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Standard Guide for Evaluation of Nematode Control Agents—Side Effects of Nematicide Application on Other Organisms¹

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INTRODUCTION

The application of a nematicide often has direct or indirect effects on organisms other than nematodes that influence plant growth. Therefore, a complete and accurate evaluation of a nematicide must include consideration of these factors. Prior to evaluating a nematicide in a given field, the investigator should be aware of the field's history in regard to past infestations by soilborne fungal and bacterial pathogens, nematode-borne viruses, and soil insects. If available, a selective pesticide for any of the above pests should be included for comparison, thus enabling the investigator to measure more precisely the nematicidal effectiveness of the test compound *per se*.

1. Scope

This guide provides examples of some possible complicating factors to alert the investigator to sources of side-effects of nematicide application. It is not intended to provide intensive and extensive methods of investigating the associated organisms or the diseases they cause because the expertise and responsibility for this lie outside the discipline of nematology. Essentially, short summary statements are made relative to specific documented associations.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Indirect Effects of Nematicides

2.1 *Fungi*—Nematodes increase the severity of fungal diseases by acting as vectors and wounding agents, by modifying host tissue and rhizosphere, and by breaking varietal resistance. Some of the more important and well-known associations are as follows (1)²:

2.1.1 *Belonolaimus* spp. greatly increases the development of *Fusarium* wilt in cotton, break resistance to *Fusarium* in *Fusarium*-resistant cultivars (2, 3, 4)² and increase the severity of *Pythium aphanidermatum* on chrysanthemums (5, 6).

2.1.2 *Helicotylenchus* spp. penetrate the mycorrhizal mantle of short-leaf pine seedlings, create infection courts for *Phytophthora cinnamoni* (7) and cause superficial lesions which are considered important as infection courts for *Rhizoctonia* spp. in banana roots (8).

2.1.3 *Ditylenchus dipsaci* injures or weakens, or both, potato stems and increases host susceptibility to infections with *Phoma solanicola* (9).

2.1.4 *Heterodera glycines* greatly increases the severity of *Fusarium* wilt in soybeans (10).

2.1.5 *Heterodera schachtii* facilitates the entrance of *Rhizoctonia solani* in sugarbeets (11) and increases damping-off of sugarbeets by *Pythium ultimum* (12).

2.1.6 *Globodera rostochiensis* increases the severity of *Verticillium dahliae* infection of potato (13) and *Rhizoctonia solani* infection of tomato (14).

2.1.7 *Globodera tabacum* increases the severity of *Verticillium albo-atrum* infection in tomato (15).

2.1.8 *Hoplolaimus* spp. (a) prolong the susceptibility of cotton seedlings to postemergence damping-off by *Rhizoctonia solani* (16); (b) penetrate the mycorrhizal mantle of pine seedlings and increase their exposure to fungal pathogens (17); (c) are associated with *Fusarium oxysporum* in suppressed growth of peach seedlings (18); and (d) facilitate entry of *Fusarium oxysporum* f. sp. *pisi* into the vascular bundle of peas (19).

2.1.9 *Meloidogyne* species are the most important in predisposing their host plants to fungal diseases. This problem usually results from a modification of the host tissue which creates a better substrate for the fungus (20).

2.1.9.1 *M. arenaria* causes a synergistic increase in peanut root rot when combined with *Pythium myriotylum* (21).

2.1.9.2 *M. hapla* causes a significantly greater incidence and density of *Aspergillus flavus* in kernels of peanut (22).

2.1.9.3 *M. incognita* (a) greatly increases *Fusarium* wilt in tomato, muskmelon, tobacco, cotton, cabbage, and mimosa (1, 23, 24, 25, 26, 27, 28, 29); (b) causes a synergistic increase in cotton seedling diseases when associated with each of the following fungi: *Alternaria tenuis*, *Glomerella gossypii*, *Fusarium oxysporum* f. sp. *vasinfectum*, and *Rhizoctonia solani* (30); (c) predisposes tobacco to *Pythium ultimum*, *Trichoderma harzianum*, *Curvularia trifolii*, *Botrytis cinerea*, *Aspergillus ochraceus*, *Penicillium martensii* (31); (d) predisposes cotton seedlings to damping-off caused by *Pythium*

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² The boldface numbers in parentheses refer to the list of references at the end of this guide.



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TABLE 1 Pesticides Used in Nematode Control

Common Name	Trade Name	Insects and Related Pests Controlled
Fumigants:		
chloropicrin	Picfume [®] , Larvacide [®] , Chlor-o-pic 100 [®]	grubs, wireworms
1,3-dichloropropene-chloropicrin mixes	Telone C-17 [®]	wireworms, garden centipedes
methyl bromide	Dowfume MC ₂ [®] , Brom-o-gel [®] , Brozone [®]	many insects and mites
chloropicrin-methyl bromide mixes	Terr-o-gas [®] , Dowfume MC-33 [®]	soilborne insects, wireworms
1,3-dichloropropene	Telone [®] -II	garden centipedes, wireworms
sodium methyl dithiocarbamate	Vapam [®]	garden centipedes
Nonfumigants:		
aldicarb	Temik [®]	aphids, boll weevil, Colorado potato beetle, cotton leaf perforator, flea beetles, leafhoppers, leafminers, lygus bugs, mealybugs, mites, sugar beet root maggot, thrips, white flies
carbofuran	Furadan [®]	alfalfa weevil, armyworms, corn borers, corn rootworms, flea beetles, lygus bugs, pea aphid, snout beetles, sugarcane borer, thrips, wireworms
diazinon	Diazinon [®] , Sarolex [®]	ants, armyworms, clover mites, cutworms, diggerwasps, earwigs, springtails, sod webworms, sowbugs
fensulfthion	Dasanit [®] , Terracur P [®]	cabbage maggot, corn rootworms, European corn borer, lesser cornstalk borer, onion maggot, seed corn beetle, seed corn maggot, sugar beet root maggot, thrips, tuber flea beetle larva, wireworms
ethoprop	Mocap [®]	corn rootworms, flea beetles, wireworms
oxamyl	Vydate [®]	flea beetles
Miscellaneous:		
parathion	Parathion [®]	many insects
phorate	Thimet [®]	soil and systemic insecticide
fenamiphos	Nemacur [®]	aphids, mites, thrips, flea hoppers, mealybugs, and adult cucumber beetles
disulfoton	DI-Syston [®]	aphids, flea beetles, leafhoppers, mites, rootworms, southern potato wireworm, thrips, whiteflies
fonofos	Dyfonate [®]	corn rootworms, cutworms, garden centipedes
terbufos	Counter [®]	many insects

debaryanum (16); (e) increases severity of *Rhizoctonia solani* and *Phytophthora* of tobacco (32); and (f) breaks resistance of tobacco cultivars to *Phytophthora parasitica* (33, 34) and of tomato cultivars to *Fusarium oxysporum* f. sp. *lycopersici* (35).

2.1.9.4 *M. javanica* increases the severity of *Fusarium* wilt to: tomato, mimosa, tobacco, cowpea, sweet potato, and chrysanthemum (36, 37, 38, 39) and causes synergistic increase in kenaf root rot caused by *Macrophomina phaseoli* (40).

2.1.10 *Paratylenchus namatus* is associated with *Rhizoctonia* in root rot of celery (41).

2.1.11 *Pratylenchus* spp. nematodes usually predispose their hosts to fungal infection by creating wounds which facilitate fungal penetration (42).

2.1.11.1 *P. brachyurus* causes a synergistic increase in the number of soybean seedlings dampened-off by *Rhizoctonia solani* (43).

2.1.11.2 *P. neglectus* (*P. minyus*) reduces incubation time, increases the incidence and severity of *Verticillium dahliae* in peppermint (44); is consistently associated with *Rhizoctonia solani* in root rot of wheat (45); and increases severity of *V. dahliae* on potato (46).

2.1.11.3 *P. penetrans* and other *Pratylenchus* spp. (a) break resistance in the pea cultivar Wisconsin Perfection to *Fusarium oxysporum* f. sp. *pisi*, and enhance *Fusarium* wilt in the pea cultivar Rondo (47, 48); (b) increase severity of *Verticillium* wilt in: tomato, cotton, eggplant, and potato (46, 49, 50, 51); (c) increase severity of *Aphanomyces euteiches* infection on peas when the inoculum level of the fungus is low (52); and (d) increase incidence and severity of

Verticillium wilt on Scotch spearmint (53).

2.1.11.4 *P. pratensis* causes a synergistic reduction in growth of potato, carrot, red clover, tomato, spinach, and violet seedlings when associated with *Cylindrocarpum radicola* (54).

2.1.11.5 *P. scribneri* causes a synergistic decrease in corn growth when associated with *Fusarium moniliforme* (55).

2.1.11.6 *P. vulnus* is associated with *Fusarium oxysporum* in suppressing growth of peach trees (18).

2.1.11.7 *P. zeae* causes synergistic growth inhibition of sugarcane when associated with *Pythium graminicola* (56, 57).

2.1.12 *Radophilus similis* causes a 100 % increase in the incidence of *Fusarium oxysporum* f. sp. *cubense* infection in banana and an increase in the incidence and severity of *Fusarium* sp. in citrus trees (58, 59).

2.1.13 *Rotylenchulus reniformis* causes a synergistic increase in *Fusarium* wilt severity in cotton, is able to break resistance to wilt in some varieties (60, 61), and increases the susceptibility of cotton to *Rhizoctonia solani* infection when present at high populations (16).

2.1.14 *Paratrichodorus minor* (*Trichodorus christiei*) is associated with *Fusarium moniliforme* in suppressing root growth of sugarcane (62) and increases the infection incidence of *Verticillium albo-atrum* on tomato (63, 64).

2.1.15 *Tylenchorhynchus* spp.:

2.1.15.1 *T. claytoni* may increase incidence of *Fusarium* wilt in tobacco (65).

2.1.15.2 *T. martini* increases incidence of root rot of peas caused by *Aphanomyces euteiches* (66).

2.1.15.3 *T. dubius* increases *Fusarium* blight of turf (67).

2.1.16 *Tylenchulus semipenetrans* increases incidence of

Fusarium oxysporum in rough lemon by 33 % and that of *F. solani* by 350 % (68).

2.1.17 *Tylenchus agricola* increases penetration of the vascular stele of corn by *Fusarium roseum* (69).

2.2 **Bacteria**—Nematicides may affect some bacterial diseases of plants because nematodes are vectors for bacterial pathogens of apical meristems, and are vectors or predisposing agents for endophytic soft rot bacteria, vascular wilt pathogens, or bacteria that cause cankers (70, 71). Nematodes may also act as antagonists of beneficial bacteria such as the nitrogen fixers (72, 73, 74). *Pratylenchus neglectus* and *P. penetrans* increases severity of wilt on potato caused by *Erwinia carotovora* subsp. *carotovora* (see 2.1.11.2).

2.2.1 *Anguina tritici* is an essential vector of *Clavibacter tritici* which causes tundu or yellow slime disease of wheat (75, 76).

2.2.2 *Aphelenchoides ritzemabosi* is an essential vector of *Rhodococcus facians* which together with the nematode causes cauliflower disease of strawberry (70).

2.2.3 *Criconomella xenoplax* increases susceptibility of peach and plum trees to bacterial canker (*Pseudomonas syringae*) probably by reducing the vigor of the host (77, 78).

2.2.4 *Ditylenchus dipsaci* assists by wounding and as a vector of *Erwinia rhaponticum* which causes crown rot of rhubarb (79) and acts as a vector of *Clavibacter michiganensis* subsp. *insidiosus*, the cause of bacterial wilt of alfalfa (80).

2.2.5 Certain races of *Heterodera glycines* inhibit the formation of nitrogen nodulation by *Bradyrhizobium japonicum* on soybean (72).

2.2.6 *Meloidogyne* spp. assist by wounding to increase the severity of carnation wilt caused by *Pseudomonas caryophylli* (81).

2.2.7 *Meloidogyne incognita* increases the severity of bacterial canker (*Clavibacter michiganensis* subsp. *michiganensis*) on tomato (82) and assists by wounding to markedly increase the incidence and severity of Granville wilt (*Pseudomonas solanacearum*) on tobacco (83, 84).

2.2.8 *M. hapla* greatly increases the incidence of bacterial wilt (*C. michiganensis* subsp. *insidiosus*) on alfalfa (85, 86).

2.2.9 *Helicotylenchus dihystra* assists by wounding to cause an increase of carnation wilt caused by *Pseudomonas caryophylli* (81).

2.2.10 *Xiphinema americanum* and *Criconomella xenoplax* is associated with Cytospora canker of spruce (87).

2.3 **Viruses**—The following species are known vectors of the indicated viruses. Control of these nematodes could result in crop improvement by lowering the incidence of virus infection.

2.3.1 *Longidorus* spp.

2.3.1.1 *L. attenuatus* transmits lettuce ringspot virus (88).

2.3.1.2 *L. elongatus* transmits raspberry leafcurl, beet ringspot, and tomato black ring viruses (88).

2.3.1.3 *L. macrosoma* transmits raspberry ringspot virus (88).

2.3.2 *Paratrichodorus* spp.

2.3.2.1 *P. allius*, *P. minor*, *P. nanus*, *P. pachydermus*, *P. porosus* and *P. teres* transmit tobacco rattle virus (88).

2.3.2.2 *P. anemones*, *P. pachydermus* and *P. teres* transmit pea early browning virus (88).

2.3.3 *Trichodorus* spp.

2.3.3.1 *T. cylindricus*, *T. primitivus*, and *T. similis*

transmit tobacco rattle virus (88).

2.3.3.2 *T. viruliferus* transmits pea early browning virus (88).

2.3.4 *Xiphinema* spp.

2.3.4.1 *X. americanum* transmits tobacco ringspot and tomato ringspot viruses (88).

2.3.4.2 *X. coxi* transmits cherry leafroll and arabis mosaic viruses (88).

2.3.4.3 *X. diversicaudatum* transmits strawberry latent ringspot, arabis mosaic, carnation ringspot, and cherry leafroll viruses (88).

2.3.4.4 *X. index* transmits grapevine fanleaf virus (88).

2.3.4.5 *X. italiae* transmits grapevine fanleaf virus (88).

3. Direct Beneficial Effects of Nematicides

3.1 **Fungi**—Several of the fumigant nematicides have fungicidal properties, especially at high rates of application. It is thus possible for a nematicide to have either or both a direct and indirect action on a given nematode-fungus disease (89).

3.1.1 *Telone* (a) reduces *Pythium arrhenomanes* 60 % in pineapple fields treated with 355 L/hectare and reduces below a detection level by 710 L/hectare (90); (b) kills *Phytophthora cinnamoni*, *Rhizoctonia solani*, and *Thielaviopsis basicola* at 0.074 $\mu\text{L}/\text{cm}^3$ in a sealed container held at 24°C (91); (c) reduces *Phytophthora citrophthora* and *P. parasitica* in the 30 to 60-cm soil horizon when applied at 27 635 kg/hectare (92).

3.1.2 *DBCP* (no longer available) (a) reduces the inoculum potential of *Rhizoctonia solani* for 106 days in a peanut field treated at the rate of 14 L/hectare applied in the row (93); (b) reduces *Rhizoctonia solani* infection on Kentucky bluegrass in the absence of a significant population of plant parasitic nematodes when applied at the rate of 1.87 mL/m² (83); (c) prevents damping-off of cotton seedlings due to *Pythium ultimum* in greenhouse experiments when applied at the rate of 14 L/hectare (16); and (d) reduces *Pythium* sp. populations in soil by 66 % when applied at 22.4 L/hectare (94). Mixes of 1,3-dichloropropene-chloropictin, currently available materials, are effective against many fungi and bacteria.

3.2 **Insects**—Although insects can disseminate (95, 96, 97) and prey (98, 99, 100, 101, 102) on nematodes, and many insects and nematodes have common hosts, there is little information on separation of damage due to insects from that due to nematodes following either direct or indirect application of nematicides. This is surprising, as it is well known that many chemicals used in nematode control also have insecticidal properties. Some granular nonvolatile nematicides were first tested, registered, and marketed as insecticides and their use in nematode control came later. Knowing that chemicals being tested or used as nematicides are also insecticidal may help in interpreting results. However, it should be recognized that some chemicals in use have not been tested thoroughly either as nematicides or insecticides and that the possibility remains that the biocidal activity may be greater than the label or the manufacturer specifies.

3.2.1 Several chemicals used or being tested as nematicides, which have been labeled as insecticides, are indicated in Table 1. This list is a guide and is not