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Entomopathogenic Nematodes

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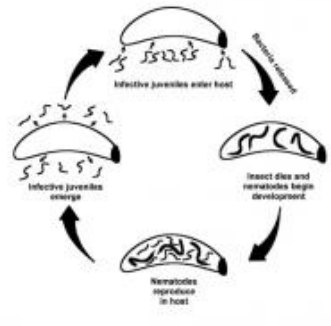

Figure 1. Generalized life cycle of a steinernematid nematode.

Reprinted with permission from Shapiro-Ilan, D.I. and Gaugler, R. (n.d.). Nematodes. In Biological Control: A Guide to Natural Enemies in North America (Anthony Shelton, editor).

Insect-pathogenic, or entomopathogenic, nematodes are a group of soil-dwelling roundworms which only kill insects that live in, on, or near the soil surface, usually closely associated with plants. These nematodes occur naturally in soil and are found in most places where plants grow. Research has demonstrated that entomopathogenic nematodes can be mass produced, have a narrow host specificity against pests, and are safe to plants and vertebrates; and, therefore, the U.S. Environmental Protection Agency has exempted them from all registration requirements and related regulation. Entomopathogenic nematodes have been available commercially to agriculturists for several years and have been used in a variety of cropping systems.

There are two main groups of entomopathogenic nematodes: the steinernematids and the heterorhabditids. Both have similar life cycles, and only the free-living, infective juvenile stage is able to infect the target (pest) insect. It is the juvenile stage that is found in or on the soil, searching out a host to infect. In fact, the juvenile form is the only form found outside of the host.

Nematode selection

The choice of an entomopathogenic nematode *(Steinernema* spp. or *Heterorhabditis* spp.*)* depends on the targeted insect pest. In general, nematodes in the genus Steinernema are considered “sit-and-wait predators” or ambushers and are used against insects whose immature stages (larvae or pupae) spend most of their time at or near the soil surface. Other species are highly mobile and roam through the soil searching for potential hosts. The host-finding strategy of most *Steinernema* is to wait until the prey bumps into the nematode, and then infects it. In contrast, nematodes in the genus *Heterorhabditis* actively seek out or hunt for their prey, sometimes several inches below the soil surface, and stay in one spot for an extended period of time. Thus, nematodes in the genus *Steinernema (S. feltiae)* are the best choice against fungus gnat larvae, often found on the soil surface of potted plants, while *Heterorhabditis (H. megidis, H. marelatus,* or *H. bacteriophora)* are the best choices against the black vine weevil, deeper in the soil. There are over ten entomopathogenic nematodes commercially-produced as a biological insecticide for over 25 insect pests.

There is some overlap between the two species with regards to host-finding ability. Consult a nematode manufacturer/supplier for selection of the proper entomopathogenic nematode product.

Life cycle

When a juvenile nematode locates a host insect, the juvenile enters via a natural opening; or, in certain instances, it may penetrate a weak spot in the insect's cuticle. Once inside the host blood system, the juvenile releases a symbiotic bacterium that it carries. The bacteria are released into the blood of the host, rapidly multiply, and produce compounds that kill the host insect generally within 48 hours. The bacteria protect and preserve (via antibiotics) the dead insect from invasion by unwanted, contaminating soil microbes and the nematodes provide shelter for the bacteria. The infective nematodes complete one to several generations inside the host, feeding on the bacteria and nutrients within the dying host. Only when all the host tissues have been consumed does a new generation of juveniles emerge, all carrying the symbiotic bacteria with them in search of new hosts (see Figure 1).

One generation from egg to egg typically takes from 4 to 7 days. In most instances, there are at least two generations inside a host before the new juveniles emerge seeking a new host, so from the time of first infection by juveniles to the time "new" juveniles emerge may be from 8 to 14 days. The length of time is determined by the temperature of the soil, the size of the host, and which nematode is involved. A large host such as a cutworm will support several generations before conditions become too "crowded" and juveniles emerge, compared to a strawberry root weevil larva, where there may be only one or two generations before juvenile emergence. Similarly, a large nematode such as *S. carpocapsae* has fewer generations than *S. feltiae* when infecting similar-size hosts.

Application methods

Though the adult stage of some insect pests also is susceptible, entomopathogenic nematodes generally are used for controlling the soil-borne larval or pupal stages of a pest. Therefore, entomopathogenic nematodes most often are applied by drench or band application. While broadcast application has been used at times, the immature pest insect usually is not located between the crop rows as there is usually no food source there. If, however, the crop has a closed canopy like cranberries or mint, a broadcast application may be warranted. Select your application method wisely, as it may impact greatly the success of host location, infection, and control by the entomopathogenic nematodes.

Entomopathogenic nematodes come in a variety of formulations: water-dispersible granules, nematodes on gel, micronized vermiculite, nematode wool, and an aqueous suspension of nematodes. All of the formulations are intended to be mixed with water to release the nematodes through common application equipment such as small pressurized sprayers, mist blowers, electrostatic sprayers, or even helicopters (aerial application). One of the more promising methods for applying entomopathogenic nematodes uses irrigation systems in a manner similar to chemigation.

Regardless of the method, nematodes can withstand application pressures of approximately 300 psi and can pass through most spray nozzles without difficulty, though operating pressures between 20 to 60 psi generally are sufficient. Keep in mind that nozzle orifices should not be smaller than 50 microns (0.00019685 inch), and that any screens in the system should have an opening of at least 50 mesh (0.0117 inch) or larger to allow the free passage of nematodes through the system. In any case, follow the manufacturer's directions.

Nematodes require a film of water around soil particles to move through the soil profile in search of a host. Therefore, pre-irrigate the soil in the treatment area with about 0.25 to 0.5 inch of water no later than a few hours before application of the nematodes. Following the application, "water in" the nematodes with an additional 0.5 inch of water to wash them off of foliage and protect them from damaging UV radiation. Further irrigation to maintain adequate soil moisture for at least 7 days following nematode application also is recommended. Be

careful not to over-irrigate, because excess water inhibits the movement of oxygen in the soil, and the nematodes will drown. A good rule of thumb is to avoid standing water in your fields.

Key points for success in using entomophathogenic nematodes

- When applying agrichemicals in the area where entomopathogenic nematodes are to used, be sure that there is enough separation time between applications of toxic compounds and entomopathogenic nematodes (Table 1). Some chemicals have been found to affect nematode efficacy when nematodes are exposed to them. These should be applied with care when used in conjunction with nematodes.
- Entomopathogenic nematodes require a moist, not saturated, soil environment so they can move around and locate their host.
- Soil temperature where nematodes are to be applied should be above 55°F and less than 90°F. Nematodes are also affected by suboptimal soil type, thatch depth, and irrigation frequency.
- Protect nematodes from excessive exposure to ultra violet (UV) rays which can inactivate and kill them.
- Time application of entomopathogenic nematodes to target the susceptible stage of the pest.
- Select the proper nematode species to match the most susceptible pest stage.
- Storage of formulated nematode species varies: Steinernematids at 39-46°F; Heterohabditids at 50-60°F. Do not leave in a hot vehicle.
- Select the application rate and method to maximize contact between entomopathogenic nematodes and the target pest.
- In all cases, refer to the manufacturer's label for recommendations.

Note: We appreciate the contributions of past employees of Oregon State University, Peter Guthro and Ralph Berry, to this document.

Table 1. Chemical-use patterns with nematodes[1]

Compiled from D. Shetlar, 1999, and K. Smith, 1999; Alumai and Grewal, 2004

May be tank-mixed with nematodes			
Compound	**Trade name**	**Compound**	**Trade name**
acephate	Orthene	fenoxycarb	Logic
azadirachtin[2]	Azatin, Neem[2]	fertilizers	Various
Bacillus thuringiensis (Bt)	M-One, Dipel	fipronil[2]	Chipco Choice[2]
		fosethyl-Al	Aliette
benomyl	Benelate	glyphosate	Roundup
bifenthrin	Talstar	insecticidal soap[2]	Various
bromine-chlorine	Agribrom	iprodione	Chipco 26019
carbaryl[2]	Sevin[2]	isofenphos	Oftanol

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carbofuran[2]	Furadan[2]	kinoprene	Enstar
chlorothalonil	Daconil	metalaxyl	Subdue
chlorthal dimethyl	Dacthal	methidathion	Supracide
copper hydroxide	Kocide	methomyl[2]	Lannate[2]
cyfluthrin	Tempo	methoprene	Apex
cythion	Malathion	oryzalin	Surflan
diazinon	Knox-out	oxamyl[2]	Vydate[2]
dienochlor	Pentac	oxazoidinedione	Ornalin
diflubenzurion	Dimilin	pentachloronitrobenzene	Terrachlor
endosulfan	Thiodan	thiophanate-methyl	Zyban
esfenvalerate	Asana	triademefon	Bayleton
etridiazole	Terrazole		
1-wk separation		**2-wk separation**	
anilazine	Dyrene	ethoprop	Mocap
bendiocarb	Turcam, Ficam	fenamiphos	Nemacur
chlorpyrifos	Dursban	isazophos	Triumph
dimethyl benzyl ammonium chloride	Physan 20		
fenarimol	Rubigan		
mercurous chloride	Calo-Clor		
2,4-D	Various		
triclopyr	Turflon, Confront		

[1] Note with caution: Environmental conditions could affect the pathogenicity, virulence and effectiveness of entomopathogenic nematodes with selected pesticide formulations; and moreover the nematode species can differ in their susceptibility and sensitivity to different formulations to the same chemical pesticides

[2] Use pattern not well-established. Monitor closely.

References for Table 1

Alumai, A. and P. Grewal, 2004. Tank-mix compatibility of the entomopathogenic nematodes, Heterorhabditis

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Compiled from D. Shetlar, 1999, and K. Smith, 1999; Alumai and Grewal, 2004

bacteriophora and Steinernema carpocapsae, with selected chemical pesticides used in turfgrass. 2004. Biocontrol Science and Technology, 14(7). DOI: 10.1080/09583150410001724334.

Shetlar, D.J. 1999. "Application Methods in Different Cropping Systems," in Proceedings of Workshop—Optimal Use of Insecticidal Nematodes in Pest Management, Aug. 28–30, 1999. S. Polavarapu, ed.

Smith, K. 1999. "Factors Affecting Efficacy," in Proceedings of Workshop—Optimal Use of Insecticidal Nematodes in Pest Management, Aug. 28–30, 1999. S. Polavarapu, ed.

Additional information on entomopathogenic nematodes and their application can be found in:

Miles, C., C. Blethen, R. Gaugler, D. Shapiro-Ilan and T. Murray. 2012. *Using entomopathogenic nematodes for crop insect pest control.* PNW Extension Publication 544. http://cru.cahe.wsu.edu/CEPublications/PNW544/PNW544.pdf

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Hollingsworth, C.S. (Ed.). 2016. Pacific Northwest Insect Management Handbook.

Use pesticides safely!

- Wear protective clothing and safety devices as recommended on the label. Bathe or shower after each use.
- Read the pesticide label—even if you've used the pesticide before. Follow closely the instructions on the label (and any other directions you have).
- Be cautious when you apply pesticides. Know your legal responsibility as a pesticide applicator. You may be liable for injury or damage resulting from pesticide use.

Trade-name products and services are mentioned as illustrations only. This does not mean that the participating Extension Services endorse these products and services or that they intend to discriminate against products and services not mentioned.