ENTOMOPHAGA 37 (1), 1992, 107-114

FIELD TEST OF THE NEMATODE *STEINERNEMA FELTIAE* (*NEMATODA : STEINERNEMATIDAE*) AGAINST YELLOWJACKET COLONIES (*HYM. : VESPIDAE*)

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The insect parasitic nematode *Steinernema carpocapsae* (Weiser) was applied to 4 colonies of *Vespula* wasps in the field. At all treated colonies worker activity was reduced by at least 50 % after one week. Two treated colonies partially recovered, and 2 colonies were completely destroyed. *Vespula* workers removed nematode-killed and dying nestmates from treated colonies. The results suggest that under certain conditions, nematodes could be used as biological control agents of yellowjackets.

KEY-WORDS : Insecta, Nematoda, *Vespula, Steinernema carpocapsae,* insect parasitism.

Although yellowjackets of the genus *Vespula* (Thomson) are considered by some to be beneficial because of their predatory habits, they are most often considered pests because of health problems caused by their stinging behavior (**Akre,** 1982 ; **Akre & MacDonald,** 1986). The negative impact of members of the *Vespula vulgaris* species group is exacerbated by their attraction to many of the foods consumed by humans, and the recent range expansions of several species (**Akre & MacDonald,** 1986). Yellowjacket abatement measures have generally relied on chemical pesticides (**Ennik,** 1973 ; **Moore** *et al.,* 1977), but the undesireable side effects of the chemicals used for this purpose have led to reduced availability of some and increasing public resistance to others.

Biological control offers an alternative to chemical control, and a program using the ichneumonid *Sphecophaga vesparum* (Curtis) against *V. vulgaris* (L.) and *V. germanica* (F.) in New Zealand has yielded promising early results (**Donovan** *et al.,* 1989). Other natural enemies have been identified (**Kemper & Döhring,** 1967 ; **Spradbery,** 1973 ; **Edwards,** 1980 ; **Gambino & Thomas,** 1988), but none have been successfully manipulated to reduce yellowjacket populations in the field. The nematode *Steinernema carpocapsae* (Weiser) [= *Neoaplectana carpocapsae* (Weiser) = *Steinernema feltiae* Filipjev] has been shown to be effective in laboratory trials against *Vespula* spp. larvae and adult workers (**Poinar & Ennik,** 1972 ; **Gambino,** 1984 ; **Guzman,** 1984 ; **Wojcik & Georgis,** 1988). The nematode serves as vector for symbiotic insect-pathogenic bacteria (*Xenorhabdus* spp.) which it carries internally (**Poinar,** 1979). In this study, the nematode/bacterium complex (hereafter referred to as *S. carpocapsae*) was tested in the field to evaluate its potential as a practical control for yellowjackets.

MATERIALS AND METHODS

Nematodes were obtained from 2 sources. The Hopland strain was reared in laboratory-infected larvae and pupae of *Dolichovespula arenaria* (F.) and extracted according to **Poinar** (1979) ; dauers were stored at 10 °C in shallow tap water in plastic tissue culture flasks for up to 2 months. The all strain was reared by a liquid fermentation process ; dauers were stored on moist sponges in plastic bags at 4-8 °C for up to one month, and subsequently stored at 10 °C for up to one month.

The study was conducted during the summer of 1986 at a mixed forest/chaparral hillside (El Sobrante, California, USA) that supported populations of *V. pensylvanica* (Saussure) and *V. vulgaris*. Both species are in the *V. vulgaris* species group, and their biologies in northern California are similar. They typically adhere to an annual colony cycle and construct a multicomb subterranean nest enclosed by an envelope (**Akre & MacDonald,** 1986). Worker populations in the study area usually peak during late August and early September.

Thirteen colonies were divided into 3 treatment groups : 4 colonies (3 *V. pensylvanica,* one *V. vulgaris*) were inoculated with a water suspension of dauer (infective) stages of the nematode *S. carpocapsae* (table 1) ; 3 colonies (2 *V. pensylvanica,* one *V. vulgaris*) received a water treatment ; 6 colonies (one *V. pensylvanica,* 5 *V. vulgaris*) received no treatment. At colonies that received *S. carpocapsae* or water treatments, some overlying soil was removed several days prior to treatment, exposing the outer layers of the envelope covering the top of the nest. Treatments were administered at night by poking a hole through the envelope, slowly pouring in 8 liters of water or thoroughly mixed nematode suspension, and covering the exposed nest portion with a thin layer of soil.

One assay of nematode efficacy was to monitor the removal by workers of dead or diseased nestmates, a component of hygienic behavior (**Akre** *et al.,* 1976). All observations of colony activity were made on bright sunny days ; at each nest, the surface entrance to the nest cavity was observed for a total of 30 min prior to treatment. Thirty-six hours after treatment each nematode- or water-treated colony was observed for approximately 45 min. Additional 45 min observations were made at nematode-treated colonies at intervals ranging from 60 to 204 h posttreatment. Untreated control colonies were observed for a total of 30 min each during visits to the study site for up to 4 weeks following the initial nematode applications. Exiting workers carrying out nestmates or fragments of nestmates were netted. Their insect loads were taken from them and placed individually on sterile filter paper in 40-mm plastic Petri dishes. In the laboratory the filter paper in each dish was moistened with sterile water ; dishes were stored in 150-mm plastic Petri dishes (8 per large dish) and held at room temperature (23 °C) for 1 to 13 days. Fragments that dried out or became overgrown with fungal mycelia were discarded. The remaining specimens were dissected in water using a binocular dissecting scope and examined for the presence of nematodes within the hemocoel, indicative of a successful infection.

A 2nd assay was the effect of treatments on worker foraging rate, a crude measure of overall colony health. A colony's activity level was estimated by counting the number of worker sorties during a 5 min period. On each day that a colony was monitored, counts from 2 separate 5 min periods, separated by an interval of at least 5 min, were pooled to generate a single mean number of sorties per minute. Activity counts, including at least one set of pretreatment observations, were made at 4 nematode-treated colonies, one water-treated *V. pensylvanica* colony, and one untreated *V. pensylvanica* colony. The remaining 7 colonies (2 water-treated, 5 untreated) were destroyed during the posttreatment period after yellowjacket populations had become a public nuisance in the study area ; although

it was not possible to construct seasonal activity profiles for these colonies, subjective observations of colony vigor and defense were made at the time of colony destruction.

The nest at which activity quickly dropped to zero after nematode application was excavated 4 days after treatment. It was stored in a sealed container at 10 °C for 2 days, after which the contents were examined. Five of 7 combs contained dead larvae and had dead workers directly beneath. From each of these combs 10 larvae and 5 workers (or all the insects in these categories if there were fewer than 10 or 5 respectively) were rinsed externally and examined as described above for insects removed by workers.

RESULTS

The removal of nestmates by workers was not observed at any time at untreated or water-treated colonies. Nestmate removal was observed at all 4 nematode-treated colonies, but only after the nematodes had been applied. A total of 53 insects or insect fragments from the treated colonies were collected ; 41 were examined for nematodes (table 1). Nematodes were found in 31 insects, including all intact adults (fig. 1). The only insect that appeared in good health when collected, a *V. pensylvanica* larva, died in the laboratory and produced developing nematodes (fig. 2). The nematode recovery rate of 75.6 % likely underestimates the true infection rate of removed insects for 2 reasons. In the case of fragments of adults, the unrecovered portions of the insects may have contained the nematode(s). Second, nematodes may have escaped detection if penetration into the host hemocoel was incomplete, or if only one or a few penetrated the hemocoel but failed to develop.

TABLE 1

Application of Steinernema carpocapsae *to* Vespula *colonies and recovery of infected individuals*

		Nematodes			Insects Removed ([a])									Insects in Nest			
		Date	Strain	Dose	Adults			Pupae			Larvae			Adults		Larvae	
Colony	Species	Treated		($\times 10^6$)	R	E	I	R	E	I	R	E	I	E	I	E	I
8601	*V. pensylvanica*	4 Aug	All	30	8	7	5	0			2	0	0				
8602	*V. pensylvanica*	4 Aug	Hopland	2	8	6	3	0			1	1	1				
8610	*V. vulgaris*	4 Aug	All	50	7	3	3	2	2	2	1	0	0	19	11	45	11
8613	*V. pensylvanica*	26 Aug	All	100	7	6	4	3	3	2	14	13	11				
					30	22	15	5	5	4	18	14	12	19	11	45	11

([a]) R = no. removed ; E = no. examined ; I = no. infected with nematodes.

With regard to seasonal patterns of activity, colony 8611 (untreated) represented the typical pattern for *Vespula* colonies in the study area, with a peak in foraging rate in late August and early September, followed by a gradual decline (fig. 3a). All 7 prematurely terminated colonies were in vigorous good health when destroyed in August, indicating no major deviation from the normal colony cycle. Colony 8612, treated with water, did not

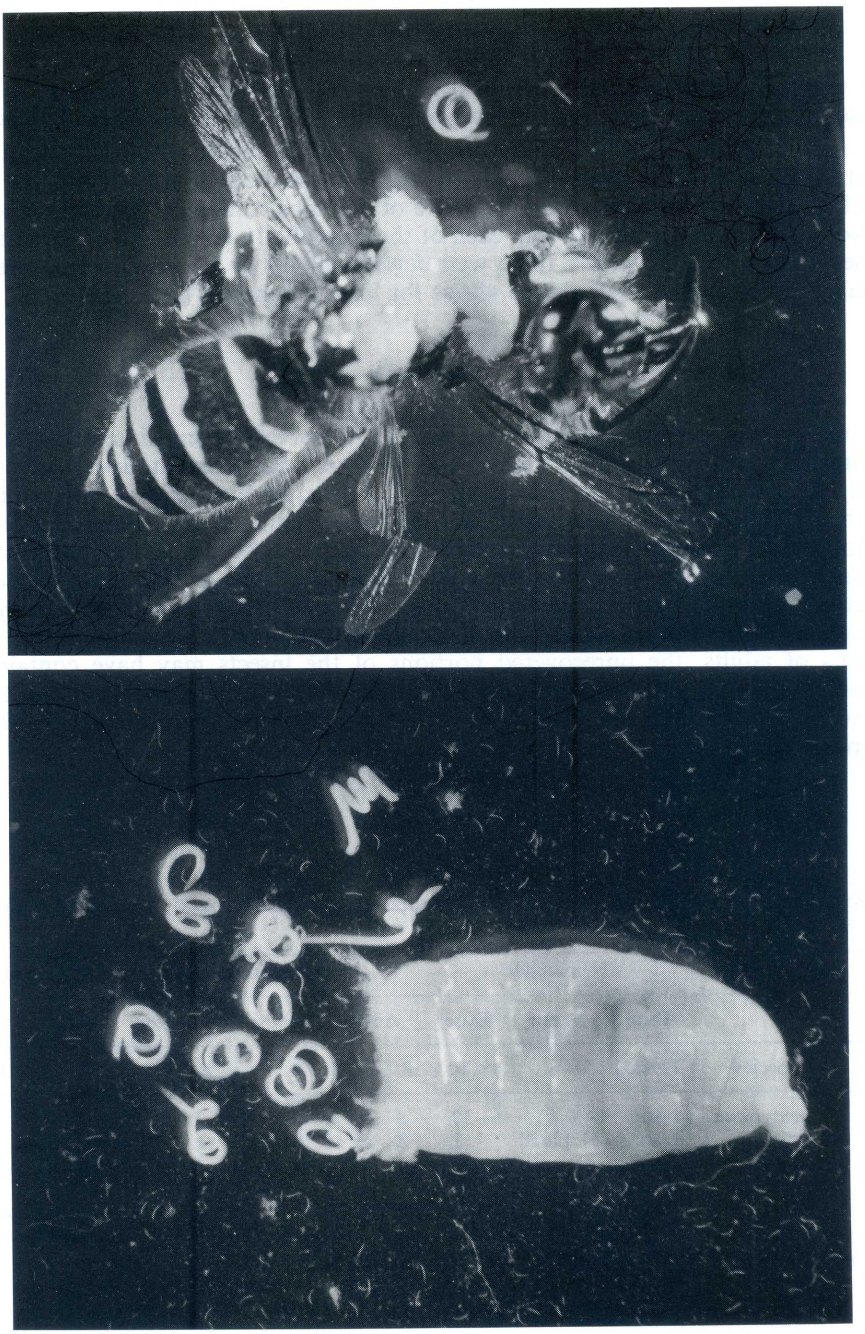

Fig. 1. Dead *Vespula vulgaris* worker that was carried out of a nematode-treated colony by a nestmate. Note developing *Steinernema carpocapsae* female removed from the wasp body cavity.

Fig. 2. Dead *Vespula pensylvanica* larva removed from a nematode-treated nest. Note developing *Steinernema carpocapsae* adults and young juveniles removed from the body cavity.

strictly follow the typical activity pattern, instead showing a slight decline in late August ; however, activity continued into late September, and there was no abrupt posttreatment decrease in foraging rate (fig. 3b).

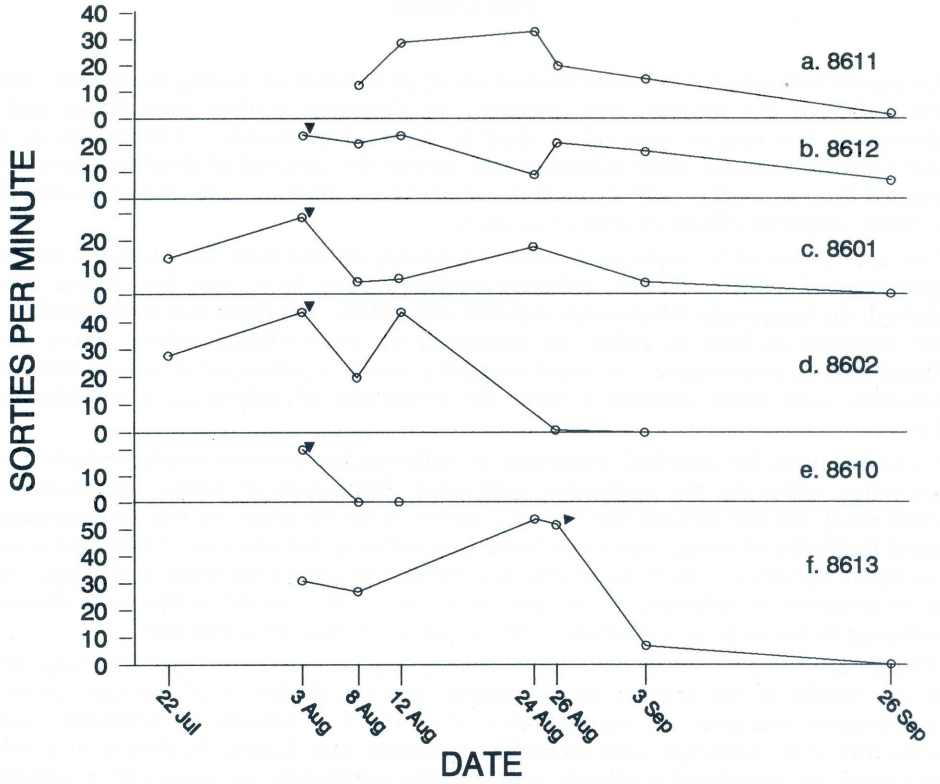

Fig. 3. Seasonal foraging rates at (a) untreated ; (b) water-treated ; (c-f) nematode-treated *Vespula* colonies. Arrows indicate treatments.

In contrast, at all 4 nematode treated colonies there was a sharp decline in activity during the week following treatment ; their subsequent responses were variable. The foraging rate at colony 8601 (fig. 3c) decreased by 82.8 % 4 days after treatment, but the colony recovered, and activity continued at a fairly low level for another month. The colony was dug up by a skunk between 3 September and 26 September. The foraging rate at colony 8602 (fig. 3d) decreased by 54.5 % 4 days after treatment. The colony apparently recovered but soon thereafter suffered a massive invasion of the ant *Iridomyrmex humilis* Mayr ; wasp activity dropped to zero approximately 3 weeks after treatment. The foraging rate at colony 8613 (fig. 3e) decreased by 86.5 % 8 days after treatment ; the colony was subsequently dug up and destroyed by a skunk between 3 September and 26 September. Activity at colony 8610 (fig. 3f) dropped to zero 4 days after treatment, at which time it was also overrun by *I. humilis*. The nest was excavated and examined in the lab. The only live wasps were several workers that had apparently recently emerged from capped cells.

Nematodes were found in 22 (34.4 %) of 64 intact dead insects examined. Again, this figure likely underestimates the true infection rate, because some mortality caused by *S. carpocapsae* would escape detection by the examination method.

DISCUSSION

Untreated yellowjacket colonies showed no atypical behavior during the season ; overall good health of the colonies was indicated by abundant worker populations and the undetectably low rate of removal of dead or diseased nestmates. Colonies treated with water probably suffered some mortality, but neither the removal of dead nestmates nor a sustained drop in worker activity were detected. Thus, colonies were able to recover from the minor transient effects of water treatment.

The application of *S. carpocapsae* caused mortality among both the adult and immature populations of treated colonies, reducing worker activity by at least half within a week. Although the long range effects were variable, one colony was destroyed fairly quickly, and none persisted as long as either the untreated or water-treated colony. These results indicate that *S. carpocapsae* can cause mortality within a yellowjacket colony under field conditions, and could provide a basis for treatment of individual pest yellowjacket colonies.

Considerations for practical treatment of yellowjacket colonies would include ease of application, safety for the applicator, and quick destruction of colony inhabitants. The present study did not address the former 2 points, since the objective was to determine the general feasibility of using nematodes to destroy yellowjacket colonies. Additional research focusing on application methods to enhance contact between nematodes and target insects, and on selection of yellowjacket-virulent nematode strains, would improve the chances of developing nematodes as a practical control agent for pest yellowjackets.

The concentrated resources of an insect colony may attract various exploiting organisms, and the results of the present study suggest that the depletion of workers caused by *S. carpocapsae* increases the susceptibility of colonies to attacks by predators such as skunks and ants. Although such secondary invasions may hasten the demise of a colony, they cannot be considered a reliable supplemental component of nematode treatment.

Several aspects of the biology of eusocial insects create problems not associated with solitary insect pests, and merit consideration in assessing the potential of various control measures. Mortality of a large number of colony members may not be sufficient to ensure total destruction of the colony, and if enough colony members survive the treatment, recovery is possible. Although nearly all *Vespula* colony members can be found in the cells of combs or in the space immediately surrounding them (thus offering a more concentrated target than the dispersed colonies of many ant and termite species), the internal nest structure of horizontally oriented combs may impede distribution of a nematode suspension throughout the nest. Also, capped cells in yellowjacket colonies provide some immatures with refugia from chemical and biological control agents.

The hygienic behavior of many social insects (**Wilson,** 1971), including yellowjackets (**Akre** *et al.*, 1976), results in the removal or insulation of dead and diseased nestmates from active areas of the colony. Hygienic behavior reduces the ability of parasites such as *S. carpocapsae* to develop and generate new infective stages within the nest. An effective nematode treatment would require that the initial application be the direct cause of mortality for colony occupants, rather than the inoculative source for a subsequent epizootic.

ACKNOWLEDGEMENTS

The manuscript benefitted from critical review by **H. Daly, L. Le Beck,** and **J. Rosenheim.** Nematodes were supplied by Biosys, Inc. ; the East Bay Municipal Utility District provided access to the research site. Partial funding support was provided by the Achievement Rewards for College Scientists (ARCS) Foundation, Inc., the East Bay Regional Park District, and the Minority Summer Research Exchange Program (MSREP) of Cornell University and the University of California at Berkeley.

RÉSUMÉ

Essais du nématode *Steinernema carpocapsae* (*Nematoda : Steinernematidae*) contre les nids des guêpes sociales (*Hymenoptera : Vespidae*)

Le nématode entomophage *Steinernema carpocapsae* (Weiser) a été appliqué à quatre nids de guêpes sociales du genre *Vespula* dans les conditions naturelles. Au bout d'une semaine, l'activité des ouvrières a été réduite d'au moins 50 % dans tous les nids traités. Deux nids traités se sont rétablis en partie, et deux ont été détruits complètement. Les ouvrières *Vespula* ont transporté hors des nids traités les individus morts ou malades. Ces résultats suggèrent la possibilité d'utilisation des nématodes dans certaines conditions pour la lutte biologique contre les guêpes nuisibles.

MOTS CLÉS : Insecta, Nematoda, *Vespula, Steinernema carpocapsae,* parasitisme.

Received : 5 July 1990 ; Accepted : 13 December 1990.

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