

USING ENTOMOPATHOGENIC NEMATODES AND CONVENTIONAL AND BIORATIONAL PESTICIDES FOR CONTROLLING BAGWORM

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Abstract. Formulated microbial biological control agents such as entomopathogenic nematodes and *Bacillus thuringiensis* have potential as alternatives to conventional control pesticides for arborists offering IPM and Plant Health Care services. However, few data compare the efficacy of these materials with other pesticides under field conditions. This study demonstrates that in some cases microbial biological control agents are effective in controlling bagworms on evergreens.

Bagworm, *Thyridopteryx ephemeraeformis*, an indigenous, defoliator damage a wide range of evergreen and deciduous plants. Bagworm feeds on over 128 species of plants (2), but does the most serious damage to evergreens such as arborvitae, Leyland cypress, spruce, pines, and junipers. Even relatively small amounts of defoliation cause nurserymen severe economic loss. Sadof and Raupp (11) reported that as little as 4% defoliation by bagworms significantly reduced the value of arborvitae in retail nurseries.

Control of bagworms is most effective when synthetic or bacterial insecticides are applied to young larvae (7,8). Improved timing of insecticide applications can be obtained using heat accumulation models to predict emergence of bagworm (9). Unfortunately, arborists and nurserymen often overlook small, early instar bagworms and pesticide applications are made to late instar larvae. Late season control using recommended dosages of synthetic carbamate and organophosphate insecticides produced mortality percentages of less than 28 percent (8).

Public concern about adverse effects of chemical insecticides has created an environment in which biological, botanical, less acutely toxic insecticides are regarded as promising alternatives to some older material with higher toxicities. The purpose of this study was to field test several biological, botanical, and newer syn-

thetic insecticides for efficacious control of middle and late instar bagworms.

A major group of biological agents that we were interested in evaluating were entomopathogenic nematodes. The entomopathogenic nematode, *Steinernema carpocapsae*, has been reported to infect several Lepidopterous larvae including spruce budmoth, *Zeiraphera canadensis* (4), Mexican rice borer, *Eoreuma loftini* (10), peachtree borer, *Synanthedon exitiosa* (5), and dogwood borer, *Synanthedon scitula* (3). In a petri dish bioassay, steinernematid and heterorhabditid nematodes gave high mortality, over 80%, to caterpillars of the giant looper, *Boarmia selenaria* (6). Based on these previous studies we included entomopathogenic nematodes of *Steinernema* species in our field trials. We were particularly interested in the effectiveness of several tactics to control mid- season to late season bagworm larvae since there are relatively few effective biological or biorational control options for these stages.

Bacillus thuringiensis strains are effective in controlling early instars of lepidopterous larvae but have generally not performed as well on later instar stages (1). In the second year of this study we evaluated a wettable powder formulation of *Bacillus thuringiensis* var. *kurstaki*.

Materials and Methods

The first field trial was conducted in the summer of 1992. Forty four Arborvitae 'Emerald Green', grown in 1 gallon containers and irrigated with a trickle system, were infested with 10 bagworm larvae. Larvae were allowed to feed for 7 days before pesticides were applied. Larval densities were adjusted to 10 per plant before the treatments were started. The field trial was a complete, ran-

domized block with 4 replications of eleven treatments. A commonly used carbamate, carbaryl, and a pyrethroid, cyfluthrin were used in the trial. These materials were selected because of their widespread use by arborists and landscapers. Two formulations of the botanical insecticide neem were also evaluated. Nematode applications were made on July 22 at the rate of 500 nematodes per 2.5 cm. sq. (1 in. sq.) of plant foliage. Based on recommendations from the supplier of the nematodes we included combinations of folicote (spreader/sticker) and a 0.25% horticultural oil mixed with entomopathogenic nematodes. We considered the shape of the shrub to be a cylinder to perform calculation of the rate of nematodes used per plant. Material and rates used in the 1992 field trials are in Table 1.

Treatments were made using a Birschmeyer backpack sprayer. Each plant received 200 ml of mixture. Treatment in 1992 started at 4:00 p.m. and concluded at 5:35 p.m. The nematode treatments were made between 5:15 – 5:30 p.m.. This late day application was made in an attempt to reduce the chance of desiccation before the nematodes reached the caterpillars within the bag. In the 1992 trial the temperature at 4:00 p.m. was 27°C and relative humidity was 48%. At 5:30 p.m. temperature was 23°C, relative humidity 55% with overcast skies. It started raining the next morning at 5:30 a.m.

One branch of 10 cm in length was removed from each nematode treatment block at 9:00 a.m. on July 23 and examined under a 40X magnification dissecting microscope. Living nematodes were found on the foliage of all nematode treated plants. The weather remained cloudy and rainy over the next 4 days.

Thirteen days after treatment, all bagworms were harvested from each plant, and the number of living bagworms was observed. The efficacy of control was determined by comparing the number of living larvae found in each treatment with an analysis of variance (ANOVA) for a completely randomized block design (12). The mean number of surviving larvae found in each treatment was compared with a multiple comparison test (Tukey test, 12).

In 1993 the field trial was repeated with emphasis

on evaluating efficacy of entomopathogenic nematodes, *Bacillus thuringiensis*, and cyfluthrin. Another entomopathogenic nematode, *Steinernema feltiae*, was added to the trails. To evaluate whether foliar applications of entomopathogenic nematodes made in the evening were more efficacious than applications made in the afternoon, 2 split time, replicated, complete randomized blocks were used. There were 5 blocks for each treatment. Leyland cypress were used as the host plant for the bagworm larvae in the 1993 field trial. The leyland cypress were grown in 3 gallon containers, and irrigated using trickle irrigation.

On July 19, 1993 mid-season bagworm larvae treatments were applied using a Birschmeyer 3 liter backpack sprayer. The first time sequence applications started at 2:00 p.m. in the afternoon and all applications were completed by 4:15 p.m. Each plant received 400 ml of treatment solution. The temperature at 2:00 p.m. was 28°C, relative humidity was 93% under heavy cloud cover. At 4:00 p.m. the temperature was 27°C and relative humidity was 94%. A light, misty rain, lasting 45 minutes started at 5:00 p.m.

The second sequence of time treatments started at 6:20 p.m. and all treatments were completed by 7:30 p.m. We noted that bagworms were actively feeding prior to treatments but when treatments were applied the larvae pulled back into the protection of their bag. The temperature at 6:30 p.m. was 27°C and the relative humidity 95%. Heavy rainfall started at 9:00 p.m. and continued intermittently through the next day.

At 9:00 a.m on July 20th, we removed one, randomly selected 10 cm branch from each of the nematode treated blocks and examined with a 40X magnification dissecting scope. Living nematodes were found on all the samples but in relatively low numbers.

Eleven days after treatment all bagworms were harvested from each plant, and the number of living bagworms were observed. The efficacy of each treatment and the effect of applying materials at different times were determined by comparing the number of living larvae found in each treatment and time combination with an analysis of variance (ANOVA) for a factorial design (12). The mean

number of surviving larvae found in each treatment was compared with a multiple comparison test (Tukey test, 12). The entire experiment was repeated on August 5, 1993 when the same plants were reinfested with ten, fourth and fifth instar bagworms and the application of all materials was repeated. At the times of application, 2 pm and 6 pm, the sky was partly cloudy. The temperatures were 29°C and 21°C, respectively. The relative humidities were 48% and 61%, respectively. Ten days after the insecticidal applications, bagworms were harvested. Data were collected and analyzed as in the first experiment.

Results

Comparisons of the performance of the nematode *S. carpocapsae* with neem and conventional insecticides revealed significant differences in the levels of control provided by these materials (ANOVA, $F = 7.21$, $P = 0.000$). In 1992 nematodes either alone or with oil or antidessicant provided highly acceptable levels of control of middle instar bagworms (Table 1). Application of

nematodes alone provided the same level of control as did the synthetic pyrethroid, cyfluthrin. No living bagworms were found on plants treated with either of these materials. Carbaryl and granular acephate also provided highly acceptable levels of control with reductions in the number of living bagworms of 83% and 86%, respectively. Two different formulations of neem applied at two different rates provided intermediate levels of bagworm control with population reductions ranging from 36% to 56%.

The second set of experiments examined two aspects of the use of entomopathogenic nematodes, *Bacillus thuringiensis*, and conventional materials for bagworm control. First, the applications were conducted to determine if the time of day, early afternoon compared to early evening, affected the performance of nematodes and other materials. When nematodes were applied to both middle and late instar bagworms, the time of the application did not affect the efficacy of the materials (middle instars, ANOVA, $F = 3.82$, $P = 0.074$; late instars, ANOVA, $F = 4.22$, $P = 0.062$). However, as in the previous experiments, the type of material applied had a major effect on the levels of control for both middle and late instar larvae (middle instars, ANOVA, $F = 10.32$, $P = 0.000$; late instars, ANOVA, $F = 28.66$, $P = 0.000$). The synthetic pyrethroid, cyfluthrin, provided the highest levels of control of both middle and late instar bagworm larvae. This material reduce populations 95% and 97%, respectively (Tables 2 and 3). The biological control agents, *Bacillus thuringiensis* and the nematodes *S. carpocapsae* and *S. feltiae* provided intermediate levels of control of middle and late instar bagworms (Tables 2 and 3). Nematodes did not differ in their abilities to control bagworms. Both species reduced populations of middle instar larvae by about 70% and reduced late instar larvae by about 60%. The addition of oil to the nematodes did not appear to improve the efficacy of these agents and may have reduced efficacy slightly.

Discussion

In the 1992 field trial the entomopathogenic nematode, *S. carpocapsae* alone and in combination with 0.25% UltraFine Spray oil gave control

Table 1. Effects of nematodes, neem and conventional insecticides on bagworms, 1992.

Treatment and rate (a.i./100 gal)	Living bagworms	Reduction %
Control (water)	9.0(0.8)a*	--
Neem 1 (Margosan-0)		
1:360, 16 oz.	5.8(1.2)ab	36
1:160, 21 oz.	5.0(3.1)abc	44
Neem 2 (Azatrin)		
1:2133, 6 oz.	4.0(1.3)abc	56
1:1066, 7.5 oz.	4.0(1.3)abc	56
Carbaryl (XLR form.)	1.5(1.0)bc	83
Acephate 0.66 g/L pot	1.3(1.1)bc	86
<i>S. carpocapsae</i> (with oil)		
500 nema/sq. in. foliage, oil at 0.25%	0.8(0.3)bc	91
<i>S. carpocapsae</i>		
500 nema/sq. in. foliage	0.5(0.3)bc	94
<i>S. carpocapsae</i> (with antidessicant)		
500 nema/sq. in. foliage	0.0(0)c	100
Cyfluthrin 0.04 L (1.5 oz)	0.0(0)c	100

* Means that share the same letter do not differ significantly by a Tukey test at $p = 0.05$

Table 2. Effects of nematodes, B.t., and conventional insecticides on mid-instar bagworms, 1993.

Treatment and rate(a.i./100 gal.)	Living bagworms	Reduction %
Control (water)	7.3(0.3)a*	--
S. carpocapse (with oil) 500 nema./sq.in.	4.1(1.0)b	44
S. feltiae (with oil) 500 nema./sq.in.	4.0(1.0)b	45
S. feltiae 500 nema./sq.in.	2.4(1.1)bc	67
S. carpocapse 500 nema./sq.in.	2.2(0.3)bc	70
Bacillus thuringiensis, 1.5 lb.	1.7(0.4)bc	77
Cyfluthrin, 1.5 oz.	0.4(0.3)c	95

* Means that share the same letter do not differ significantly by a Tukey test at $p = 0.05$

Table 3. Effects of nematodes, B.t., and conventional insecticides on late-instar bagworms, 1993.

Treatment and rate(a.i./100 gal.)	Living bagworms	Reduction %
Control (water)	10 (0)a*	--
S. carpocapse (with oil) 500 nema./sq.in.	5.8(1.0)b	42
S. feltiae (with oil) 500 nema./sq.in.	5.5(0.7)b	45
S. feltiae 500 nema./sq.in.	4.9(0.6)bc	41
S. carpocapse 500 nema./sq.in.	4.2(0.6)b	58
Bacillus thuringiensis, 2.0 lb.	4.1(0.5)b	59
Cyfluthrin, 1.5 oz.	0.3(0.2)c	97

* Means that share the same letter do not differ significantly by a Tukey test at $p = 0.05$

comparable with carbaryl and acephate. The highest levels of control were obtained with cyfluthrin and *S. carpocapsae* combined with folicote, with no significant difference between the two.

Bacillus thuringiensis is one of the biological materials we encourage IPM practitioners to utilize in controlling Lepidopterous pests since it has little impact on predators and parasites. *Bacillus thuringiensis* has been effective in controlling early instar to mid instar bagworm in Maryland but

control was reported by local arborist to be greatly reduced later in the season. *Bacillus thuringiensis* var *kurstaki* (1) gave reductions as high as 96% in June and July applications at 1 lb per 100 gal rate but as larvae matured, greater amounts were required for comparable results after mid-July in Nebraska. In our mid-July field trial of 1993, *Bacillus thuringiensis* compared favorably against cyfluthrin (Table 2). For the late season application in late July, cyfluthrin was clearly the most efficacious material (Table 3).

The level of control for *Bacillus thuringiensis* dropped from 77% in the mid-July applications to 59% in the late July 1993 applications.

Entomopathogenic nematodes performed the best in the 1992 season (Table 1) giving control comparable to cyfluthrin and carbaryl. In the 1993 trials the two species of entomopathogenic nematodes gave 69% to 70% control in mid-July but control declined to 51% to 58% for the later instars. The weather conditions may have affected the efficacy of the nematodes. In 1992 the relative humidity was 55% with overcast skies and rain occurring 12 hours after the applications and rainy weather continuing for the next 4 days. This 12 hour interval before the rain may have allowed the nematodes, to move from the foliage into the caterpillars. In July 1993 a rain fell approximately 1 to 1.5 hours after the applications of nematodes in the afternoon and evening. It is possible that the rain washed some of the nematodes off the foliage before they were able to enter the protective bag of the insect.

In summary, these trials demonstrate that biological control agents such as entomopathogenic nematodes and *Bacillus thuringiensis* can provide control of bagworm under certain conditions. The synthetic pyrethroid cyfluthrin provided the best and most consistent control under all conditions.

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Résumé. Les produits biologiques de contrôle à base d'agents microbiens, tel les nématodes entomopathogéniques et le *Bacillus thuringiensis*, ont un excellent potentiel comme alternative aux pesticides conventionnels de contrôle pour les arboriculteurs offrant des services de lutte intégrée des insectes et des maladies (Integrated Pest Management – IPM) et de soins à la santé des végétaux (Plant Health Care – PHC). Quoiqu'il en soit, peu de données comparent, en conditions réelles de terrain, l'efficacité de ces produits avec celle des autres pesticides. Cette étude démontre que, dans certains cas, le contrôle biologique par des agents microbiens est aussi efficace, sinon plus, que les pesticides conventionnels pour le contrôle des chenilles à cases sur les conifères.

Zusammenfassung. Formulierten mikrobielle Wirkstoffe im Einsatz zur biologischen Kontrolle wie die entomopathogenen Nematoden und der *Bacillus thuringiensis* bieten hervorragende Möglichkeiten als Alternative zu konventionellen Pestiziden, da sie den Arboristen integrierten Pflanzenschutz ermöglichen. Trotzdem gibt es wenig Daten über die Effizienz dieser Wirkstoffe im Vergleich zu anderen Pestiziden im Feldversuch. Diese Untersuchung zeigt, daß in einigen Fällen die mikrobiellen biologischen Wirkstoffe genauso effektiv oder gar effektiver als konventionelle Pestizide zur Bekämpfung von Insektschäden an immergrünen Gehölzen sind.