 plants with four replicates for each treatment in a randomized complete block design. The insecticides used for foliar spray, seed treatment and band spray are listed in Table 11. All treatment rates were registered commercial rates (Greenbook Group 2003) or were based on our pre-

Table 4. Mean damage ratings in 2001 trials at Markham and Stouffville for cabbage treated with pyrethroid and organophosphate insecticides to prevent damage by *C. nasturtii*

Location and treatments	Mean damage rating (± SE)[a]							
	27 June	6 July	12 July	18 July	25 July	1 Aug.	7 Aug.	
Cabbage-Markham[b]								
Control	0.1 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.3 ± 0.1	0.4 ± 0.2	1.3 ± 0.1	0.6 ± 0.1	a
Untreated control	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.1 ± 0.1	1.0 ± 0.0	0.4 ± 0.1	ab
Deltamethrin	0.1 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.2 ± 0.1	0.9 ± 0.1	0.5 ± 0.1	ab
λ-Cyhalothrin Matador Low	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.2	0.1 ± 0.1	0.3 ± 0.2	0.5 ± 0.1	0.5 ± 0.2	ab
λ-Cyhalothrin Matador CDN	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.3 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	ab
λ-Cyhalothrin Warrior Low	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.4	0.2 ± 0.1	0.2 ± 0.1	0.5 ± 0.2	b
λ-Cyhalothrin Warrior High	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.4 ± 0.1	b
Permethrin Low	0.1 ± 0.1	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.6 ± 0.2	0.5 ± 0.1	ab
Permethrin High	0.1 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.7 ± 0.1	0.7 ± 0.2	ab
Acephate	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	1.0 ± 0.1	0.4 ± 0.1	ab
Cabbage-Stouffville[c]								
Control	0.2 ± 0.1	0.3 ± 0.1	0.8 ± 0.2	0.6 ± 0.2	1.0 ± 0.2	1.4 ± 0.1		ab
Untreated control	0.2 ± 0.1	0.4 ± 0.1	1.0 ± 0.2	0.6 ± 0.2	0.9 ± 0.2	1.4 ± 0.2		a
Deltamethrin	0.1 ± 0.1	0.1 ± 0.1	0.5 ± 0.2	0.4 ± 0.2	0.4 ± 0.1	0.7 ± 0.2		ab
λ-Cyhalothrin Matador Low	0.2 ± 0.1	0.4 ± 0.2	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.7 ± 0.2		ab
λ-Cyhalothrin Matador CDN	0.2 ± 0.1	0.2 ± 0.1	0.4 ± 0.2	0.3 ± 0.1	0.4 ± 0.1	0.4 ± 0.1		b
λ-Cyhalothrin Warrior Low	0.2 ± 0.1	0.2 ± 0.1	0.4 ± 0.2	0.3 ± 0.1	0.3 ± 0.1	0.6 ± 0.1		b
λ-Cyhalothrin Warrior High	0.2 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.3 ± 0.2	0.5 ± 0.1		b
Permethrin Low	0.1 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.4 ± 0.2	0.4 ± 0.1		b
Permethrin High	0.2 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	0.5 ± 0.1		b
Acephate	0.2 ± 0.1	0.3 ± 0.1	0.6 ± 0.2	0.5 ± 0.1	0.8 ± 0.2	0.9 ± 0.1		ab

Three insecticide applications were made at Markham (25 June; 10 and 31 July) and at Stouffville (26 June; 10 and 31 July). The means separations indicated represent the differences between treatments over the course of the season in damage ratings, and not differences between the actual means presented in the table. Treatments within an experiment followed by the same letter are not statistically different, by multiple means comparisons using Tukey's adjustment for LS Means, with $\alpha = 0.05$.

[a] 0, no damage; 1, mild twisting of stem or leaves and/or mild swelling of petioles; 2, severe twisting of stem and/or crumpling of leaves and/or swelling of florets; 3, death of apical meristem and/or multiple compensatory shoots.

[b] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 3.65$; df = 9,1607; $P = 0.0002$; day, $F = 76.21$; df = 6,1607; $P < 0.0001$; treatment × day, $F = 2.27$; df = 54,1607; $P < 0.0001$.

[c] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 3.45$; df = 9,1736; $P = 0.0003$; day, $F = 23.53$; df = 5,1736; $P < 0.0001$; treatment × day, $F = 1.50$; df = 45,1736; $P = 0.018$.

vious tests for unregistered compounds (Wu et al. 2006). Seed treatments were applied as above. Foliar sprays were applied with a CO_2 backpack sprayer with a one-row boom consisting of one nozzle over the top and a plastic screen on each side to prevent insecticide drift between plots, using TeeJet XR8002VS nozzles delivering 28 liters/ha at 276 kPa and 3.2 km/h. Band sprays were also applied with a CO_2 backpack sprayer at the same spray volume and speed as the foliar sprays, but the spray was directed at the base of the plants. Plots sprayed with water were used as the control. Both foliar and band spray treatments were applied only once at transplanting.

Three plants were randomly sampled from each plot 1, 2 and 3 wk after transplanting. Each plant sample was placed in a plastic bag and returned to the laboratory for rating damage symptoms and counting the number of live *C. nasturtii* larvae on each plant under a dissecting microscope. One *C. nasturtii* pheromone trap was set up on the border of the field to monitor *C. nasturtii* populations during the course of the trial (3–25 July).

Insecticide Resistance Bioassays. *Insect Culture.* An initial laboratory colony of *C. nasturtii* was kindly received from R. Baur from Switzerland (Swiss Federal Research Station for Horticulture, Wädenswil, Switzerland) in 2004 and was subsequently reared at Cornell/NYSAES in a chamber under quarantine conditions on cauliflower, *Brassica oleracea* variety *botrytis*, 'Snow crown', plants with eight to 10 true leaves at 22°C, 75–78% RH, and a photoperiod of 16:8 (L:D) h (Wu et al. 2006, Chen et al. 2007). The Swiss colony was considered insecticide-susceptible as original collections were made from insecticide-free field plots and the colony was maintained without exposure to insecticides. A Canadian *C. nasturtii* field colony was collected from infested fields at Stouffville in August 2005, returned to Cornell/NYSAES and reared in the quarantine chamber following the same protocols as above.

Both *C. nasturtii* colonies were used to test the efficacy of different insecticides in laboratory bioassays. Bioassays were performed on generations 23–26 of the Swiss colony (laboratory standard) and generations 2–5 of the Canadian colony.

Bioassays. A diet overlay assay similar to the method described by Iracheta et al. (2000) and Zhao et al. (2002) was used to determine the susceptibility of *C. nasturtii* laboratory and field colonies to different commercially formulated insecticides (Table 12). Five to six concentrations of each insecticide plus a control (distilled water) were included in each bioassay. An aliquot of 0.2 ml of insecticide solution was applied to and evenly distributed over the diet surface (surface area ≈7 cm^2) of 30-ml plastic cups (Wincup, Phoenix, AZ) with 5 ml of high wheat germ-based artificial diet for *Trichoplusia ni* (Hübner) (preliminary tests indicated that *C. nasturtii* could live on the diet for >7 d).

Table 5. Mean damage ratings in 2002 trials at Markham and Stouffville for cabbage treated with pyrethroid and organophosphate insecticides to prevent damage by *C. nasturtii*

Location and treatments	Mean damage rating (± SE)[a]							
	26 June	5 July	12 July	19 July	25 July	1 Aug.	9 Aug.	
Cabbage-Markham[b]								
Control	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.1	0.5 ± 0.1	0.6 ± 0.2			ab
Deltamethrin	0.0 ± 0.0	0.1 ± 0.1	0.4 ± 0.1	0.7 ± 0.1	0.6 ± 0.2			ab
λ-Cyhalothrin Matador Low	0.0 ± 0.0	0.1 ± 0.1	0.5 ± 0.1	0.8 ± 0.2	0.5 ± 0.2			ab
λ-Cyhalothrin Matador CDN	0.0 ± 0.0	0.1 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	0.8 ± 0.2			ab
λ-Cyhalothrin Warrior Low	0.0 ± 0.0	0.1 ± 0.1	0.6 ± 0.1	0.6 ± 0.1	0.8 ± 0.2			ab
λ-Cyhalothrin Warrior High	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.4 ± 0.1	0.4 ± 0.1			ab
Permethrin Low	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.3 ± 0.1	0.4 ± 0.1			b
Permethrin High	0.0 ± 0.0	0.1 ± 0.1	0.6 ± 0.1	0.4 ± 0.1	0.4 ± 0.1			ab
Acephate	0.0 ± 0.0	0.1 ± 0.1	0.7 ± 0.2	0.7 ± 0.2	0.8 ± 0.2			a
Cabbage-Stouffville[c]								
Control	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 0.2	1.5 ± 0.2	1.7 ± 0.1	1.7 ± 0.1	1.6 ± 0.1	a
Deltamethrin	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.2	1.1 ± 0.2	1.0 ± 0.2	0.8 ± 0.2	1.0 ± 0.2	b
λ-Cyhalothrin Matador Low	0.1 ± 0.1	0.0 ± 0.0	0.8 ± 0.2	0.7 ± 0.1	1.0 ± 0.2	1.0 ± 0.2	0.8 ± 0.2	b
λ-Cyhalothrin Matador CDN	0.0 ± 0.0	0.1 ± 0.1	0.5 ± 0.1	0.8 ± 0.2	1.1 ± 0.2	0.9 ± 0.2	0.9 ± 0.2	b
λ-Cyhalothrin Warrior Low	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.2	0.9 ± 0.2	1.2 ± 0.2	1.2 ± 0.1	0.9 ± 0.2	b
λ-Cyhalothrin Warrior High	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.2	1.2 ± 0.2	1.3 ± 0.2	1.4 ± 0.2	1.2 ± 0.2	ab
Permethrin Low	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.2	1.1 ± 0.2	1.3 ± 0.2	0.9 ± 0.1	1.0 ± 0.2	b
Permethrin High	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.2	0.7 ± 0.2	0.9 ± 0.2	0.9 ± 0.2	0.5 ± 0.1	b
Acephate	0.0 ± 0.0	0.1 ± 0.1	1.4 ± 0.2	1.2 ± 0.2	1.4 ± 0.2	1.3 ± 0.2	1.0 ± 0.2	ab

Two insecticide applications were made at Markham (28 June and 12 July), and three at Stouffville (28 June; 12 and 30 July). The means separations indicated represent the differences between treatments over the course of the season in damage ratings, and not differences between the actual means presented in the table. Treatments within an experiment followed by the same letter are not statistically different, by multiple means comparisons using Tukey's adjustment for LS Means, with $\alpha = 0.05$.

[a] 0, no damage; 1, mild twisting of stem or leaves and/or mild swelling of petioles; 2, severe twisting of stem and/or crumpling of leaves and/or swelling of florets; 3, death of apical meristem and/or multiple compensatory shoots.

[b] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 2.21$; df = 8,1421; $P = 0.02$; day, $F = 63.06$; df = 4,1421; $P < 0.0001$; treatment × day, $F = 1.19$; df = 32,1421; $P = 0.212$.

[c] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 4.18$; df = 8,1823; $P < 0.0001$; day, $F = 145.88$; df = 6,1823; $P < 0.0001$; treatment × day, $F = 1.94$; df = 48,1823; $P = 0.0001$.

Bond spreader sticker (Loveland Industry, Loveland, CO) was added at 0.1% (vol:vol) to all test concentrations and to the water control. Ten *C. nasturtii* larvae (10 d old after oviposition) were transferred into each cup. Cups were covered with lids and placed in the insect rearing chamber for 24 h to determine mortality. Seven insecticides were used for laboratory bioassays, with five replications per concentration: λ-cyhalothrin (Warrior), acetamiprid (Assail 70 WP), imidacloprid (Provado 1.6F), chlorpyrifos (Lorsban 4E), methomyl (Lannate LV), acephate (Orthene 75S, Valent USA Corporation, Walnut Creek, CA), and spinosad (SpinTor 2 SC, Dow AgroSciences, Indianapolis, IN).

Statistical Analyses. Damage ratings from all Ontario field efficacy trials were analyzed in SAS version 9.1 by repeated measures analyses of variance (ANOVA) using PROC MIXED, with plot designated as the repeated subject and replicate designated as a random variable. In field trials all larval count data, as well as damage ratings in the New York field trial, were obtained by destructive sampling, so data among dates were considered independent of date and were analyzed for each date separately by mixed model ANOVAs, using PROC MIXED, with replicate designated as a random variable. Because efficacy of an insecticide on *C. nasturtii* could be affected both by insecticide type and time after application, data for each treatment in the New York field trial also were analyzed by mixed model ANOVAs across time. All multiple means comparisons were performed using the Tukey's adjustment for LS Means, with $\alpha = 0.05$ (SAS Institute 1999).

Linear regressions were conducted using PROC GLM to examine the relationship between larval numbers per plant and damage ratings on the same day, 20–25 d (i.e., 4 versus 29 July, and 29 July versus 18 August) or 45 d (i.e., 4 July versus 18 August) later in the 2005 trials evaluating efficacy of organophosphate, carbamate and neonicotinoid insecticides applied as foliar sprays.

The POLO program was used for probit analysis of susceptibility of insecticide (dose–response) data (Russell et al. 1977). Differences in susceptibility were considered significant when 95% CL of LC_{50} values did not overlap.

Results

Insecticide Efficacy Field Trials in Ontario, Canada. Repeated measures ANOVAs are useful for examining the efficacy of insecticides over the whole season; however, the effect of the pattern of damage development on results of repeated measures ANOVAs should be noted. For example, two treatments may have very similar final damage ratings, but due to different timings of damage development they may be found to differ statistically from one another, whereas treatments with apparently dif-

Table 6. Mean number of *C. nasturtii* larvae and mean damage ratings in 2005 trials at Stouffville for broccoli and cabbage treated with organophosphate, carbamate, and neonicotinoid insecticides to prevent damage by *C. nasturtii*

Crop, exp. and treatment	Mean damage rating (± SE)[a]			
	4 July	29 July	18 Aug.	
Broccoli-Stouffville[b]				
Untreated control	0.1 ± 0.0	1.7 ± 0.2	2.9 ± 0.1	a
λ-Cyhalothrin Matador CDN	0.8 ± 0.2	1.2 ± 0.2	2.4 ± 0.2	a
λ-Cyhalothrin Matador US	1.2 ± 0.2	1.6 ± 0.2	2.3 ± 0.2	a
Acetamiprid CDN	0.2 ± 0.1	1.2 ± 0.1	2.8 ± 0.1	a
Acetamiprid US	0.7 ± 0.2	1.7 ± 0.2	2.7 ± 0.1	a
Imidacloprid	0.7 ± 0.2	1.7 ± 0.2	2.6 ± 0.1	a
Acephate	0.8 ± 0.2	1.9 ± 0.2	2.7 ± 0.1	a
Chlorpyrifos	0.3 ± 0.1	0.9 ± 0.1	2.8 ± 0.1	a
Methomyl	0.8 ± 0.2	1.5 ± 0.2	2.6 ± 0.1	a
Oxamyl	0.6 ± 0.2	1.5 ± 0.2	2.7 ± 0.1	a
Spinosad CDN	0.1 ± 0.1	1.8 ± 0.1	3.0 ± 0.0	a
Spinosad US	1.5 ± 0.2	2.5 ± 0.1	3.0 ± 0.0	a
Cabbage-Stouffville[c]				
Untreated control	0.0 ± 0.0	1.1 ± 0.1	1.0 ± 0.1	ab
λ-Cyhalothrin Matador CDN	0.0 ± 0.0	0.7 ± 0.1	1.1 ± 0.2	ab
λ-Cyhalothrin Matador US	0.0 ± 0.0	0.6 ± 0.1	0.7 ± 0.1	ab
Acetamiprid CDN	0.1 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	ab
Acetamiprid US	0.1 ± 0.1	0.7 ± 0.1	0.9 ± 0.1	ab
Imidacloprid	0.2 ± 0.1	1.1 ± 0.1	1.2 ± 0.1	a
Acephate	0.1 ± 0.1	1.1 ± 0.1	1.6 ± 0.2	a
Chlorpyrifos	0.1 ± 0.0	0.2 ± 0.1	0.4 ± 0.1	b
Methomyl	0.2 ± 0.1	1.0 ± 0.1	1.0 ± 0.2	a
Oxamyl	0.3 ± 0.2	1.0 ± 0.1	1.3 ± 0.2	a
Spinosad CDN	0.2 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	ab
Spinosad US	0.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.1	a

Eight insecticide applications were made to both broccoli (14, 21, and 30 June; 7, 14, 21, and 27 July; and 8 August) and cabbage (13, 20, and 28 June; 5, 12, 20, and 26 July; and 5 August). The means separations indicated represent the differences between treatments over the course of the season in damage ratings, and not differences between the actual means presented in the table. Means within an experiment followed by the same letter are not statistically different, by multiple means comparisons using Tukey's adjustment for LS Means, with $\alpha = 0.05$.

[a] 0, no damage; 1, mild twisting of stem or leaves and/or mild swelling of petioles; 2, severe twisting of stem and/or crumpling of leaves and/or swelling of florets; 3, death of apical meristem and/or multiple compensatory shoots.

[b] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 0.55$; df = 1,1367; $P = 0.87$; day, $F = 1005.50$; df = 2,1367; $P < 0.0001$; treatment × day, $F = 7.82$; df = 22,1367; $P < 0.0001$.

[c] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 3.31$; df = 1,1345; $P = 0.0002$; day, $F = 222.22$; df = 2,1345; $P < 0.0001$; treatment × day, $F = 2.39$; df = 22,1345; $P = 0.0003$.

ferent final damage ratings may not be found to differ statistically.

Efficacy of Pyrethroid, Organophosphate, and Spinosyn Insecticides Applied as Foliar Sprays. In 2001 broccoli trials, the higher rates of λ-cyhalothrin had significantly lower damage ratings than one or both control treatments at both sites (Table 2). At Markham (moderate populations), the higher rates of λ-cyhalothrin and both rates of permethrin had significantly lower damage ratings than the untreated controls, but not the azinphos-methyl treated controls, due to relatively subtle differences in damage development between the two control treatments. Final damage ratings at Markham were within marketable limits (i.e., <1.0) for all treatments, except the two controls. At Stouffville (very high populations), the higher rates of λ-cyhalothrin had significantly lower damage ratings than both control treatments, however, all final damage ratings were above marketable limits.

In 2002 broccoli trials at Markham, all pyrethroids, except the high rate of Warrior, had significantly lower damage ratings than those in the untreated control (Table 3), whereas damage ratings in spinosad treatments did not differ significantly from those in the untreated control. Damage ratings in the high rate of Warrior did not differ from those in the untreated control, whereas damage ratings in the low rate of Warrior did, due to the increase in damage that occurred 8 August in the high rate of Warrior treatments; a similar increase occurred in other λ-cyhalothrin treatments, but not until 13 August. All final damage ratings at Markham were within marketable limits, except the control in the pyrethroid trial. At Stouffville, no differences in damage ratings were found among treatments and all final damage ratings were well above marketable limits.

In 2001 cabbage trials, both rates of Warrior had significantly lower damage ratings than the control at Markham (Table 4). Damage ratings in Matador treatments did not differ from those in the control, whereas damage ratings in the Warrior treatments did, despite having the same active ingredient (AI λ-cyhalothrin) and rates, apparently due to the slightly earlier increase in damage ratings in Matador than Warrior treatments (1 versus 7 August). All final damage ratings were within marketable limits at Markham. At Stouffville, three of four λ-cyhalothrin and both rates of permethrin had significantly lower damage ratings than the untreated control. Final damage ratings in all treatments, except the two controls, were within marketable limits at Stouffville.

In 2002 cabbage trials, the lowest rate of permethrin had significantly lower damage ratings than acephate at Markham (Table 5). At Stouffville, all pyrethroids, except the high rate of λ-cyhalothrin (Warrior), had significantly lower damage ratings than the control, and final damage ratings for these treatments only were within marketable limits. Damage ratings in the acephate treatment did not differ significantly from the control at Stouffville.

Efficacy of Organophosphate, Carbamate, and Neonicotinoid Insecticides Applied as Foliar Sprays. In the 2005 broccoli trial at Stouffville (very high populations), no insecticide treatments had significantly lower damage ratings than the control, and all final damage ratings were above marketable limits (Table 6). Mean larval numbers were highly variable and ranged among treatments from 0.6 to 40.9 (4 July) and 0.9–24.1 (29 July) larvae per plant, but no significant differences in larval numbers were found among treatments. A significant positive correlation was found between larvae per broccoli plant and damage ratings on the same day ($F = 7.71$; df = 1,22; $P = 0.011$; $r^2 =$

Table 7. Mean damage ratings in a 2005 trial at Markham for broccoli treated with experimental insecticides to prevent damage by *C. nasturtii*

Treatment[a]	Mean damage rating (± SE)[b]							
	29 June	7 July	14 July	21 July	28 July	4 Aug.	11 Aug.	
Broccoli-Markham								
Untreated control	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.2 ± 0.1	0.7 ± 0.1	2.7 ± 0.1	2.6 ± 0.1	a
Metaflumizone	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.5 ± 0.1	2.3 ± 0.2	2.5 ± 0.1	bc
Cyromazine	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.1	2.6 ± 0.1	2.6 ± 0.1	ab
Commercial standard[c]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.5 ± 0.1	2.1 ± 0.2	2.3 ± 0.1	c

Six insecticide applications were made (23 June; 6, 11, 18, and 25 July; and 3 August). The means separations indicated represent the differences between treatments over the course of the season in damage ratings, and not differences between the actual means presented in the table. Treatments followed by the same letter are not statistically different, by multiple means comparisons using Tukey's adjustment for LS Means, with $\alpha = 0.05$.

[a] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 8.45$; df = 3,1089; $P < 0.0001$; day, $F = 771.26$; df = 6,1089; $P < 0.0001$; treatment × day, $F = 1.82$; df = 18,1089; $P = 0.019$.

[b] 0, no damage; 1, mild twisting of stem or leaves and/or mild swelling of petioles; 2, severe twisting of stem and/or crumpling of leaves and/or swelling of florets; 3, death of apical meristem and/or multiple compensatory shoots.

[c] Commercial standard, alternating applications of acetamiprid and λ-cyhalothrin (see Table 1).

0.259). Correlations between larvae per broccoli plant and damage ratings were not significant for damage ratings 20–25 d ($F = 3.71$; df = 1,22; $P = 0.067$; $r^2 = 0.144$) or 45 d ($F = 0.48$; df = 1,22; $P = 0.505$; $r^2 = 0.046$) later.

In the 2005 cabbage trial at Stouffville, chlorpyrifos had significantly lower damage ratings than imidacloprid, acephate, methomyl, oxamyl and the high rate of spinosad (Table 6). Mean larval numbers ranged among treatments from 0.1 to 36.4 (4 July) and 0.4–17.4 (29 July) larvae per plant, but no significant differences in larval numbers were found among treatments. A significant negative correlation was found between larvae per cabbage plant and damage ratings on the same day ($F = 4.77$; df = 1,22; $P = 0.0399$; $r^2 = 0.178$), and positive, but nonsignificant, relationships for damage ratings 20–25 d ($F = 1.95$; df = 1,22; $P = 0.176$; $r^2 = 0.081$) or 45 d ($F = 3.23$; df = 1,10; $P = 0.103$; $r^2 = 0.244$) later.

Efficacy of Experimental Insecticides Applied as Foliar Sprays. In this 2005 broccoli trial at Markham (high populations), the commercial standard and metaflumizone had significantly lower damage ratings than the control, but all final damage ratings were above marketable limits (Table 7).

Use Patterns of Novaluron Applied as Foliar Sprays. In the 2006 broccoli trial at Elora (moderate populations), the full and partial season treatments of the commercial standard, and the commercial standard plus the low rate of novaluron treatment, had significantly lower damage ratings than the control and than full season treatments with either rate of novaluron, indicating that novaluron is not effective against swede midge (Table 8). The lack of significant difference between the control and the commercial standard plus high low rate of novaluron treatment is reflective of the earlier increases in damage ratings in the latter compared with other commercial standard

Table 8. Mean swede midge damage ratings in a 2006 trial at Elora for broccoli treated with different use patterns of novaluron

Treatment[a]	Mean damage rating (± SE)[b]									
	22 June	27 June	5 July	13 July	18 July	25 July	1 Aug.	9 Aug.	15 Aug.	
Broccoli-Elora										
Untreated control	0.0 ± 0.0	0.1 ± 0.0	0.3 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	1.6 ± 0.1	2.3 ± 0.1	2.5 ± 0.1	2.0 ± 0.1	a
Metaflumizone	0.1 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	1.2 ± 0.1	2.2 ± 0.1	2.2 ± 0.1	2.2 ± 0.1	ab
Novaluron Low	0.1 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	1.4 ± 0.1	2.3 ± 0.1	2.6 ± 0.1	2.3 ± 0.2	a
Novaluron High	0.1 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	1.1 ± 0.1	2.1 ± 0.1	2.4 ± 0.1	2.8 ± 0.1	a
Commercial standard[c]	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.9 ± 0.1	1.4 ± 0.2	1.4 ± 0.2	1.0 ± 0.2	c
Commercial standard partial	0.1 ± 0.1	0.1 ± 0.0	0.5 ± 0.1	0.1 ± 0.0	0.1 ± 0.1	1.0 ± 0.1	1.2 ± 0.2	1.1 ± 0.2	0.9 ± 0.2	c
Commercial standard plus Novaluron Low	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.2 ± 0.1	0.1 ± 0.0	1.1 ± 0.1	1.5 ± 0.2	1.4 ± 0.1	1.3 ± 0.2	bc
Commercial standard plus Novaluron High	0.1 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	1.4 ± 0.1	1.8 ± 0.1	1.7 ± 0.2	1.3 ± 0.2	abc

Eight insecticide applications were made (14 and 23 June; 4, 11, 18, and 25 July; and 3 and 10 August) in full season treatments. Partial season treatments of the commercial standard were made until early head formation (25 July) and in the commercial standard plus novaluron treatments the commercial standard was applied until 25 July and novaluron applied from 3 August onward.

[a] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 8.75$; df = 8,3156; $P < 0.0001$; day, $F = 597.55$; df = 8,3156; $P < 0.0001$; treatment × day, $F = 7.78$; df = 64,3156; $P < 0.0001$. The means separations indicated represent the differences between treatments over the course of the season in damage ratings, and not differences between the actual means presented in the table. Treatments followed by the same letter are not statistically different, by multiple means comparisons using Tukey's adjustment for LS Means, with $\alpha = 0.05$.

[b] 0, no damage; 1, mild twisting of stem or leaves and/or mild swelling of petioles; 2, severe twisting of stem and/or crumpling of leaves and/or swelling of florets; 3, death of apical meristem and/or multiple compensatory shoots.

[c] Commercial standard, alternating applications of acetamiprid and λ-cyhalothrin (see Table 1).

Table 9. Mean swede midge damage ratings in a 2006 trial at Markham for cabbage treated with different use patterns of novaluron

Treatment[a]	Mean damage rating (± SE)[b]								
	26 June	4 July	14 July	19 July	26 July	2 Aug.	16 Aug.	24 Aug.	
Cabbage-Markham									
Untreated control	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	1.4 ± 0.2	1.5 ± 0.1	1.7 ± 0.1	1.8 ± 0.1	a
Metaflumizone	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.9 ± 0.1	1.3 ± 0.1	1.6 ± 0.1	1.8 ± 0.1	abc
Novaluron Low	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.6 ± 0.2	1.4 ± 0.2	1.6 ± 0.1	1.7 ± 0.1	ab
Novaluron High	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	1.7 ± 0.2	1.5 ± 0.1	1.5 ± 0.1	1.6 ± 0.1	ab
Novaluron Low partial	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.8 ± 0.1	1.5 ± 0.1	1.5 ± 0.1	1.7 ± 0.1	abc
Novaluron High partial	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.2	1.2 ± 0.2	1.5 ± 0.1	1.6 ± 0.1	abc
Commercial standard[c]	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.2	0.9 ± 0.2	1.4 ± 0.1	1.5 ± 0.1	c
Commercial standard partial	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	1.0 ± 0.1	1.4 ± 0.1	1.5 ± 0.1	bc

Eight insecticide applications were made (22 and 30 June; 7, 17, and 24 July; and 1, 9 and 18 August) in full season treatments. Partial season treatments of the novaluron and the commercial standard were made until cupping (24 July), with no further insecticide applications thereafter.

[a] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 3.52$; df = 8,2805; $P = 0.0005$; day, $F = 635.51$; df = 7,2805; $P < 0.0001$; treatment × day, $F = 4.07$; df = 56,2805; $P < 0.0001$. The means separations indicated represent the differences between treatments over the course of the season in damage ratings, and not differences between the actual means presented in the table. Treatments followed by the same letter are not statistically different, by multiple means comparisons using Tukey's adjustment for LS Means, with $\alpha = 0.05$.

[b] 0, no damage; 1, mild twisting of stem or leaves and/or mild swelling of petioles; 2, severe twisting of stem and/or crumpling of leaves and/or swelling of florets; 3, death of apical meristem and/or multiple compensatory shoots.

[c] Commercial standard, alternating applications of acetamiprid and λ-cyhalothrin (see Table 1).

treatments (25 July versus 1 August). Final damage ratings for the full and partial season commercial standard treatments were the only ones within marketable limits.

In the 2006 cabbage trial at Markham (high populations), the full and partial season treatments of the commercial standard had significantly lower damage ratings than the untreated control (Table 9). The full season commercial standard treatment also had significantly lower damage ratings than the full season

Table 10. Mean damage ratings in 2006 trials at Stouffville for broccoli and cabbage treated with a seed treatment, greenhouse plug tray drench, band spray, or foliar spray insecticide to prevent *C. nasturtii* damage

Crop, exp. and treatments	Application method[a]	Mean damage rating (± SE)[b]						
		21 June	26 June	4 July	11 July	17 July	21 July	
Broccoli-Stouffville[c]								
Untreated control		0.0 ± 0.0	0.1 ± 0.1	0.4 ± 0.1	2.0 ± 0.1	2.3 ± 0.1	2.5 ± 0.1	a
Clothianidin Low	ST	0.0 ± 0.0	0.1 ± 0.0	1.3 ± 0.1	2.3 ± 0.1	2.4 ± 0.1	2.3 ± 0.1	a
Clothianidin Int	ST	0.0 ± 0.0	0.1 ± 0.0	0.9 ± 0.1	2.0 ± 0.1	2.3 ± 0.1	2.4 ± 0.1	a
Thiamethoxam Low	ST	0.0 ± 0.0	0.1 ± 0.1	0.9 ± 0.1	2.0 ± 0.1	2.4 ± 0.1	2.4 ± 0.1	a
Thiamethoxam Int	ST	0.0 ± 0.0	0.1 ± 0.1	0.9 ± 0.1	2.1 ± 0.1	2.5 ± 0.1	2.5 ± 0.1	a
Acetamiprid High	GD	0.0 ± 0.0	0.1 ± 0.0	1.2 ± 0.1	2.3 ± 0.1	2.5 ± 0.1	2.6 ± 0.1	a
Imidacloprid High	GD	0.0 ± 0.0	0.2 ± 0.1	0.3 ± 0.1	0.1 ± 0.0	0.2 ± 0.1	0.2 ± 0.1	b
Imidacloprid	BS	0.0 ± 0.0	0.1 ± 0.1	0.8 ± 0.1	2.1 ± 0.1	2.2 ± 0.1	2.4 ± 0.1	a
Thiamethoxam	BS	0.0 ± 0.0	0.1 ± 0.1	0.6 ± 0.1	1.9 ± 0.1	2.4 ± 0.1	2.3 ± 0.1	a
Acetamiprid CDN	FS	0.0 ± 0.0	0.2 ± 0.1	0.7 ± 0.1	2.0 ± 0.1	2.3 ± 0.1	2.7 ± 0.1	a
Cabbage-Stouffville[d]								
Untreated control		0.0 ± 0.0	0.3 ± 0.1	0.8 ± 0.1	1.4 ± 0.2	1.9 ± 0.1	1.8 ± 0.1	ab
Clothianidin Low	ST	0.0 ± 0.0	0.2 ± 0.1	0.5 ± 0.1	1.8 ± 0.1	2.0 ± 0.1	1.8 ± 0.1	ab
Clothianidin Int	ST	0.0 ± 0.0	0.2 ± 0.1	0.1 ± 0.1	1.6 ± 0.1	1.9 ± 0.1	1.7 ± 0.1	ab
Thiamethoxam Low	ST	0.0 ± 0.0	0.2 ± 0.1	0.3 ± 0.1	1.2 ± 0.2	1.7 ± 0.1	1.6 ± 0.1	ab
Thiamethoxam Int	ST	0.0 ± 0.0	0.2 ± 0.1	0.3 ± 0.1	1.5 ± 0.2	1.9 ± 0.1	2.0 ± 0.1	ab
Acetamiprid High	GD	0.0 ± 0.0	0.3 ± 0.1	0.3 ± 0.1	1.7 ± 0.1	2.3 ± 0.1	1.8 ± 0.1	a
Imidacloprid High	GD	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	c
Imidacloprid	BS	0.0 ± 0.0	0.1 ± 0.1	0.5 ± 0.1	1.3 ± 0.2	1.7 ± 0.2	1.7 ± 0.1	ab
Thiamethoxam	BS	0.0 ± 0.0	0.2 ± 0.1	0.4 ± 0.1	1.6 ± 0.1	1.7 ± 0.2	1.6 ± 0.2	ab
Acetamiprid CDN	FS	0.0 ± 0.0	0.2 ± 0.1	0.1 ± 0.1	1.1 ± 0.2	1.4 ± 0.2	1.3 ± 0.2	b

Greenhouse drench applications were made on 6 or 14 June (imidacloprid and acetamiprid, respectively) and band spray applications on 16 June. Five foliar applications (16, 22, and 29 June; 7 and 14 July) were made. The means separations indicated represent the differences between treatments over the course of the season in damage ratings, and not differences between the actual means presented in the table. Treatments followed by the same letter are not statistically different, by multiple means comparisons using Tukey's adjustment for LS Means, with $\alpha = 0.05$.

[a] ST, seed treatment; GD, greenhouse plug tray drench; BS, band spray; and, FS, foliar spray.

[b] 0, no damage; 1, mild twisting of stem or leaves and/or mild swelling of petioles; 2, severe twisting of stem and/or crumpling of leaves and/or swelling of florets; 3, death of apical meristem and/or multiple compensatory shoots.

[c] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 33.11$; df = 9,2337; $P < 0.0001$; day, $F = 1854.84$; df = 5,2337; $P < 0.0001$; treatment × day, $F = 25.56$; df = 45,2337; $P < 0.0001$.

[d] Mixed model repeated measures ANOVA, Type 3 tests of fixed effects: treatment, $F = 13.94$; df = 9,2337; $P < 0.0001$; day, $F = 559.81$; df = 5,2337; $P < 0.0001$; treatment × day, $F = 9.22$; df = 45,2337; $P < 0.0001$.

Table 11. Mean damage ratings in a 2006 trial at Niagara County, NY, for broccoli and cabbage treated with a seed treatment, band spray, or foliar spray insecticide to prevent *C. nasturtii* damage

Treatment name	Application method[a]	Mean damage rating (± SE)[b,c,d]		
		July 11	July 18	July 25
Control		0.0 ± 0.0aB	0.5 ± 0.3aB	2.0 ± 0.1aA
Chlorpyrifos	FS	0.0 ± 0.0aA	0.9 ± 0.5aA	0.9 ± 0.3abA
Methomyl	FS	0.0 ± 0.0aA	1.2 ± 0.6aA	1.0 ± 0.6abA
Acetamiprid US	FS	0.0 ± 0.0aA	0.3 ± 0.2aA	0.7 ± 0.4abA
λ-Cyhalothrin Warrior US	FS	0.0 ± 0.0aB	0.1 ± 0.1aAB	0.7 ± 0.2abA
Imidacloprid High	FS	0.0 ± 0.0aA	0.3 ± 0.3aA	1.0 ± 0.4abA
Dimethoate	FS	0.0 ± 0.0aB	0.0 ± 0.0aB	0.4 ± 0.1bA
Clothianidin High	ST	0.0 ± 0.0aA	0.2 ± 0.2aA	0.0 ± 0.0bA
Thiamethoxam High	ST	0.0 ± 0.0aA	0.2 ± 0.2aA	0.3 ± 0.1bA
Imidacloprid	BS	0.0 ± 0.0aA	0.0 ± 0.0aA	0.0 ± 0.0bA
Acetamiprid	BS	0.0 ± 0.0aA	0.1 ± 0.1aA	0.2 ± 0.2bA

A single application of foliar and band sprays was made at transplanting on 3 July. Means (± SE) followed by the same lowercase letters within a column or the same capital letters within a row for each parameter are not significantly different by multiple means comparisons using Tukey's adjustment for LS Means, with $\alpha = 0.05$.

[a] FS, foliar spray; ST, seed treatment; and BS, band spray.

[b] 0, no damage; 1, mild twisting of stem or leaves and/or mild swelling of petioles; 2, severe twisting of stem and/or crumpling of leaves and/or swelling of florets; 3, death of apical meristem and/or multiple compensatory shoots.

[c] Mixed model ANOVAs by date, Type 3 tests of fixed effects, treatment, df = 10,30; July 18, $F = 2.02$, $P = 0.068$; July 25, $F = 4.28$, $P = 0.0009$.

[d] Mixed model ANOVAs by treatment, Type 3 tests of fixed effects: week, df = 2,6; Control, $F = 25.33$, $P = 0.0012$; Chlorpyrifos, $F = 2.95$, $P = 0.13$; Methomyl, $F = 3.64$, $P = 0.09$; Acetamiprid US, $F = 2.85$, $P = 0.13$; Warrior US, $F = 6.58$, $P = 0.03$; Imidacloprid High, $F = 4.94$, $P = 0.054$; Dimethoate, $F = 6.94$, $P = 0.028$; Clothianidin High, $F = 1.00$, $P = 0.42$; Thiamethoxam High, $F = 3.00$, $P = 0.13$; Acetamiprid, $F = 1.00$, $P = 0.42$.

treatments with either rate of novaluron. Damage ratings in the commercial standard treatments did not differ significantly from those observed in the partial season treatments of novaluron, but marketable limits were exceeded in the partial novaluron treatments 2 wk earlier than observed in the full or partial commercial standard treatments. Damage ratings in the metaflumizone treatment were not significantly different than the control. Final damage ratings in all treatments were above marketable limits.

Efficacy of Seed Treatments, Greenhouse Drenches, and Band Spray Treatments. In the 2006 broccoli trial Stouffville (very high populations), imidacloprid applied at a high rate as a greenhouse drench, but not when applied as a band spray at a rate equivalent to that recommended for aphid control on Brussels sprouts (*Brassica oleracea* Gemmifera Group), had very low levels of damage throughout the trial period, and was the only treatment with significantly lower damage ratings than the control (Table 10). Final damage ratings in all other treatments were well above marketable limits.

In the 2006 cabbage trial at Stouffville, damage ratings in the imidacloprid greenhouse drench treatment were extremely low throughout the trial period and were significantly lower than all other treatments (Table 10). The registered Canadian rate of acetamiprid applied as a foliar spray had significantly lower damage ratings than that of the acetamiprid greenhouse drench, but was not significantly different from the control or any other treatments. At 3 wk after transplanting, very low damage ratings were observed in the clothianidin seed treatment, the imidacloprid greenhouse drench and the acetamiprid foliar spray treatments. However, damage ratings were above marketable limits for all treatments except the imidacloprid greenhouse drench treatment from 4 wk after transplanting.

Insecticide Efficacy Field Trial in New York State. The number of adult male *C. nasturtii* captured by the pheromone trap was 3.0 ± 0.7 (mean ± SE) per trap per day during the course of the trial, indicating that this was a site of low infestation in 2006. There were no significant differences in damage ratings among treatments in the first two sampling weeks; however on 25 July, damage ratings in the dimethoate foliar spray, the clothianidin and thiamethoxam seed treatments, and the imidacloprid and acetamiprid band

Table 12. Susceptibility of *C. nasturtii* larvae to selected insecticides after 24 h by using the diet-overlay method in laboratory bioassays

Insecticide tested		Slope (± SE)		LC_{50} ppm (95% CL)		χ^2 (df)	
Active Ingredient	Product name	Lab colony	Canadian colony	Lab colony	Canadian colony	Lab colony	Canadian colony
λ-Cyhalothrin	Warrior	1.3 ± 0.2	1.6 ± 0.4	1.6 (0.8–2.6)	0.9 (0.3–1.7)	0.5 (3)	0.4 (3)
Acetamiprid	Assail 70WP	1.1 ± 0.2	1.2 ± 0.2	2.4 (0.7–5.6)	8.7 (5.6–13.4)	5.4 (4)	2.4 (4)
Imidacloprid	Provado 1.6F	1.2 ± 0.2	0.9 ± 0.2	3.8 (2.5–5.9)	9.0 (4.2–17.6)	1.7 (4)	0.9 (4)
Chlorpyrifos	Lorsban 4E	1.9 ± 0.6	1.0 ± 0.1	7.3 (4.1–11.6)	9.2 (4.3–22.0)	3.7 (3)	4.3 (4)
Methomyl	Lannate LV	1.3 ± 0.2	1.1 ± 0.2	8.0 (5.2–12.1)	15.7 (8.4–28.6)	2.2 (3)	0.9 (3)
Acephate	Orthene 75S	1.1 ± 0.1	1.9 ± 0.4	27.7 (17.4–45.4)	52.6 (12.5–93.1)	1.5 (4)	0.7 (4)
Spinosad	SpinTor 2SC	1.6 ± 0.3	1.3 ± 0.2	33.3 (20.8–49.8)	32.5 (21.1–50.3)	0.9 (3)	1.8 (3)

spray treatments were significantly lower than damage ratings in the control (Table 11). Damage ratings increased significantly over time in the control, λ-cyhalothrin and dimethoate treatments. However, in all treatments, except the control, damage ratings 3 wk after transplanting were within marketable limits. The number of live larvae found on each plant (0.0–0.2, 11 July; 0.0–4.8, 18 July; 0.0–3.7, 25 July) did not differ significantly among insecticide treatments nor among sampling times after insecticide application.

Insecticide Resistance Bioassays. Under laboratory conditions, both the laboratory and Canadian colonies exhibited differences in susceptibilities to different insecticides (Table 12). Both colonies were most susceptible to λ-cyhalothrin, followed by the neonicotinoids acetamiprid and imidacloprid. Both colonies were least susceptible to acephate and spinosad. For all tested insecticides, no significant differences were found between LC_{50} values of the two colonies.

Discussion

During the early phase of regional colonization by *C. nasturtii* in Ontario (i.e., from introduction until ≈2002), the pyrethroids λ-cyhalothrin and permethrin were effective in reducing damage by *C. nasturtii* (Tables 2–5). The pyrethroids were initially selected for evaluation because of their reported use against *C. nasturtii* in Europe. In the 2001–2002 trials, damage to plants treated with λ-cyhalothrin was within acceptable limits for marketability, except under high population pressure in broccoli (i.e., Stouffville; Tables 2 and 3). On the basis of these results, λ-cyhalothrin (Matador) was registered in Canada for use against *C. nasturtii* in cole crops in 2003 (registration 24984.00, Pest Management Regulatory Agency). The neonicotinoid acetamiprid (Assail) was subsequently registered for this use (registration 27128.00; Pest Management Regulatory Agency), and approximately alternating applications of Assail (maximum five applications per year) and Matador (maximum three applications per year) were the recommended commercial standard in Ontario during the course of this study. In New York, registration expansions of λ-cyhalothrin (Warrior) and imidacloprid (Admire) were recently approved under Section 2 (ee) to include *C. nasturtii.* These complement the already approved national registration for acetamiprid (Assail) for *C. nasturtii.*

Of the other insecticides examined (but see below for discussion of the neonicotinoids), there were few that were found to be effective either during the early or later (i.e., from 2005) phases of regional colonization. Foliar applications of spinosad (Tables 3 and 6), novaluron (Tables 8 and 9), cyromazine (Table 7), and the carbamates methomyl and oxamyl (Tables 6 and 11) were not effective in reducing damage by *C. nasturtii.* Among the organophosphates, dimethoate was effective (Table 11), but acephate was not (Tables 4–6) and chlorpyrifos was effective on cabbage, but not broccoli (Tables 6 and 11). In a short season trial, metaflumizone was effective (Table 7), but this did not hold up during a subsequent full season trial (Tables 8 and 9).

In 2001–2002, damage by *C. nasturtii* was kept within marketable limits in all broccoli and cabbage trials conducted under moderate population pressure (i.e., Markham), but not in broccoli trials, nor some cabbage treatments, conducted under very high population pressure (i.e., Stouffville). These results point to differences in crop susceptibility to swede midge damage and the effect of population pressure on insecticide efficacy. In later phases of colonization, such as in Ontario in 2005, treatments were rarely able to maintain damage levels within marketable limits at either location and for either crop. In prior studies using the laboratory colony, *C. nasturtii* larvae were susceptible to λ-cyhalothrin, acephate, acetamiprid, chlorpyrifos, and methomyl applied as foliar sprays; and adults were susceptible to all of these, except acetamiprid (Wu et al. 2006). In field trials in New York, these products were relatively effective over a 3-wk period, prompting us to examine whether insecticide resistance had developed within the Canadian *C. nasturtii* population. With only two active ingredients (λ-cyhalothrin and acetamiprid) registered for field use against *C. nasturtii* in Canada and multiple generations per season (Goodfellow 2005, Hallett et al. 2007), there is a high risk of insecticide resistance evolving in *C. nasturtii.* However, susceptibility of *C. nasturtii* to both λ-cyhalothrin and acetamiprid was confirmed through insecticide resistance comparisons between the laboratory and Canadian colonies, and this hypothesis was rejected. Colony populations were found to be least susceptible to spinosad and acephate, which agreed with field efficacy results. The risk of insecticide resistance development still exists, however, and these LC_{50} results provide important baseline data against which to assess changes in insecticide susceptibility of *C. nasturtii* from this location and populations from different locations.

Rather than being related to insecticide-resistance, it seems that the inability of most foliar-applied insecticides to maintain damage within acceptable levels over the course of the 2005 season was due to the presence of continuous and high populations of *C. nasturtii,* as shown by pheromone trap catches in Ontario frequently exceeding 50, and reaching 333 male adults per trap per day during the trials (in contrast to three per trap per day in New York). In 2006, the commercial standards maintained damage within acceptable levels under moderate, but not high, population pressure in Ontario. Under high population conditions, it is challenging to prevent damage over the course of the entire season. Insecticide applications in these trials were based on a calendar schedule; timing of insecticide applications according to pheromone trap captures of *C. nasturtii* may have improved efficacy. However at locations with high populations, there are usually no adult midge-free time periods from late June to early September (Hallett 2007, Hallett et al. 2009). Larvae are protected between compressed leaves and/or within swollen petioles and florets; thus, systemic activity, spray penetration and coverage may be also be important factors in the occurrence of failures to control *C. nasturtii* damage in the field, and may explain the dramatic increase in damage ratings that often occurs in late July, particularly in broccoli field trials. Density-dependent effects of *C. nasturtii* populations on efficacy of acetamiprid in combination with host plant stage are currently under investigation.

Lack of apparent efficacy over the course of a full season may also be because we assessed damage symptoms rather than insect mortality. *C. nasturtii* damage symptoms do not disappear once they have developed. Although cabbage may not show obvious signs of damage to the head if only young leaves were affected, once a broccoli plant has begun to form a head it is not possible to distinguish new damage from old. Thus, it may be more difficult to demonstrate efficacy using damage ratings than with insect mortality measures, but damage ratings are reflective of marketability and thus may be the most appropriate metric to use. The damage rating approach was adopted due to the large number of plants that would be required for destructive sampling over the course of the season—a number incompatible with replicated small plot research. In an attempt to overcome this limitation, larval assessments were conducted on plants at three intervals in 2005 trials. Overlapping insect generations and lag times associated with plant damage expression often resulted in the anomaly of high numbers of larvae but low damage ratings or vice versa on a given observation date. Larval numbers were also highly variable with standard errors frequently ≥50% of the mean. Consequently, a positive correlation between larval numbers per plant and damage ratings on the same day was not observed in cabbage. However, a significant positive relationship between larval numbers per plant and damage ratings on the same day was observed in broccoli, indicating that damage ratings are reflective of larval populations and thus a reasonable surrogate for larval mortality data.

The neonicotinoids proved efficacious with a number of different application methods, particularly at the higher rates examined. Acetamiprid (included in the commercial standard) showed consistent efficacy as a foliar application under moderate to high population pressure (Elora and Markham, Ontario) and at least 3 wk efficacy when applied as a band spray under low population pressure (New York). Greenhouse plug drench applications of imidacloprid at a high rate effectively suppressed *C. nasturtii* damage in Ontario trials, and high volume band spray applications were more effective than a single foliar spray in New York trials. The imidacloprid band spray was likely more effective in New York than Ontario trials due to higher population pressure of *C. nasturtii* in Ontario. Neonicotinoid soil drenches and seed treatments were effective in New York field trials and confirmed results of lab studies (Wu et al. 2006), in which complete control of larvae was observed for several weeks. Thus, use of an early season neonicotinoid treatment (i.e., seed treatment, treatment of transplants in the greenhouse before shipping, or a band spray immediately after transplanting to the field) may be the most effective way to control *C. nasturtii* and to minimize damage symptoms in the first 3–5 wk after transplanting. These early season treatments would require supplemental control with foliar insecticides for the remainder of the season but would reduce the number of foliar applications required and thus reduce insecticide usage. Early season treatments also may reduce *C. nasturtii* populations sufficiently to reduce damage later in the season, but this effect could not be evaluated in our small plot field trials. However, there should be concern about *C. nasturtii* developing resistance to neonicotinoids if they are used in both the greenhouse and field, or used excessively in either situation. There are many factors that will influence the evolution of resistance: the intensity of selection in an area, number of generations produced annually, the homogeneity of the population, the number and dominance of genes involved, the persistence of the insecticide and the inherent toxicity mechanisms of a particular class of insecticides (Roush and Tabashnik 1990). None of these factors are presently known for *C. nasturtii.* However, recent research in Canada and New York has indicated that *C. nasturtii* colonizes several cruciferous weed hosts in and around vegetable crucifer production (Hallett 2007; Chen et al. 2009), and these may serve as refuges for susceptible alleles in the population. However, their role in the overall ecology of *C. nasturtii* and potential to delay resistance is not known. Considerable research is required to develop an effective insecticide resistance management program for *C. nasturtii.* Biological control options for the swede midge are currently quite limited and require further investigation (Corlay et al. 2007). Thus, an integrated pest management program that uses cultural controls such as soil manipulations that reduce emergence from the pupal stage (Chen and Shelton 2007), management of cruciferous weeds (Chen et al. 2009), and host plant resistance (Hallett 2007), with judicious use of insecticides, is needed for sustainable management of this newly invasive pest.

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