Journal of Nematology 20(2):317–320. 1988.

Field Evaluation of *Steinernema feltiae* Against the Web-spinning Larch Sawfly *Cephalcia lariciphila*

RAMON GEORGIS[1] AND NIGEL G. M. HAGUE[2]

Abstract: Field trials were conducted in Rheola Forest, Wales, Great Britain, to determine the effectiveness of *Steinernema feltiae* UK strain in controlling the web-spinning larch sawfly *Cephalcia lariciphila*. Foliar sprays at the rate of 5,000–20,000 nematodes/100 cm branch resulted in 3.4–29.4% infection of sawfly larvae. Soil application of 200 nematodes/cm² resulted in 61% infection of sawfly prepupae and 17.3% of pupae. Prepupal infection ranged from 4.8 to 14.7% 1 year after nematode application. Soil applications of this nematode show that it has potential for biological control of sawfly prepupae.

Key words: biological control, *Cephalcia lariciphila*, entomogenous nematode, persistence, *Steinernema feltiae*.

The first reported outbreak in Great Britain of the web-spinning larch sawfly, *Cephalcia lariciphila* (Hymenoptera: Pamphiliidae), occurred on larch, *Larix* spp., at Margam Forest, West and Mid-Glamorgan, South Wales, in 1973 (2). Subsequently, 22 forests became infested between 1972 and 1978. These infestations resulted in economic loss of timber (1).

The sawfly adult emerges in May and June and lays eggs on larch leaves. The larvae feed actively from June to mid-July, then drop to the ground, burrow 2–10 cm into the soil around the tree, and become prepupae in late July. They overwinter as prepupae, and pupation occurs in April. About 1 month later they emerge as adults.

A parasitic nematode, later identified as *Steinernema feltiae* (= *Neoaplectana carpocapsae*) UK strain (6), was reported in prepupae of *C. lariciphila* (1). Low-cost in vitro mass-rearing methods for this nematode has increased the feasibility of field experimentation on some important insect pests with modest success (9,10). The present study was conducted to determine the potential of *S. feltiae* UK strain for the control of larvae, prepupae, and pupae of the web-spinning larch sawfly in the forest.

Received for publication 7 May 1987.

[1] Biosis, 1057 East Meadow Circle, Palo Alto, CA 94303.

[2] Department of Zoology, University of Reading, White Knights, Reading, United Kingdom.

We thank Dr. H. K. Kaya, Department of Entomology, University of California, Davis, and Dr. G. O. Poinar, Jr., Department of Entomology and Parasitology, University of California, Berkeley, for reviewing this manuscript.

MATERIALS AND METHODS

Nematode culture: S. feltiae was cultured in larvae of the greater wax moth, *Galleria mellonella* (4). After extraction, infective nematodes were stored in distilled water at 5 C for 2 weeks and were checked for infectivity before use.

Foliar application: The first test was conducted in June 1979 against mixed populations of first-instar and second-instar larvae in Rheola Forest, Wales, Great Britain. Four branches (100 cm long) were selected from an uninfested larch tree, and each was infested with 50 larvae collected from the forest. Each treated branch was immediately enclosed in a cellulose acetate cage (70 cm long × 15 cm d). The cage had 10 holes (5 cm d), each sealed with screen to allow for air exchange. One day after infestation the cages were removed and 50 ml of nematode suspension containing 10% glycerin was applied at 2000 hours with a hand sprayer so that each branch received ca. 5,000, 10,000, and 20,000 infective juveniles. Infested branches treated with 50 ml 10% glycerin solution served as controls. Cages were replaced over the branches after the treatment. There were three trees per treatment with each branch on the tree serving as a replicate. Treated larvae were removed 24 hours after treatment and placed in containers with larch leaves. Dead and live larvae were examined microscopically for the presence of nematodes 3 days after treatment. Nematode survival on larch foliage was determined by removing 20

TABLE 1. Infection rate of *Cephalcia lariciphila* sawfly larvae on foliage with *Steinernema feltiae* under field conditions.

Nematode dose/ branch†	% infected larvae			
	1st & 2nd instars	95% confidence limit	3rd & 4th instars	95% confidence limit
5,000	3.4 ± 4.2	0.1–12.4	6.0 ± 4.0	0–16.1
10,000	5.3 ± 4.1	0.2–14.7	14.0 ± 5.3	4.3–24.6
20,000	15.3 ± 9.2	8.5–24.0	29.4 ± 8.4	21.9–47.1
Control	0		0	

Each value is the mean ± standard deviation of three replicates.
† Fifty larvae/100-cm branch.

needles from each branch treated with 20,000 nematodes and washing them in 20 ml water for 2 minutes. Samples were taken at 2, 4, 10, 12, 14, and 16 hours after treatment. Study conditions during the test were 13.3–19.7 C and 76–93% relative humidity.

The second test, conducted in July 1979 against mixed populations of third-instar and fourth-instar larvae, used the same method as described in the first test. Conditions during the test were 15.0–24.2 C and 70–95% relative humidity.

Soil application against prepupae: In August 1979, an area of ca. 100 m^2 under selected larch trees heavily infested with sawflies was chosen and cages (50 × 50 × 15 cm) were placed at 5-cm depths in the soil. The cages were made of wood with zinc mesh lids and open bottoms. Soil in the cage was treated with 200 ml of the nematode suspension applied with a hand sprinkler at 20, 40, and 200 infective juveniles/cm^2. Cages with soil treated with 200 ml water served as controls. One month after treatment, soil was removed to a depth of 15 cm and sawfly prepupae were recovered with sieving screens. The number of dead and living prepupae was recorded, and dead prepupae were dissected and examined for nematodes. Soil temperature 5 cm deep was 15.6–18.9 C during the test period and total rainfall was 94.2 mm. Soil moisture was 32.6% at the beginning of the test and 38.9% at the end. Each treatment was replicated three times.

Soil application against pupae: This test was conducted in April 1980, in an area where no sawfly infestation was observed. The same methodology used against sawfly prepupae was followed with one exception. Each cage was infested with 60 pupae placed 4–10 cm deep in the soil and later treated with three rates of nematodes. Soil temperature 5 cm deep was 5.7–10.1 C during the test period, and total rainfall was 135.6 mm. Soil moisture was 37.5% at the beginning of the test and 44.1% at the end.

Nematode persistence: In August 1979, an area of ca. 100 m^2 under uninfested larches was selected and cages were placed at 5-cm depths as previously described. The nematode suspension was applied to the soil surface at the three rates mentioned earlier. Soil treated with water served as controls. In August 1980, the treated soil was infested with 60 healthy sawfly prepupae, and 1 month later the number of infected prepupae was recorded using the method described in the previous test. Each treatment was replicated three times. Soil temperatures at 5 cm deep were as follows: 10.0–16.8 C (August–November), 1.7–5.6 C (December–April), and 5.6–17.0 C (May–August); total rainfall during the test ranged between 31.0 and 198.3 mm per month. Soil moisture was 35.2% at the beginning of the study and 40.3% at the end.

RESULTS AND DISCUSSION

Foliar application: Nematode infection of the sawfly larvae ranged between 3.4 and 29.4% with lower mortality in the early instars than in later instars (Table 1). Larvae dissected 24 hours after feeding on treated larch foliage showed that late instars had an average of 6.0 nematodes and

TABLE 2. Infection rate of *Cephalcia lariciphila* sawfly prepupae when soil under trees was treated with *Steinernema feltiae.*

Nematode dose/cm²	No. of recovered prepupae	% infection	95% confidence limit
Evaluated 1 month after treatment			
20	53.7 ± 6.0	8.9 ± 4.4	0.8–23.2
40	52.0 ± 3.6	25.3 ± 9.7	15.2–36.5
200	47.3 ± 5.5	61.0 ± 17.8	48.3–72.4
Control	59.7 ± 6.0	3.1 ± 3.0	0.1–17.6
Evaluated 1 year after treatment			
20	56.3 ± 7.4	4.8 ± 2.3	0.6–8.3
40	58.0 ± 3.6	8.7 ± 4.5	2.6–14.5
200	54.3 ± 5.5	14.7 ± 7.6	8.0–19.6
Control	57.3 ± 2.5	0.7 ± 1.2	0–5.1

Each value is the mean ± standard deviation of three replicates.

TABLE 3. Infection rate of *Cephalcia lariciphila* sawfly pupae when soil under trees was treated with *Steinernema feltiae.*

Nematode dose/cm²	No. of recovered pupae	% infection	95% confidence limit
20	54.3 ± 5.7	1.7 ± 1.5	0–12.2
40	57.7 ± 6.5	7.7 ± 5.5	0.3–14.3
200	51.7 ± 4.6	17.3 ± 9.1	6.8–23.1
Control	54.3 ± 5.8	0	0

Each value is the mean ± standard deviation of three replicates.

early instars had an average of 3.2 nematodes. As expected, mortality for both larval stages increased as the concentration of nematodes applied increased. Nematode survival on foliage (July application) during the night (85–97% relative humidity) was 60–63% after 10 hours and only 2–6% after 11–14 hours. The probable cause for the daytime drop is low relative humidity (76–82%).

Successful applications of steinernematid nematodes have been made against certain insects in cryptic and soil habitats (9,10), but attempts to control foliage insects have been generally discouraging. The limiting factor cited most often is rapid desiccation of the nematodes. Although the nighttime relative humidity in our study was favorable for nematode survival (9), larval infection was low, demonstrating the lack of sawfly and nematode contact. Our results present further evidence that foliage application is not warranted at this time.

Soil application against prepupae: Prepupal infections were 8.9, 25.3, and 61.0% at application rates of 20, 40, and 200 infectives/cm² (Table 2). Natural prepupal infection in the control plot was 3.1%. In our experiment, the soil was characterized by thick, moist mats of organic matter which favored nematode survival (8). Moreover, soil temperature (15.6–18.9 C) was favorable for infectivity and allowed for movement toward the prepupae which were located in large numbers 2–10 cm deep (6).

Soil application against pupae: Pupal infections were 1.7, 7.7, and 17.3% at application rates of 20, 40, and 200 infectives/cm² (Table 3). Since preliminary laboratory studies showed that sawfly pupae and prepupae were equally susceptible to the nematode, low soil temperatures (5.7–10.1 C) during the test period probably were responsible for the low infection rates (6).

Although 61% of the sawfly prepupae were infected with *S. feltiae,* the benefits must be measured against possible harmful effects to another biological control agent, the parasitoid, *Olesicampe monticola.* This parasitoid spends August–March as an early-instar larva inside the sawfly prepupae (1). Laboratory experiments have shown that the parasitoid is highly susceptible to this nematode (7), and the impact of *S. feltiae* on *O. monticola* populations needs to be verified under field conditions.

Nematode persistence: Prepupal mortality was 4.8–14.7% 1 year after application, whereas natural parasitism in untreated plots was 0.7% (Table 2). Plots treated with higher nematode concentrations had higher percentages of infected prepupae. The low infection rates suggested that most of the nematodes could not persist for this length of time, possibly due to low winter temperatures (6), natural enemies (10), and respiration rates (3). Another factor which could account for low infection rates would be nematodes dispersing from the treated area (11) or being washed away by rainfall.

No labeled insecticides are registered for this sawfly, and *S. feltiae* represents an alternative control tactic. Recent developments (5) in the mass production of nematodes in a liquid fermentation process and induction of anhydrobiotic nematodes may enable them to be used economically in the management of this sawfly in larch plantations in the United Kingdom.

Literature Cited

1. Billany, D. J., and R. M. Brown. 1980. The web-spinning larch sawfly *Cephalcia lariciphila* Wachtl. (Hymenoptera: Pamphiliidae) a new pest of *Larix* in England and Wales. Forestry 53:71–80.

2. Brown, R. M., and D. J. Billany. 1973. Report on forest research. London: Forestry Commission. P. 107.

3. Burman, M., and A. E. Pye. 1980. *Neoaplectana carpocapsae*: Respiration of infective juveniles. Nematologica 26:214–219.

4. Dutky, S. R., J. V. Thompson, and G. E. Cantwell. 1964. A technique for the mass propagation of the DD-136 nematode. Journal of Insect Pathology 6:417–422.

5. Georgis, R. 1987. Nematodes for biological control of urban insects. American Chemical Society, Division of Environmental Chemistry. 194th National Meeting, New Orleans, Louisiana 27(2):816–821.

6. Georgis, R., and N. G. M. Hague. 1981. A neoaplectanid nematode in the web-spinning larch sawfly *Cephalcia lariciphila.* Annals of Applied Biology 99: 171–177.

7. Georgis, R., and N. G. M. Hague. 1982. Interaction between *Neoaplectana carpocapsae* (Nematoda) and *Olesicampe monticola,* a parasitoid of the larch sawfly *Cephalcia lariciphila.* IRCS Medical Science 10:617.

8. Ishibashi, N., and E. Kondo. 1986. *Steinernema feltiae* (DD-136) and *S. glaseri*: Persistence in soil and bark compost and their influence on native nematodes. Journal of Nematology 18:310–316.

9. Kaya, H. K. 1985. Entomogenous nematodes for insect control in IPM systems. Pp. 282–302 *in* M. A. Hoy and D. C. Herzog, eds. Biological control in agricultural IPM systems. New York: Academic Press.

10. Poinar, G. O., Jr. 1986. Entomophagous nematodes. Pp. 95–122 *in* J. M. Franz, ed. Biological plant and health protection. New York: Gustav Fischer Verlag.

11. Poinar, G. O., Jr., and A. Hom. 1986. Survival and horizontal movement of infective stage *Neoaplectana carpocapsae* in the field. Journal of Nematology 18:34–36.