Evaluation of Insecticides and Application Methods Against *Contarinia nasturtii* (Diptera: Cecidomyiidae), a New Invasive Insect Pest in the United States

QING-JUN WU,[1, 2] JIAN-ZHOU ZHAO,[1] ALAN G. TAYLOR,[3] AND ANTHONY M. SHELTON[1, 4]

J. Econ. Entomol. 99(1): 117–122 (2006)

ABSTRACT The midge *Contarinia nasturtii* (Keiffer), a serious gall-forming insect pest of cruciferous plants in Europe and southwestern Asia, was first reported in the United States in summer 2004. It had not been recorded in North America until its discovery in Ontario, Canada, in 2000. Efficacy of 20 insecticides belonging to 12 different classes was evaluated by using a foliar spray, soil drench, or seed treatment method. The broccoli cultivar 'Packman' was used in all tests at the suitable stage of four to five true leaves. Results indicated that foliar sprays of λ-cyhalothrin, acephate, acetamiprid, chlorpyrifos, and methomyl reduced *C. nasturtii* larval populations by 96.7–100%. Except for acetamiprid, the other four insecticides also were effective against adults and provided 100% mortality after 24 h. When applied by drench, acetamiprid, imidacloprid, and thiamethoxam provided 100% control of *C. nasturtii* larvae, and the duration of efficacy lasted at least 7 wk. When applied as seed treatment, clothianidin and thiamethoxam provided 100% control of larvae and did not significantly affect seed germination. Imidacloprid also provided 100% control but the percentage of germination after treatment was only 62% (96.9% in check). These results indicate that several insecticides may significantly reduce midge populations. The nicotinoid class of insecticides, which has strong systemic activity, is likely to be the first choice. It is necessary to explore and develop other control methods such as cultural control and host resistance to develop an effective integrated pest management system.

KEY WORDS *Contarinia nasturtii*, invasive insect pest, insecticide efficacy

Contarinia nasturtii (Keiffer) (Diptera: Cecidomyiidae), first described in 1888 (Kieffer 1888), is a widely distributed gall-forming pest of cruciferous plants in Europe and southwestern Asia. It was not known to occur in North America until its first identification in Ontario, Canada, in 2000 (Hallett and Heal 2001). Damage caused by *C. nasturtii* was observed as early as 1994, but it was misdiagnosed as a molybdenum nutrient deficiency (Hallett and Heal 2001). Intensive field scouting was subsequently conducted in areas of New York state near the Canadian border, where crucifer production would likely be first confronted with the threat from this invasive pest. In summer 2004, adult *C. nasturtii* were captured by using pheromone traps in four fields of Niagara County, New York. Limited damage was observed, and larvae were identified simultaneously on one of the farms (Kikkert et al. 2004).

C. nasturtii larvae are tiny yellowish maggots living gregariously mainly inside the growing tips of a plant. Some disperse to the outer leaves, stems, or axils for food when too many larvae live in the same point. They do not gnaw the plants directly but produce a secretion that breaks down the plant tissues, which then can be consumed by the larvae (Barnes 1946). As a result, the stalk becomes swollen and bends sharply inwards; swelling and twisting of the growing point are typical symptoms. The most severe damage is "blind head" or "many necks" caused by the central shoot being killed and secondary shoots produced. Often brown scars may be seen on the leaf petioles, stem, or young leaves. Sometimes the injured sites also serve as entry points for plant pathogens. The degree of plant injury depends partly on the number and distribution of larvae and partly on the growth rates of undamaged cells (Readshaw 1965). Generally, the younger the plants are when attacked, the more difficult for them to recover, but the relationship between *C. nasturtii* attack and yield loss is complex. Heading brassica vegetables such as cauliflower, broccoli, and savoy are more vulnerable than root crops such as swede (Bardner et al. 1971). Between 1996 and 1999 in Canada, up to 85% of marketable broccoli yield loss was caused by *C. nasturtii* damage (Hallett and Heal 2001).

C. nasturtii adults and larvae are small and difficult to detect in the field. The damage caused by *C. nas-*

[1] Department of Entomology, Cornell University, NYSAES, Geneva, NY 14456.
[2] Institute of Vegetables and Flowers, CAAS, Beijing 100081, China.
[3] Department of Horticultural Science, Cornell University, NYSAES, Geneva, NY 14456.
[4] Corresponding author, e-mail: ams5@cornell.edu.

0022-0493/06/0117–0122$04.00/0

Table 1. Insecticides used in efficacy tests

Chemical class	Common name	Trade name	Producer	Test[a]
Organophosphate	Acephate	Orthene 75S	Valent	FS
	Chlorpyrifos	Lorsban 4E	Dow	FS
Carbamate	Methomyl	Lannate LV	DuPont	FS
	Oxamyl	Vydate L	DuPont	FS, SD
Pyrethroid	λ-Cyhalothrin	Warrior	Syngenta	FS
Nicotinoid	Acetamiprid	Assail 70WP	Bayer	FS, SD, ST
	Clothianidin	Poncho 600	Bayer	ST
	Imidacloprid	Provado 1.6F	Bayer	FS
		Gaucho 480F	Bayer	ST
		Admire 2	Bayer	SD
	Thiamethoxam	Cruiser 5FS	Syngenta	ST
		Platinum	Syngenta	SD
Microbial	Abamectin	Agri-Mek 0.15EC	Syngenta	FS
	Bt *israeliensis*	Gnatrol	Valent	FS
	Emamectin benzoate	Proclaim 5%	Syngenta	FS
	Spinosad	SpinTor 2SC	Dow	FS
		Entrust 80W	Dow	ST
Antifeedants	Pymetrozine	Fulfill	Syngenta	FS
Botanical	Azadirachtin	Neemix 4.5	Certis	FS
Insect growth regulators	Cyromazine	Trigard OMC	Syngenta	FS
	Pyripoxyfen	Esteem 35WP	Valent	FS
Oxadiazine	Indoxacarb	Avaunt 30%	DuPont	FS
Pyrazole	Fipronil	Regent 6.2 TS	BASF	ST
Others	Kaolin clay	Surround WP	Engelhard	FS
Spray adjuvant	Silicone-polyether copolymer	Silwet L-77	OSi Specialties, Inc.	FS, SD

[a] FS, foliar spray; SD, soil drench; and ST, seed treatment.

turtii can be mistaken for physiological and/or nutritional problems or other insect pest damage. The midges pupate in the soil for >1 yr; therefore, management by rotation strategies is difficult. With about three to four overlapping generations per year in Ontario, Canada (Hallett and Heal 2001), damage may occur at any time during the season. Many weeds from the Cruciferae family can serve as alternate host plants when cultivated cruciferous crops are not available (Stokes 1953).

A first step for managing this new invasive insect pest is to find different currently labeled insecticides and application methods for controlling *C. nasturtii* to prevent it from spreading. Ouden et al. (1987) tested the efficacy of polyisobutylene polymers on *C. nasturtii*, but few studies are published for *C. nasturtii* chemical control. The current study focused on testing the efficacy of different insecticides and application methods against *C. nasturtii.* Our main objective was to identify potential control approaches that could be tested in the field. Because *C. nasturtii* populations in the United States were not sufficiently large for field testing, all our tests were conducted in the laboratory.

Materials and Methods

Insects. Initially, a population of *C. nasturtii* was provided in 2004 from Switzerland by R. Baur and was placed in a rearing chamber under quarantine conditions at 22°C, RH 75–78% and a photoperiod of 16:8 (L:D) h. The food plant was cauliflower (*Brassica oleracea* variety *botrytis*, variety 'Snow Crown'), with eight to 10 true leaves, grown in pairs in 13-cm-diameter pots. Two pots of plants were placed into 50 by 50 by 50-cm cages containing ≈100 adults, males and females, for 24 h. Then, the plants were removed and replaced by the next batch and incubated under the same conditions. The growing tips of the plants were misted with tap water every day 5–6 d after oviposition. The aboveground parts were cut off on day 15 after oviposition.

Insecticides. The insecticides used for foliar spray, soil drench, and seed coating are listed in Table 1. They belong to 12 different classes of insecticides. A silicone-polyether copolymer (Silwet L-77, OSI Specialties Inc., Greeley, CO) was used as an adjuvant, with 0.1% added to the insecticide solution in the foliar spray and soil drench tests. All the treatment rates were selected according to the Crop Protection Reference (2003).

Foliar Spray Tests on Eggs and Larvae. Broccoli (*Brassica oleracea* variety *italica*, variety 'Packman') plants with four to five true leaves were used in all tests. Broccoli seeds were planted in a 72-well Styrofoam flat. Seedlings were transplanted into 10-cm-diameter pots 3 wk later. Plants were used 4–5 wk after planting. Eight broccoli plants were placed in a 50 by 50 by 50-cm wooden cage, and 40 females and 20 males were released into the cage and allowed to oviposit. Adults were collected from the colony using a mouth aspirator. The position of each plant in the cage was changed at 24 h to increase random oviposition, and the plants were removed after 48 h. The eight plants were randomly divided into four groups, two plants in each group as one replicate. One group was used as control and the other three were sprayed with different insecticides. Spraying was done in a track chamber (Allen Machine Works, Midland, MI), y using a single nozzle 50 cm above the plant and spraying at 40 psi and 187 liters/ha. Because kaolin clay forms a barrier film

Table 2. Efficacy of insecticides applied by foliar spray on eggs and larvae of *C. nasturtii* 10 d after inoculation

Insecticide	Rate g (AI)/ha	Actual concn (ppm)	% larval reduction (±SEM)[a]	No. larvae on control plant (±SEM)
Chlorpyrifos	1,120	5,991.4	100a	110.7 ± 3.1
Methomyl	1,008	5,392.6	100a	110.7 ± 3.1
Acetamiprid	84	445.7	99.9 ± 0.08a	115.4 ± 39.7
Acephate	1,456	7,788.8	99.5 ± 0.6ab	110.7 ± 3.1
λ-Cyhalothrin	33.6	179.7	96.7 ± 3.1ab	84.4 ± 19.5
Imidacloprid	52.6	280.9	91.8 ± 5.1ab	86.5 ± 22.6
Spinosad	179.2	936.2	91.7 ± 4.2ab	84.4 ± 19.5
Oxamyl	560	2,995.7	90.6 ± 3.8bc	84.4 ± 19.5
Pyripoxyfen	369.6	655.1	72.4 ± 13.0cde	90.9 ± 12.0
Abamectin	134.4	747.5	71.2 ± 4.7def	92.3 ± 18.7
Indoxacarb	72.8	393.2	50.9 ± 14.9def	65.1 ± 13.6
B. t. israeliensis	241.5	1,276	52.7 ± 8.7def	92.3 ± 18.7
Cyromazine	16.8	89.8	46.1 ± 13.0def	51.3 ± 10.6
Pymetrozine	96.3	515.0	43.2 ± 9.1ef	56.1 ± 18.6
Kaolin clay	23,750	23,750	37.0 ± 9.2ef	107.3 ± 10.3
Azadirachtin	23.5	140.6	19.7 ± 11.8f	51.3 ± 10.6
Emamectin benzoate	25.8	468.8	18.5 ± 11.0f	51.3 ± 10.6

[a] Means within a column followed by same letters are not significantly different ($\alpha = 0.05$, Tukey–Kramer honestly significant difference [HSD] test).

to protect plants from insects, the spraying was conducted 1 d before inoculation, by using a hand sprayer. After the plants were sprayed, they were placed in the rearing chamber and watered as needed. There were six to eight replicates for each insecticide. The number of larvae in each plant was recorded 10 d after inoculation by dissecting the growing tips by using forceps under a stereomicroscope. If there was no obvious damage or eggs or larvae inside the growing points of a treated plant, the plant was not used for data collection. A test was discarded when no damage or <5 larvae were observed on both control plants.

Foliar Spray Tests on Adults. Leaves were cut from insecticide-sprayed plants 1 h after treatment and placed into 30-ml plastic cups. Each cup was infested with five male or female adults, with 10 replicates for each insecticide. Preliminary tests indicated that there was no significant difference between the susceptibility of male and female *C. nasturtii* to different insecticides. Cups were examined under a stereomicroscope eight and 24 h after infestation. Adults which were unable to stand up or could not walk two body lengths were recorded as dead.

Soil Drench Tests. Five insecticides were evaluated as soil drenches. Plant stage, method of inoculation, replicates, assessment time, methods of reading and analyzing data were the same as those used in foliar spray tests on eggs and larvae. The only difference was that the soil around the broccoli plants was drenched with 20 ml of diluted insecticide solution 48 h after the oviposition period. The duration of efficacy of the four effective insecticides also was evaluated. Plants were treated 3 d after transplant. At 1, 3, 5, and 7 wk, respectively, after drench, eight plants, two for each insecticide, and two control plants were placed into a cage containing *C. nasturtii* adults for 48 h. The number of larvae present was recorded 10 d after inoculation. There were three replicates for each treatment for efficacy duration tests.

Seed Treatment Tests. Broccoli seeds (cultivar Packman) were treated with an insecticide by using a film-coating treatment similar to that described for control of cabbage maggot (Jyoti et al. 2003). Treated seeds were planted in 3-cm pots, and the test procedure was similar to that of the foliar spray. Transplants with four to five true leaves were exposed to *C. nasturtii* adults for 48 h. Plants were then removed and placed in the rearing chamber. The number of larvae in each plant was recorded 10 d after inoculation. At the same time, the number of plants showing *C. nasturtii* injury also was recorded.

The roll towel method was used to evaluate the germination of the coated seeds (Association of Official Seed Analysts 1993). Seeds were placed in the dark at a constant temperature of 20°C. The germination percentage was recorded after 9 d and assessed based on examination of the cotyledons, hypocotyls, and roots of the plants (Association of Official Seed Analysts 1992).

Data Analysis. Efficacy evaluation was conducted from egg to larva stage. The initial exact number of eggs was uncountable. Efficacy of different insecticides was assessed as larval reduction compared with the control. Larval reduction (%) = [(larvae per control plant − larvae per treated plant)/larvae per control plant] × 100%. All percentage data were arcsine square-root transformed before being subjected to analysis of variance (ANOVA). Treatment means were compared and separated by Tukey–Kramer at $\alpha = 0.05$ by using JMP software (JMP Start Statistics 2000).

Results

Foliar Spray Tests on Eggs and Larvae. There were 17 insecticides evaluated in foliar spray tests for efficacy of controlling eggs and newly hatched larvae. The most effective insecticides were chlorpyrifos, methomyl, acetamiprid, and acephate, with larval reduction of 99.5–100% (Table 2). No damage was observed on plants treated with acetamiprid, chlorpyrifos, and methomyl. When the growing points of the plants

Table 3. Efficacy of insecticides on adults of *C. nasturtii*

Insecticide	Rate g (AI)/ha	Actual concn (ppm)	No. adults infested	8 h		24 h	
				No. dead	% mortality (±SEM)[a]	No. dead	% mortality (±SEM)[a]
Chlorpyrifos	1,120	5,991.4	58	58	100a	58	100a
Methomyl	1,008	5,392.6	54	54	100a	54	100a
λ-Cyhalothrin	33.6	179.7	54	52	97.5 ± 1.7a	54	100a
Acephate	1,456	7,788.8	58	36	61.2 ± 6.6b	58	100a
Indoxacarb	72.8	393.2	54	31	56.9 ± 5.5b	49	90.9 ± 3.1b
Imidacloprid	52.6	280.9	55	33	60.0 ± 3.9b	45	81.6 ± 2.7c
Oxamyl	560	2,995.7	57	36	62.9 ± 5.1b	38	66.9 ± 3.6d
Pymetrozine	96.3	515.0	57	11	19.1 ± 5.2d	31	56.3 ± 8.4d
Acetamiprid	84	445.7	46	20	39.2 ± 5.9c	22	42.8 ± 5.5e
Spinosad	179.2	936.2	57	3	5.7 ± 4.2e	15	27.8 ± 7.5f
Abamectin	25.8	140.4	49	4	6.9 ± 3.6de	8	14.9 ± 3.3fg
Emamectin benzoate	16.8	89.8	55	2	4.0 ± 2.7e	4	8.0 ± 3.3g
Pyripoxyfen	369.6	655.1	57	3	5.7 ± 2.9d	3	5.7 ± 2.9g
Azadirachtin	23.5	140.6	51	1	2.0 ± 2.0e	3	5.3 ± 2.7g
Control	0	0	51	0	0 e	1	2.0 ± 2.0g

[a] Means within a column followed by same letters are not significantly different ($\alpha = 0.05$, Tukey–Kramer HSD test).

were dissected, clusters of dead eggs or dead newly hatched larvae were seen inside, which meant these three insecticides prevented the eggs from hatching or the residue in plants killed the newly hatched larvae directly. In acephate-treated plants, only 2.5 larvae per plant were found in one replicate, and the growing tips showed a little swelling, whereas 114 larvae per control plant were found, resulting in death of the growing tips. The larval reduction by λ-cyhalothrin, imidacloprid, spinosad, and oxamyl was 90.6–96.7%. Slightly swollen and crumpled growing tips were observed in some plants. Pyripoxyfen, an insect growth regulator (IGR), provided 72.4% efficacy. The other nine insecticides tested produced <72% control of *C. nasturtii* eggs and larvae.

Foliar Spray Tests on Adults. Fourteen insecticides were tested on *C. nasturtii* adults. Four insecticides that were effective on larvae in the foliar spray trial (chlorpyrifos, methomyl, acephate, and λ-cyhalothrin) also were effective on adults with 100% mortality 24 h after treatment (Table 3). Both chlorpyrifos and methomyl had quick and excellent activity with 100% mortality 8 h after infestation. λ-Cyhalothrin knocked down the adults in <2 h, and the mortality was 97.5% after 8 h and reached 100% after 24 h. Although there was only 61.2% mortality for acephate after 8 h, the mortality reached 100% at 24 h. Indoxacarb and imidacloprid treatments resulted in 90.9 and 81.6% mortality, respectively, after 24 h. The other eight insecticides were less effective.

Soil Drench Tests. Each insecticide was tested at two rates except for cyromazine (Table 4). Both rates of acetamiprid, imidacloprid, and thiamethoxam provided 100% control of *C. nasturtii.* None of the transplants treated with these three insecticides showed any symptoms and no live larvae were observed. Moreover, many dead eggs or dead newly hatched larvae could be seen in the growing tips. These results indicate that the three systemic neonicotinoid insecticides killed the eggs or larvae before they caused any damage. Another chemical, oxamyl, belonging to the carbamate class of insecticides, also produced 100% larval reduction. The difference was that some treated plants exhibited swelling or crumpling, indicating that some larvae survived several hours or days, fed, and deformed the growing points. However, the survivors did not develop beyond second instar and died before causing further damage. An IGR, cyromazine, had limited efficacy, and the larval reduction was only 68.5%.

Treatment with acetamiprid, imidacloprid, and thiamethoxam resulted in excellent control for at least 7 wk (Table 5). Numerous dead newly hatched larvae were seen in the growing tips. Slight phytotoxicity was

Table 4. Efficacy of insecticides on *C. nasturtii* 8 d after soil drench

Insecticide	Trade name	Rate mg (AI)/plant	Actual concn (ppm)	% larval reduction (±SEM)[a]
Acetamiprid	Assail	1.7	83.3	100a
		8.9	445.2	100a
Imidacloprid	Admire	8.4	420	100a
		40.0	2,017.6	100a
Oxamyl	Vydate	11.0	560.8	100a
		60.0	3,000	100a
Thiamethoxam	Platinum	2.7	140	100a
		13.5	675	100a
Cyromazine	Trigard	14.9	747.5	68.5 ± 8.9b

$n = 139.6 \pm 10.2$ larvae on control plants.
[a] Means within a column followed by same letters are not significantly different ($\alpha = 0.05$, Tukey–Kramer HSD test).

Table 5. Residual activity of insecticides on *C. nasturtii* applied by soil drench

Insecticide	Rate mg (AI)/plant	Actual concn (ppm)	% larval reduction (±SEM) 10 d after inoculation[a]			
			1 wk[b]	3 wk[b]	5 wk[b]	7 wk[b]
Acetamiprid	1.7	83.3	100a	100a	100a	100a
	8.9	445.2	100a	100a	100a	100a
Imidacloprid	3.5	175	100a	100a	100a	100a
	8.4	420	100a	100a	100a	100a
	40.0	2,017.6	100a	100a	100a	100a
Thiamethoxam	2.7	87.5	100a	100a	100a	100a
	13.5	140	100a	100a	100a	100a
Oxamyl	11.0	560.8	100a	81.4 ± 6.4b	39.6 ± 11.5b	15.3 ± 4.9b

n = 153.4 ± 12.1, 188.3 ± 18.8, 172.2 ± 29.6, and 170.8 ± 29.4 larvae on control plants at 1, 3, 5, and 7 wk after drench treatment, respectively.
[a] Means within a column followed by same letters are not significantly different (α = 0.05, Tukey–Kramer HSD test).
[b] Inoculation time after drench treatment.

observed at the highest rate of acetamiprid- and imidacloprid-treated plants 3 wk after treatment. The edge of the outer leaves turned dry and lightly curled downward. Slight discoloration was visible on some leaves. No such symptoms were found at the lower rates or with thiamethoxam, and no phytotoxicity was observed in the above-mentioned soil drench tests (Table 4), which were drenched 48 h after inoculation and read at 8 d posttreatment. For oxamyl, the larval reduction was 100% when inoculated 1 wk after soil drench, but when inoculated at 3 wk, typical damage such as swelling and crumpling was found and the efficacy decreased to 81.4%. Many dead larvae and some live larvae coexisted inside the growing tips. More larvae survived when inoculated at 5 and 7 wk after treatment, and the larval reduction was 39.6 and 15.3%, respectively.

Seed Treatment. Results of efficacy of broccoli seeds treated with different insecticides on *C. nasturtii* and germination tests are listed in Table 6. None of the plants which germinated from seeds treated with clothianidin, imidacloprid, and thiamethoxam showed any symptoms of *C. nasturtii* injury. Many dead eggs or dead newly hatched larvae were observed on growing tips, and the larval reduction was 100% compared with the control. These three insecticides are systemic insecticides belonging to the nitroguanidine subgroup of nicotinoid insecticides. The active ingredient seems to penetrate the seed capsule and move upward through the entire plant. Clothianidin and thiamethoxam had no significant effect on seed germination compared with nontreated seeds. However, imidacloprid had a lowered germination percentage of 62%. Another neonicotinoid insecticide, acetamiprid, had little efficacy on *C. nasturtii* with only 34% larval reduction and <50% germination. Spinosad and fipronil produced 48 and 28.8% control, respectively.

Discussion

C. nasturtii is a common insect pest in Europe and the biology, distribution, and damage were studied from the 1940s to 1970s. However, few published documents are available on its chemical management. For a new invasive insect pest in the United States, the immediate concern is to find effective control methods to prevent serious crop damage and further spreading. Chemical control is the quickest and most effective way. From our study, we found that several insecticides were effective in controlling *C. nasturtii.* Acephate, acetamiprid, chlorpyrifos, methomyl, and λ-cyhalothrin were effective foliar sprays. Acetamiprid, imidacloprid, oxamyl, and thiamethoxam were very effective when applied by drench. The efficacy duration of acetamiprid, imidacloprid, and thiamethosam drenches could last at least 7 wk. Clothianidin and thiamethoxam were efficient and safe insecticides for seed treatment. Pyripoxyfen, an IGR, provided ≈70% control when applied as a foliar spray but did slow larval development.

C. nasturtii is a meristematic living insect pest. The larvae are hidden in the stem tips, making them hard to detect and more difficult to control. For insecticidal control the chemical must reach the target pest. Some systemic insecticides tested in this study killed the insects within the plant. Foliar sprays for adults also

Table 6. Efficacy of treated broccoli seeds for controlling *C. nasturtii*

Seed treatment	Trade name	Rate g (AI)/100 g seed	% larval reduction, 10 d	% plants injured[a] (±SEM)	% germination[a] (±SEM)
Clothianidin	Poncho	4.5	100a	0a	94.5 ± 1.5a
Imidacloprid	Gaucho	4.5	100a	0a	62.0 ± 3.9b
Thiamethoxam	Cruiser	4.5	100a	0a	93.5 ± 3.9a
Spinosad	Entrust	4.5	48.0 ± 9.8b	66.7 ± 13.6b	93.8 ± 1.4a
Acetamiprid	Assail	4.5	34.0 ± 10.5b	78.6 ± 11.4b	48.0 ± 5.8b
Fipronil	Regent	4.5	28.8 ± 11.2b	70.0 ± 5.8b	96.0 ± 0.8a
Control				90.7 ± 9.3b	96.9 ± 0.5a

n = 81.4 ± 14.6 larvae on control plants.
[a] Means within a column followed by same letters are not significantly different (α = 0.05, Tukey–Kramer HSD test).

may be an important and necessary tool to control *C. nasturtii* to reduce the ovipositional potential. *C. nasturtii* has a high reproductive rate with each female capable of laying ≈100 eggs during her short (1–4 d) lifetime. Bouma (1996) mentioned that a mere 100 midges in the first generation could give rise to 80,000 midges in the third generation. Four insecticides provided 100% control of *C. nasturtii* adults in our tests. When and how to use these foliar insecticides will depend on the population dynamics in the field, such as the time of emergence of the overwintering adults, peak flights of each generation, and the number of generations each year.

Our results indicate the most effective insecticides for controlling *C. nasturtii* are neonicotinoid insecticides, either applied by spray, drench, or seed treatment. However, sole reliance on this class of insecticides raises concerns about insecticide resistance, so use of other insecticide classes may be necessary. During the soil drench tests, we also observed phytotoxicity with acetamiprid and imidacloprid treated plants at very high rates. These plants had two true leaves when treated and phytotoxicity occurred ≈3 wk after treatment. This indicated that the active ingredient was continuously absorbed by the root system and accumulated in plants over time. It is important to apply these insecticides at the lowest effective rate to avoid phytotoxicity. Seed treatments may provide an attractive alternative to foliar sprays or drenches of neonicotinoid insecticides because of their low use rate.

Because of the current situation in the United States where *C. nasturtii* has only been found in a single county (and at a low infestation), we were unable to conduct meaningful field studies. Although this could be considered a limitation in some sense, conducting the tests under controlled laboratory conditions in which inoculations of the insects and applications of insecticides could be made at specific times, provided useful data on the potential performance of each insecticide and application method in the field. Field evaluations of the most effective treatments in these trials will be conducted in fields in Canada that are heavily infested with *C. nasturtii.*

Use of insecticides is one of the most effective ways to control *C. nasturtii*, but it may not be the only method. For example, in Switzerland, where insecticide options on organic production are limited (spinosad is the only permitted insecticide), exclusion fences have been shown to be more effective on *C. nasturtii* than spinosad (Wyss and Daniel 2004). Whether this strategy would be effective with larger production systems common in the United States is questionable. Many other strategies, including resistant varieties, transgenic plants, and cultural control also need to be explored in the future.

Acknowledgments

We thank Y. M. Cheung and H. Collins for assistance throughout this study. This research was supported by the New York State Department of Agriculture and Markets.

References Cited

Association of Official Seed Analysts. 1992. Seedling evaluation handbook. Association of Official Seed Analysts Contrib. No. 35.

Association of Official Seed Analysts. 1993. Rules for testing seeds. J. Seed Technol. 16: 1–113.

Bardner, H. M., C. A. Edwards, M. K. Arnold, and J. P. Rogerson. 1971. The symptoms of attack by swede midge (*Contarinia nasturtii*) and effects on the yield of swedes. Entomol. Exp. Appl. 14: 223–233.

Barnes, H. F. 1946. Gall midges of economic importance, vol. 1: gall midges of root and vegetable crops. Crosby Lockwood, London, United Kingdom.

Bouma, E. 1996. Contapré, prototype of a model for prediction of emerging of the swede midge (*Contarinia nasturtii*). SP-Rapport, Statens Planteavlsforsg. 15: 25–30.

Crop Protection Reference. 2003. 19th ed. Chemical and Pharmaceutical Press, Inc., New York.

Hallett, R. H., and J. D. Heal. 2001. First Nearctic record of the swede midge (Diptera: Cecidomyiidae), a pest of cruciferous crops from Europe. Can. Entomol. 133: 713–715.

JMP Start Statistics. 2000. A guide to statistics and data analysis using JMP and JMP IN software, 2nd ed. SAS Institute, Cary, NC.

Jyoti, J., A. M. Shelton, and A. G. Taylor. 2003. Film-coating seeds with chlorpyrifos for germination and control of the cabbage maggot on cabbage transplants. J. Entomol. Sci. 38: 553–565.

Kieffer, J. J. 1888. Beiträge zur Kenntniss der Gallmüchen. Entomol. Nachr. 14: 263–164.

Kikkert, J. R., C. A. Hoepting, and A. M. Shelton. 2004. Swede midge found in New York: results of the 2004 survey. Cornell Cooperative Extension Vegetable Newsletter, No. 11 (2004). (http://www.cce.cornell.edu/~Ontario/agriculture/commercial_vegetables/vegetable_newsletter/000225.php).

Ouden, H. D., J. Theunissen, and A. M. Shelton. 1987. Prevention of plant injury by cabbage gall midge (*Contarinia nasturtii* Kieffer) and onion thrips (*Thrips tabaci* Lindemann) using emulsions of polyisobutylene. J. Appl. Entomol. 104: 313–318.

Readshaw, J. L. 1965. The biology of the swede midge, *Contarinia nasturtii* (Kieff.) (Diptera, Cecidomyiidae). Life-history and influence of temperature and moisture on development. Bull. Entomol. Res. 56: 685–700.

Stokes, B. M. 1953. Biology investigation into the validity of *Contarinia* species living on the Cruciferae, with special reference to the swede midge, *Contarinia nasturtii* (Kieffer). Ann. Appl. Biol. 40: 726–741.

Wyss, E., and C. Daniel. 2004. The effect of exclusion fences on the colonization of broccoli and kohlrabi by the Swede midge, *Contarinia nasturtii* (Diptera: Cecidomyiidae). Mitteilungen Deutschen Gesellshaft Allgemeine Angewandte Entomol. 14: 387–390.

Received 14 June 2005; accepted 29 September 2005.