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College of Agricultural Sciences • Cooperative Extension

Entomological Notes

Department of Entomology

INSECT-PARASITIC NEMATODES FOR THE MANAGEMENT OF SOIL-DWELLING INSECTS

Steinernematidae and *Heterorhabditidae*

INTRODUCTION

Insects have many types of natural enemies. As with other organisms, insects can become infected with disease-causing organisms, called pathogens. Soil serves as a natural home and reservoir for many kinds of insect pathogens, including viruses, bacteria, protozoa, fungi, and nematodes. We can take advantage of these natural enemies of insects to help manage insect pests. The use of natural enemies to manage pests is called **biological control**.

DESCRIPTION

What Is a nematode? Nematodes are microscopic, whitish to transparent, unsegmented worms (Fig. 1). They occupy almost every conceivable habitat on earth, both aquatic and terrestrial, and are among the most common multicelled organisms. Nematodes are generally wormlike and cylindrical in shape, often tapering at the head and tail ends; they are sometimes called roundworms or eelworms. There are thousands of kinds of nematodes, each with their particular feeding behavior -- for example, bacterial feeders, plant feeders, animal parasites, and insect parasites, to name a few.

Insect-Parasitic Nematodes. Traditionally, soil-inhabiting insect pests are managed by applying pesticides to the soil or by using cultural practices, for example, tillage and crop rotation. Biological control can be another important way to manage soil-inhabiting insect pests. A group of organisms that shows promise as biological control agents for soil pests are insect-parasitic nematodes. These organisms, which belong to the families Steinernematidae and Heterorhabditidae, have been studied extensively as biological control agents for soil-dwelling stages of insect pests. These nematodes occur naturally in soil and possess a durable, motile infective stage that can actively seek out and infect a broad range of insects, but they do not infect birds or mammals. Because of these attributes, as well as their ease of mass production and exemption from EPA registration, a number of commercial enterprises produce these nematodes as biological "insecticides."

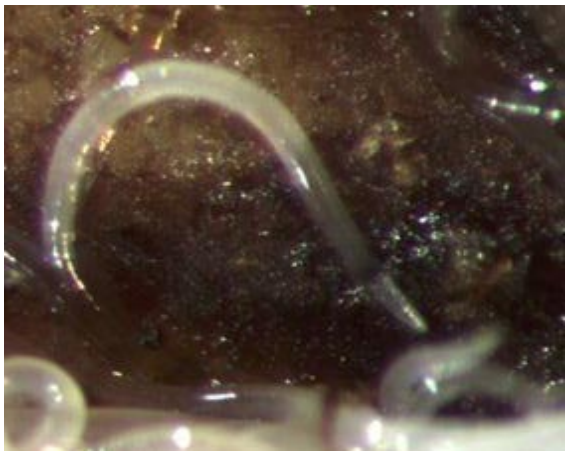

Photo by Cathy Nardozzo

Figure 1. An insect-parasitic nematode

Both of these nematode groups carry within their bodies insect-pathogenic bacteria -- *Xenorhabdus* in the case of steinernematids and *Photorhabdus* in the case of heterorhabditids. Steinernematid and heterorhabditid nematodes are termed **entomopathogenic** because of their association with these bacteria**.** The relationship between the nematodes and bacteria is a true obligate mutualism because the bacterium needs the nematode to carry it into the insect body cavity. The nematode needs the bacterium to create conditions in the insect suitable for its reproduction and growth, and as food. The bacteria are safe to vertebrates and only occur in association with these nematodes and infected insects. They have never been detected living freely in soil. The bacteria produce pigments, so that insects infected with heterorhabditid nematodes turn a brick-red or maroon color, and those infected with steinernematids turn ochre, tan, or brown. Nematode-infected insect cadavers do not smell putrid, and the insect cuticle stays intact until very late in the infection process.

LIFE HISTORY

The **infective third-stage juvenile** (sometimes referred to as dauer or IJ) is the only life stage of the nematode that exists outside of the host insect. The IJ is the stage that is purchased in commercial products. The IJ is nonfeeding and is more resistant than other stages to environmental conditions. It carries the bacteria in its intestinal tract. Upon locating a suitable insect host, the infective juvenile

enters through natural openings (anus, spiracles, mouth) of the insect and penetrates into the insect body cavity. There it releases its bacteria, which multiply and kill the host insect.

The nematodes develop into adults on bacterial cells in the insect cadaver and reproduce. As resources of the insect are depleted and crowding occurs, IJ are produced. The IJ emerge from the cadaver to search for new insect hosts in the soil. The reproductive potential of entomopathogenic nematodes is very high. Thousands of nematodes can be produced from a single infected insect host. The time from infection of the insect until infective juveniles emerge takes about two weeks in the laboratory. Under natural conditions the recycling time may vary depending on environmental conditions and the susceptibility of the host insect (Fig. 2).

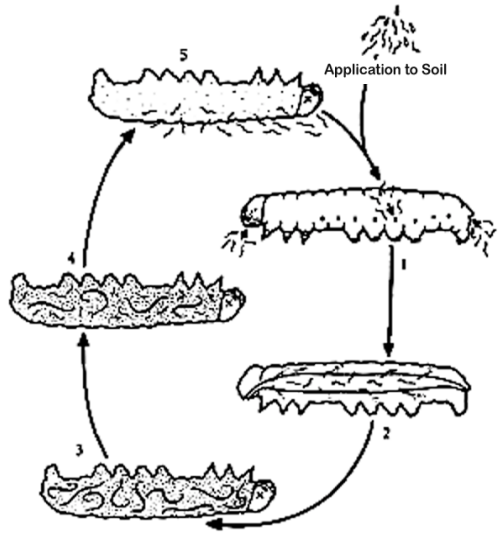

Figure 2. Life Cycle of Insect-Parasitic Nematodes
1. Infective juvenile nematodes in soil enter insect body through natural openings.
2. Nematodes enter insect body cavity.
3. Nematodes develop into adults.
4. Nematodes reproduce and produce offspring.
5. Infective juvenile nematodes leave the dead insect and seek a new insect host.

APPLICATION OF INSECT-PARASITIC NEMATODES

Some nematodes that are commercially available are *Steinernema carpocapsae*, *S. feltiae*, *S. riobrave*, *Heterorhabditis bacteriophora*, *H. marelatus,* and *H. megidis*. These nematodes are most commonly used for management of soil insect pests in high value crops—for example, in home lawns and gardens, turf, nurseries, citrus, cranberries, and mushrooms. Because nematodes are living organisms, their successful use is influenced by environmental conditions. Nematodes need adequate moisture, temperatures within the tolerance levels for the specific nematode, and protection from UV radiation (direct sunlight) during application.

These nematodes, like most soil nematodes, are actually semi-aquatic. Their natural home is in the water film that surrounds soil particles. The IJ are sensitive to destruction by bright sunlight and desiccation if they are sprayed on plant foliage unless they are especially formulated for that use. The most common usage is in soil, although in some instances they have been successfully applied aboveground to insect tunnels or mines in plant tissue.

Nematodes are formulated as suspensions in liquid, on sponge, in gels, or as semidry granules. The main application approach for use is as an aqueous suspension at a typical rate of 2.5 billion/hectare (1 billion/acre), but this rate varies depending on the crop. They can be applied with conventional chemical application equipment, but nozzle filters or screens smaller than 50 mesh will clog and it is best to remove screens in nozzles when applying nematodes with a back-pack sprayer or spray rig. Care should be taken when using hydraulic pumps that have high internal pressure and high shear force as these will shred the nematodes.

Nematodes tend to settle in the tank, so agitation must be provided for uniform application. Nematodes can be killed by excessive tank agitation through sparging (recirculation of a portion of spray mix) or excessive mechanical stirring that is used to keep the nematodes in suspension. Pump pressure and temperature above 300 pounds per square inch and 85°F, respectively, will kill nematodes.

It is best to apply entomopathogenic nematodes to moist soil in the early morning or late evening when air temperatures are between 60 and 85°F. A pre-application irrigation can be applied to moisten the soil and a post-application irrigation can be applied to wash any nematodes on plant surfaces to the soil surface. The post-application irrigation should be applied before spray droplets dry and must provide sufficient (0.1–0.25 inches) water to allow the nematodes to move into the upper soil layers, out of sun or drying air exposure. Applications can be made before or even during a rainfall to wash nematodes to the soil surface.

Successful application of nematodes is influenced by spray volume. Most nematode labels suggest volumes of two to six gallons of spray per 1000 square feet (87–260 gallons per acre). This is achievable for many boom sprayers and lawn shower nozzle sprayers that are equipped with sufficiently large nozzles. Some turf applicators use shower nozzles that deliver 1–1.5 gallons of spray per 1000 square feet. When lower spray volumes are used, pre- and post-application irrigation can be adjusted to counteract the problem of low volume sprays and to assist in moving the nematodes to the soil and off exposed surfaces.

Nematodes can also be applied with irrigation. However, some irrigation systems, especially low volume trickle systems, may not move water fast enough to keep nema-

todes suspended. When in doubt, check periodically by taking a sample at the emitters to determine if live nematodes are being moved through the system.

CONSERVATION OF ENTOMOPATHOGENIC NEMATODES

Entomopathogenic nematodes occur worldwide, and they have been found throughout the U.S. from many different soil types and habitats, both natural and managed. Native nematodes may play an important role in the regulation of insect populations in some systems, but the level of disturbance in agricultural systems may require the use of non-native nematodes that are tolerant to practices being used. Some studies suggest that entomopathogenic nematodes are more abundant in minimum- or no-till plots than in conventionally-tilled plots, and in less disturbed systems, such as orchards or woodlots. Different nematode species are differentially tolerant to soil disturbance. Survival of entomopathogenic nematodes is higher in mulched soil than in bare soil, probably related to soil environmental factors -- for example, soil structure, temperature and moisture.

Research has been conducted to determine the effects of pesticides on entomopathogenic nematodes. Some pesticides and fertilizers are less harmful to entomopathogenic nematodes than others. Compatibility with chemicals is usually provided on product labels or packaging information that accompanies purchased nematodes.

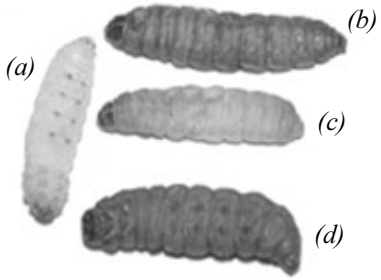

Photo by Cathy Nardozzo

Figure 3. (a) Healthy (cream); (b) Steinernema feltiae-infected (brown); (c) Steinernema carpocapsae-infected (tan) and (d) Heterorhabditis bacteriophora-infected (red) larvae of Galleria mellonella.

EFFICACY OF ENTOMOPATHOGENIC NEMATODES

To date, levels of control achieved by the application of nematodes has been mixed, with some great successes - mostly in controlled systems -- e.g. nursery containers, mushroom houses -- and some failures. The efficacy of nematodes is affected by environmental conditions -- they need adequate but not excessive moisture, temperatures within the tolerance levels for the particular nematode, and protection from UV radiation during application (apply early in morning or in the evening).

Most failures in efficacy of field applications are related to a poor match between the nematode species and target insect pest. Species of nematodes vary in their host range and in their host-finding behavior. Some nematodes, for example, *Steinernema glaseri* and *Heterorhabditis bacteriophora*, are very active in the soil and search a relatively large area for a host insect, whereas the widely available nematode, *Steinernema carpocapsae*, is relatively sedentary and tend to sit and wait for a host insect to pass by in close proximity. *Steinernema carpocapsae* is classified as an ambusher and is most suitable for mobile pests, for example armyworms and cutworms. *Steinernema riobrave* moves well through the soil. It was originally found in the Rio Grande Valley of Texas, is adapted to warm soils and is more tolerant to tilled soils than are some other nematode species. *Heterorhabditis bacteriophora* is highly parasitic on some lepidopteran and coleopteran larvae. It is classified as a cruiser and is effective against sedentary insect hosts, for example, white grubs. *Heterorhabditis megidis* is a parasite of black vine weevil and various other soil insects.

A nematode that is an active searcher (cruiser) will be more effective at finding a sedentary insect host, for example white grubs, than will a sedentary nematode (ambusher). The relatively sedentary nematodes are effective at infecting active insect hosts, such as cutworms or mole crickets. Some known appropriate pathogen-host targets are *S. glaseri* against the Japanese beetle; *S. scapterisci* against mole crickets; *S. riobrave* against cutworms and other noctuid larvae, pupae and citrus weevils; and *S. feltiae* against sawfly larvae and fungus gnat larvae.

As with any purchased natural enemy, quality of the product can affect efficacy. Quality of the product can be affected by batch, and shipping, storage, and application conditions. Nematodes are living organisms and are subject to destruction by excessive cold or heat, and lack of moisture or oxygen. A small sample of the mixed product should be checked with a hand lens or magnifying glass to observe living, moving nematodes. Nematodes that are very straight and motionless may be dead, and therefore, ineffective.

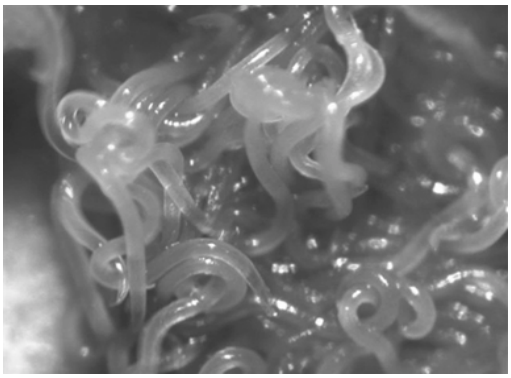

Photo by Cathy Nardozzo

Figure 4. Infective juveniles of Steinernema glaseri emerging from a Galleria mellonella larva.

WEBSITES FOR MORE INFORMATION ON INSECT-PARASITIC NEMATODES

http://www2.oardc.ohio-state.edu/nematodes

Insect Parasitic Nematodes: Tools for Pest Management

This SARE-funded site has information on the biology and ecology of entomopathogenic nematodes, instructions on application, a publications database, "Ask the Expert" advice service, list of retail suppliers, and links to other sites with information about entomopathogenic nematodes.

http://www.nysaes.cornell.edu/ent/biocontrol/pathogens/nematodes.html

Biological control: A guide to natural enemies in North America.

This booklet includes photographs, information and a list of retail suppliers.

http://nematode.unl.edu/

University of Nebraska site that has general information on plant and insect nematodes.

http://creatures.ifas.ufl.edu/nematode/soil_nematode.htm

University of Florida and Florida Department of Agriculture and Consumer Services "Featured Creature" website that has information on nematode biology.

SOME EAST COAST SUPPLIERS OF ENTOMOPATHOGENIC NEMATODES

Beneficial Insect Company
Forrest Street
Fort Mill, SC 29715
Tel: 803 547- 2301
S. carpocapsae, H. bacteriophora

BioLogic Company
Springtown Road, P.O. Box177
Willow Hill, PA 17271
www.biologicco.com/
Tel: 717-349-2789
Fax: 801-912-7137
S. carpocapsae, H. bacteriophora, S. feltiae

BioWorks
122 N Genesee Street
Geneva, NY 14456
Tel: 315-781-1703

Burpee Seed Company
300 Park Avenue
Warminster, PA 18974
Tel: 215-674-4900

Certis USA
9145 Guilford Road, Suite 175
Columbia, MD 21064
www.certisusa.com
Tel: 301-604-7030
800-847-5620
Fax: 410-531-4601
S. carpocapsae, S. feltiae, S. riobravis

Crop King Inc.
5050 Greenwich Road
Seville, OH 44273
Tel: 330-769-2002
Fax: 330-769-2616
cropking@cropking.com
H. megidis, S. feltiae

EcoSolutions, Inc.
334 East Lake Road, Suite 196
Palm Harbor, FL 34685
Tel: 813-787-3669

Extremely Green Gardening Company
44 Lookout Lane
Portsmouth, NH 03801
Tel: 603-427-0299
Fax: 603-430-1064
www.extremelygreen.com

Gardener's Supply Company
128 Intervale Road
Burlington, VT 05401
Tel: 800-955-3370
Fax: 800-551-6712
info@gardeners.com
H. bacteriophora, ***S. feltiae***

Gardens Alive
7438 N. Co. Road 100
East Osgood, IN 47037
Tel: 812-852-2322

Gardens Alive!
5100 Schenley Place
Lawrenceburg, IN 47025
Tel: 812-537-8650 (orders)
Fax: 812-537-5108
76375.2160@compuserve.co
H. bacteriophora

Great Lakes IPM
10220 Church Road NE
Vestaburg, MI 48891
Tel: 517-268-5693
517-268-5911
Fax: 517-268-5311
S. carpocapsae, ***H. bacteriophora***

Heath's Organic Pest Control, Greenhouse & Nursery
Route 18 #750
Sugar Hill, NH 03585
Tel: 603-823-8500
Fax: 603-823-5454
www.ecobugs.com
S. carpocapsae, ***H. bacteriophora***

Integrated Biocontrol Systems, Inc.
100 Brown Street, Suite 2
Greendale, IN 47025
Tel: 888-973-4227
812-537-8674
Fax: 812-537-8644
www.GoodBug-Shop.com
GoodBug@one.net
H. bacteriophora, H. indica, H. marelatus, S. carpocapsae, S. feltiae

IPM Laboratories
Main Street
Locke, NY 13092
Tel: 315-497-2063
Fax: 315-497-3129
ipmlabs@baldcom.net
S. carpocapsae*, *H. bacteriophora, S. feltiae

Johnny's Selected Seeds
Foss Hill Road
Albion, ME 04910
Tel: 207-437-9294
www.johnnyseeds.com

Koppert Biological Systems Inc.
28465 Beverly Road
Romulus, MI 48174
Tel: 734-641-3763
800-928-8827
Fax: 734-641-3799
S. feltiae, H. bacteriophora

Mellinger's, Inc.
2310 West South Range Road
North Lima, OH 44452-9731
Tel: 330-549-9861
800-321-7444 (orders/catalog)
Fax: 330-549-3716
www.mellingers.com
S. carpocapsae

Natural Farm Products
4360 Spencer Road, S.E.
Kalkaska, MI 49646
Tel: 616-369-2465

Necessary Trading Co.
P.O. Box 603
New Castle, VA 24127
Tel: 800-447-5354

N-Viro Products Ltd.
610 Walnut Avenue
Bohemia, NY 11716
Tel: 516-567-2628
Fax: 516-567-2628
S. carpocapsae

Praxis
2723 116th Avenue
Allegan, MI 49010-9095
Tel: 269-673-5209
biotools@ipraxisibc.com
http://ipraxisibc.com

The Animal Guys
4281 Cider Mill Drive
Cincinnati, OH 45245
Tel: 513-688-1050
Fax: 513-688-1160
pdmccomas@juno.com

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Tel: 603-942-8925
Fax: 603-942-8932
Info@GreenMethods.com
www.greenmethods.com
S. carpocapsae, S. feltiae, H. bacteriophora

Worm's Way Inc.
7850 N. State Highway 37
Bloomington, IN 47404-9477
Tel: 812-876-6450
800-274-9676 (mail orders)
800-283-9676 (FL)
800-284-9676 (MA)
Fax: 800-316-1264 (mail orders)
www.wormsway.com
S. carpocapsae, H. bacteriophora

WARNING

Pesticides are poisonous. Read and follow the label directions and safety precautions. Handle them carefully and store in original, labeled containers—out of the reach of children, pets, and livestock. Dispose of empty containers quickly, in a safe manner and place. Do not contaminate forage, streams, or ponds.

Mary Barbercheck
Professor
Dept. of Entomology
January 2005

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