NEMATOLOGICAL REVIEWS—RESEÑAS NEMATOLOGICAS

MANAGEMENT OF NEMATODES BY CULTURAL PRACTICES[1]

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ABSTRACT

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Cultural practices of long standing still are very important in managing plant-parasitic nematodes. Selected literature and examples of cultural practices are included with their advantages and disadvantages under different conditions. The lists of nonhost plants for various nematodes should be useful in crop rotation. Crop rotation, organic soil amendments, fallowing, and residual root destruction are the most popular types of cultural practices, whereas trap and antagonistic crops, flooding and other practices have had limited use. Implementation of each practice with the necessary precautions and promising future research are discussed.

Additional key words: Aphelenchoides spp., Belonolaimus spp., cropping systems, Ditylenchus spp., Dolichodorus spp., Globodera spp., Helicotylenchus spp., Heterodera spp., Hoplolaimus spp., host nutrition, integrated pest management, Meloidogyne spp., Nacobbus aberrans, nonhosts, Paratrichodorus spp., Pratylenchus spp., Quinisulcius spp., Radopholus similis, Rotylenchulus reniformis, Tagetes spp., Tylenchorhynchus spp., Xiphinema spp.

RESUMEN

Trivedi, P. C., y K. R. Barker. 1986. Manejo de nematodos de prácticas culturales. Nematropica 16:213-236.

Las prácticas culturales tradicionales continuan siendo importantes en el manejo de los nematodos fitoparasitos. En esta publicación se incluyen referencias bibliográficas importantes y ejemplos de las prácticas culturales mas comunes asi como sus ventajas y desventajas bajo diferentes condiciones ambientales. La lista de plantas no hospederos a determinados tipos de nematodos sera tambien de utilidad en la rotación de cultivos. Las prácticas culturales mas comunes son: rotación de cultivos, enmiendas orgánicas, barbecho y destrucción de ráices al final de la cosecha; mientras que las prácticas menos comunes son: el uso de plantas trampa, los cultivos antagónicos y la inundación de los terrenos. La aplicación de cada una de las prácticas mencionadas y las precauciones necesarias para implementarlas, asi como la investigación futura en esos campos seran tratadas en este trabajo.

Palabras claves adicionales: hospederos no efectivos, manejo integrado de plagas, condición del hospedero, sistemas de cultivo.

INTRODUCTION

Development of the concepts of pest management and their implementation have led to a greater appreciation of the need for a wide range of tactics for nematode control. Still, the greatest emphasis in management of these pests often is placed primarily on chemical soil treatments and secondarily on the use of resistant cultivars (103). Unfortunately, the recent loss of effective fumigant nematicides and the environmental hazards associated with several remaining materials are leading to severe restrictions on their use. Also important, the continuous use of resistant cultivars frequently leads to the build-up of nematode races that parasitize and damage normally resistant plants.

This paper focuses on how cultural practices can facilitate the management of plant-parasitic nematodes. The advantages and disadvantages of the major cultural practices utilized in nematode-control programs and selected examples of each tactic are included.

CROP ROTATION AND CROPPING SYSTEMS

Crop rotation is one of the oldest and one of the most effective means of controlling plant-parasitic nematodes (79,115). The aim of rotation is to allow sufficient intervals after each host crop to effect a sufficient pest population decline that will facilitate the next host crop to grow and yield at an acceptable rate. Cropping systems and crop rotation are similar concepts which have been variously defined. Crop rotation is the fixed yearly sequence and spatial arrangement of crops, or the alteration of crops and fallow on a given area (79). The alternate crop may be natural or planted. A cropping system is the sequence of growing various crops along with the required technologies for their production (90). The term "cropping system" covers all kinds of crop sequences, including continuous monoculture, whereas "crop rotation" implies an inflexible cycle or a fixed sequence of crops (79). The study of cropping systems includes quantitative analyses of the relationships among crops, pests, and management techniques which are deployed or deployable in the target system (77). The crop sequence may be temporal or spatial. In effect, the pest population will respond to individual crops as well as to the arrangement of the crops in time and space (Table 1). To limit crop losses caused by nematodes, the short and long-term effects of cropping sequences, spacing, and related interactions with biotic and abiotic environmental components on crop yields must be better understood. Special consideration also must focus on the potential impact of associated weeds and other pests in cropping systems when developing an appropriate crop rotation.

A very different concept of "crop rotation" has been used in forestry (112). Simple sequential cropping or harvests of one tree species is con-

Table 1. Types of crops and their arrangement in time and space evaluated in reference to potential development of pest problems. Some effects are high in pest potential, some intermediate, and some low.[z]

High Pest Potential	——>			Low Pest Potential
GENERAL TYPES OF CROPS AND ASSOCIATED PEST PROBLEMS				
Large pest complex (crop not competitive with weeds)		——>	Small pest complex (crop highly competitive with weeds)	
Susceptible ——>	Tolerant		Resistant	Resistant
	Cultivar	——>	pure line ——>	multigenic
	Annual	——>	Perennial	
	Long-Maturing	——>	Short-maturing	
CROP ARRANGEMENT IN TIME				
Monoculture		——>	Crop species rotation	
Continuous planting		——>	Discontinuous planting	
Asynchronous planting		——>	Synchronous planting	
Season favorable to pest		——>	Season unfavorable to pest	
CROP ARRANGEMENT IN SPACE				
Sole cropping ——>	Row or strip intercropping	——>	Mixed intercropping	
High plant density		<——	Low plant density	
Large field		<——>	Small field	
Large host-crop area		<——	Small host-crop area	
Host fields aggregated		<——	Host fields scattered	

[z]Partially after Raymundo (89).

sidered crop rotation by some forest researchers. This type of monoculture is not considered crop rotation herein.

Much knowledge is required for recommendations on specific crop rotation systems. This information should include species, race and the host range of the nematodes in question, the efficiency and susceptibility of various hosts including various crop cultivars, weeds, the basic nematode population dynamics, and knowledge of the relationship between population density and crop loss (20,78,79). An understanding of the inherent rates of population increase of given nematode species and/or races on various crops, the associated damage, and the impact of the environment on the population is essential in developing effective rotation systems.

Two primary principles of crop rotation are: 1) the reduction of initial nematode levels sufficiently to permit the subsequent crop to complete its early growth before being heavily attacked; and 2) preservation of the competitive, antagonistic, and predaceous nematodes and other organisms at population levels that are effective in buffering the pathogenic species (79). Population shifts of nematodes may be characterized numerically by various models or they may be standardized via application of the concepts that define host status. The host status of a given crop to a specific nematode may be defined in terms of the equilibrium density (E) and the maximum rate of reproduction (a) (78,79,107). Good hosts have a high equilibrium density and maximum rate of reproduction, whereas the opposite is true for poor or nonhosts. The relative host sensitivity is indicated by the tolerance limit (T) (107). Implementation of these quantitative concepts to include all major nematode-host combinations would facilitate the development of more precise and effective rotation systems.

The magnitude of nematode or disease control attained through crop rotation varies considerably with the year, location, pathogens, associated weed hosts, and the nature and length of the rotation (27). Effective weed-control is essential for best results with rotation systems designed to manage nematodes having common weed hosts. Weeds such as *Taraxacum* (dandelion) and *Galinsoga* spp. are excellent, widespread hosts for *Meloidogyne* spp. (46). Similarly, *Spergula arvensis* L. is a widespread weed host of *Nacobbus aberrans* (Thorne) Thorne and Allen in some regions of Latin America (23). Recent publications (2,57,58,79,89,90) have provided evidence that efficacious selection of cropping systems can reduce the population of some major pathogenic nematodes to safer levels and thus minimize crop damage. Crop rotation may be less effective in instances where a wide range of nematode species and other pest species occur. No simple cropping system is sufficient for controlling various nematodes on a range of crops (58). Nevertheless, the value of crop rotation has been established for controlling nematodes such as *Meloidogyne* spp. (4,57,78,79,86,90), *Heterodera* spp. (22,35,47,63,100,106), *Ditylenchus* spp. (3) *Belonolaimus* spp. (50,94), and *Pratylenchus* spp. (45,80).

Rotation has long been used as a primary tactic for reducing population levels of *Meloidogyne* spp. Rotation sequences involving 2-4 years generally give excellent results for controlling these nematodes. The degree of success, however, depends on the particular host sequence and the relative levels of susceptibility and resistance involved. Nonhosts, such as fescue and orchard grass are particularly effective in reducing populations of *M. incognita* (Kofoid and White) Chitwood in many locations (79,113). Of several combinations designed to limit *M. arenaria* (Neal) Chitwood—race 1 damage, highest peanut yields were obtained from plots that had been planted with corn or sorghum in the preceding 2 years and which had been fumigated every year (98). The differential host suitability of these crops for race 1 of *M. arenaria* is the key to this control (Fig. 1). Selected examples of nonhosts that limit damage caused by various *Meloidogyne* spp. are given in Table 2.

The most important information component of successful crop rotation is the availability of resistant and tolerant plants that can be used in the target farming systems. Unfortunately, the wide host ranges of *Meloidogyne* spp. greatly restrict the options for alternate crops. Related difficulties are compounded by the frequent occurrence of crop or even host-cultivar-specific races of *M. incognita* as well as other taxa (104).

Most cyst nematodes, including species of *Heterodera* and *Globodera*, have narrow host ranges, which increase the options for developing

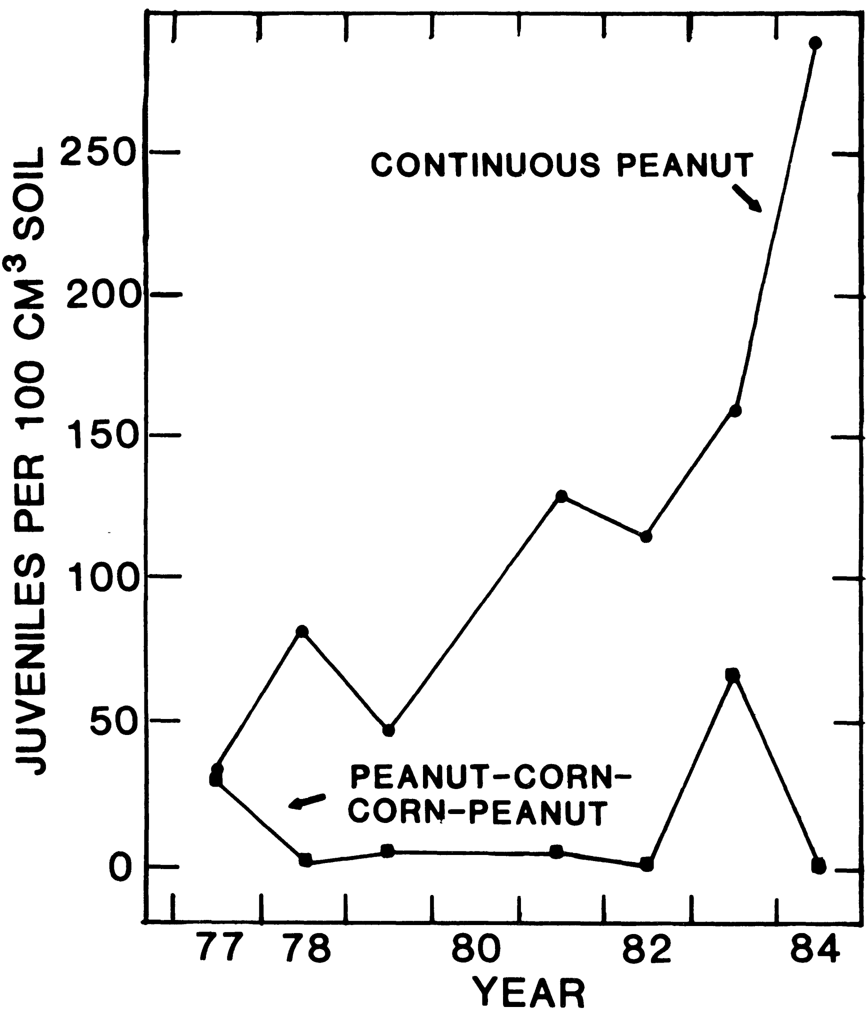

Fig. 1. Impact of a rotation scheme on juvenile populations of *Meloidogyne arenaria* compared to those on a monoculture of peanut (after Rodriguez-Kabana and Ivey, unpublished).

Table 2. List of selected nonhost plants useful in crop rotations.

Nematode spp.	Nonhosts or Poor Hosts*	References
Belonolaimus:		
B. longicaudatus	*Crotalaria* spp., *Crotalaria spectabilis,* hairy indigo, marigold, tobacco	18,91,96
B. gracilis	*Crotalaria* spp., tobacco, watermelon	50
Dolichodorus heterocephalus	*Crotalaria spectabilis*	91
Helicotylenchus dihystera	Alfalfa, corn, fescue*	18
Heterodera, Globodera:		
H. glycines	Corn, cotton, cowpea, potato, small grains, tobacco, most vegetables	35,100
H. schachtii	Alfalfa, bean, clover, corn, *Hesperis matronalis,* onion, potato, small grains	43,47,64,73
Globodera rostochiensis	Corn, greenbeans, red clover	65
Hoplolaimus indicus	Cabbage, chili, eggplant	2
Meloidogyne:		
M. javanica	*Andropogon, Crotalaria* spp., cotton, peanut, sorghum, velvet bean	28,29
M. hapla; M. thamesi	Castor bean	61
M. hapla	Corn, cotton, grasses, lettuce, onion, radish	126
M. incognita	Fescue, orchard grass	78,113
Meloidogyne spp.	*Crotalaria spectabilis* *Indigofera hirsuta,* millet, oats	26,44,63,67
Paratrichodorus minor	Corn*, *Crotalaria spectabilis*	18
Pratylenchus:		
P. leiocephalus	Peanut	45
P. penetrans	Alfalfa*, beet, fescue, marigold, oats, sudangrass, rye	32,45,80,81
Pratylenchus spp.	Lettuce, onion, radish	126
Radopholus similis	*Crotalaria spectabilis*	15
Tylenchorhynchus:		
T. mirzai	Wheat	2

Table 2. List of selected nonhost plants useful in crop rotations (continued).

Nematode spp.	Nonhosts or Poor Hosts*	References
T. brassicae	Potato, tomato	2
Xiphinema americanum	Alfalfa*, corn*, fescue*, tobacco	18,39

*Some populations of respective nematode species will reproduce rapidly on crop plants so identified.

effective rotations (Table 2), as compared to the root-knot nematodes. However, their protected eggs in the resistant cysts frequently survive for many years in the absence of a host. This prolonged survival often increases the time required for effective rotation of a host crop with nonhost crops. For example, a 4 to 7 year rotation may be necessary to provide adequate control of the potato-cyst nematodes in England (20). In contrast, rotations of only one or two years greatly enhance soybean yields in *Heterodera glycines* Ichinohe-infested fields (100,106).

Crop rotation is frequently effective in restricting the population levels of *Pratylenchus* spp., but one must be cognizant of the host specificity of the particular species involved in a given field. For example, infestations of *Pratylenchus leiocephalus* Steiner can be reduced by growing nonhost crops of peanut in rotation with maize (45). However, the damage caused by *Pratylenchus penetrans* (Cobb) Filipjev and Schuurmans Stekhoven on many crops, including potatoes and red clover, is much more difficult to prevent by rotation (81). Several suggestions have been offered as guidelines in restricting the damage caused by this nematode. These include: 1) the cultivation of potatoes, oats, rye, and red clover should be avoided in infested nurseries where practical; 2) beets or marigolds should be grown before potatoes or red clover on heavily infested soil; and 3) the cultivation of red clover should be avoided on infested soils (81). Other research has indicated that the planting of oats or sudangrass as cover or use of green manure crops may help in reducing the populations of *P. penetrans* (32).

As with all plant-parasitic nematodes, *Pratylenchus* spp. increase differentially on various crops. *Pratylenchus penetrans* and *P. scribneri* Steiner reproduce readily on corn and soybean, but *P. neglectus* (Rensch) Filipjev and Schuurmans Stekhoven increases primarily on wheat; *P. hexincisus* Taylor and Jenkins readily increases on corn, but reproduces only moderately on soybean (38). This overlapping of host ranges results in rotations being of limited benefit in controlling two or more *Pratylenchus* spp which have different host preferences (74,80).

Crop rotation may have little practical value in controlling nematodes that attack the foliage of crops. This tactic has limited application with nonpersistent species such as *Aphelenchoides* which typically are introduced on new plants, or with those which are extremely persistent such as *Ditylenchus dipsaci* (Kühn) Filipjev in heavy soils (20). Other important limitations of this tactic applicable to most nematode species are: 1) the degree of control is based on the level of resistance of the crops used and the number of years between susceptible crops; 2) populations of other species of nematodes may occur on alternate crops as indicated earlier; 3) the nonhost or resistant crops grown in the rotation may produce little farm income (6); and 4) farmers' resistance to changing cropping patterns.

Rotation often results in complex combinations of beneficial and detrimental effects. The use of sod crops such as fescue may improve the soil structure and enhance the water-holding capacity of soils and thereby increase the yields of subsequent crops (79). Numerous non-target diseases also may be controlled through this practice. In contrast, non-target nematode species, other pathogens, or soil insects may increase dramatically under a cropping sequence designed to control a particular pest.

Research on cropping systems for the management of nematodes needs renewed emphasis, especially in the humid tropics. Fortunately, these studies have been increasing in the last few years (4,5,58,69,77,89, 90,98). Farmers in these geographic areas find the cost of chemical control to be prohibitive and in most cases have no resistant cultivars. Thus, crop rotation and improved cropping systems are the only effective options for increasing the productivity of small landholders and farmers with mixed crops. Increased prices of nematicides in the United States also have resulted in their becoming cost ineffective for many crops.

NUTRITION AND GENERAL CARE OF HOSTS

Nematode-infected plants often exhibit symptoms of nutrient deficiencies as a result of root damage and impaired uptake. This damage to some crops may be partially offset by proper nutrition, moisture, and protection from adverse conditions, such as cold, which stress plants (6). Although these management factors do not provide satisfactory or acceptable control of nematodes alone, they should be considered as part of the overall nematode-management program. Among host or plant nutrients, the role of potassium (K) in nematode host interactions probably has received the most attention. As early as 1911, Bessey (13) suggested that addition of this element would enable plants to produce a good crop in spite of root-knot nematodes. An increased supply of K limits the damage caused by these nematodes on *Phaseolus lunatus* L. (84). Experiments involving increased K levels on tomato have shown that this element can suppress the reproduction of root-knot nematodes (75). Supplemental K may also enable soybean to tolerate greater numbers of *H. glycines* (62).

Nematode population responses to K levels in the plant vary with the species of host and nematode. Low K on cherry may favor *Xiphinema americanum* Cobb and *P. penetrans,* whereas *Helicotylenchus dihystera* (Cobb) Sher and *Tylenchorhynchus* spp. are favored by high K (60). A high percentage of *Meloidogyne javanica* (Treub) Chitwood males in intact roots was recorded at low K levels, whereas in excised roots the proportion of males in the population rose as the K levels increased (114).

Nematode responses to changes in nitrogen levels vary with experimental conditions and nitrogen source. Inhibition of juvenile emergence and reproduction of *H. glycines* was noted with a higher nitrogen level (12). Sodium nitrate-fertilized plants infected with *M. javanica* weighed more than plants receiving equivalent levels of ammonium nitrate, independent of the K level (114). Thus, nematodes may behave differently as fertilizer rates and formulations change. Conflicting results in field versus microplot experiments with *H. glycines* were obtained on soybean (99,101). High rates of $NaNO_3$ in microplot tests supported increased plant growth but resulted in fewer nematodes developing (99). However, increased nitrogen fertilization of soybean in field plots gave enhanced yields and higher final nematode numbers (99). Equivalent applications of ammonium sulfate resulted in increased cyst numbers of *Heterodera avenae* (Mortensen) Filipjev, especially when applied at seeding, but urea had only a marginal effect (22). A positive relationship between the level of *Meloidogyne* parasitism of tobacco and the amount of ammonium sulphate application has been reported (75,88).

Higher calcium levels supplied to plants may increase their resistance to nematodes. *Ditylenchus dipsaci* was found to reproduce at lower rates as calcium was increased on alfalfa (109). Disease development and severity of infection is typically greater in plants that are deficient in one or more essential nutrients (16). Further research is needed to gain understanding of the relationships between host nutrition and nematode damage on plants.

TRAP AND ANTAGONISTIC CROPS

Trap Crops. The concept of trap crops involves the growth of susceptible plants which parasitic nematodes rapidly infect, followed promptly by their destruction at the proper time before nematode reproduction. An ideal trap crop is one which will induce the nematodes to hatch, become heavily invaded, but will not support reproduction. A list of trap crops used for different nematodes is given in Table 3. Unfortu-

Table 3. Trap crops for plant-parasitic nematodes.

Nematode	Trap Crop	Reference
Meloidogyne spp.	*Crotalaria spectabilis* cowpea, English peas	26,42
Heterodera avenae	Oat	116
H. schachtii	*Hesperis matronalis*	73
Globodera spp.	Potato	24

nately, this tactic has limited practicality because of the time and cost involved, as well as the possible noxious weed status of the trap crop. Nevertheless, this tactic may be less expensive and more effective than nematicides, where land availability is not a limiting factor.

There are many other problems associated with the use of trap crops. If a host crop is not destroyed at the correct time, the nematode may then mature and the population, instead of being reduced, will increase. Additional side effects include animal toxicity from certain plants such as *Crotalaria,* an excellent trap crop for *Meloidogyne,* which produces a toxin which may kill cattle (44).

Antagonistic Plants. These plants have roots in which nematodes either do not penetrate or increase little if invasion occurs. Certain marigolds, *Tagetes* species, are recorded as exceptional plants that demonstrate strong nematicidal effects or excellent resistance to certain nematodes but not others (29,83,117). Significant suppression of root galling occurred in tomato where precrop marigolds were used (102). Most of the early work on *Tagetes* spp. was reviewed by Suatmedji (117). The nematicidal properties of *T. erecta* L. were found to be due to highly toxic polythienyls (121) such as α-terthienyl. Root extracts of *T. erecta* inhibited egg hatching, infectivity, and development of *M. incognita,* but the plant did not affect nematode population densities when intercropped with susceptible tomato plants (30). Recent research (10) indicates that the activity of α-terthienyl is dependent on photoactivation, which explains the variable results obtained with *Tagetes* spp.

Lists of several plants with some nematicidal properties have been published (1,55). Water soluble root extracts of *Euphorbia odoratum* Walp., *Ricinus communis* L., *Lycopersicum esculentum* Mill., and *Vigna unguiculata* Walp. were inhibitory to the juvenile hatch of *M. incognita* (4). Antagonistic plants may have potential for control of plant-parasitic nematodes, but all have limitations. Before recommending any antagonistic plant, a number factors should be considered: 1) can the recommended antagonistic plants be grown in the season along with the crop being planted? 2) do they have economic importance or toxic effects on nontarget organisms or weed potential? 3) are they available locally and do they grow rapidly? and 4) is knowledge of possible differential response of the target nematode species available?

ORGANIC AMENDMENTS AND MULCHING

Organic amendments have been used by farmers for centuries with little knowledge or concern for their effects on nematodes. These materials play an important role in restricting populations of plant-parasitic nematodes (54,76,111). Recent research on organic amendments has included the use of oil-cakes, green manure, mature crop residue, chitin, and hemicellulose (31,54,66,97,110,122). Several organic and inorganic nitrogenous amendments affect hatchability and development of nematodes *in vitro* (9,127). Plots of *M. incognita*-susceptible tomato plants treated with manure, manure plus aldicarb and marigolds, or aldicarb plus compost were identified with greatest yields among a number of treatments in the field (102). Leaves of *Azadirachta* spp. (neem) and their water extracts were found to be nematicidal in action (33,48). Chitin gives striking suppression of root galling caused by *Meloidogyne* spp. (41,71). Adding crustacean chitin to soil resulted in significant control of *H. glycines* on soybean (97). Various kinds of oil-cakes also are effective in controlling phytonematodes (72,108). Water extracts of oil-cakes also were found to be toxic to nematodes (14,120). These treatments still are not practical for implementation for the field level.

Although much information has been published on the use of organic amendments, the related mechanisms of action are poorly understood. Decomposition products such as butyric acid and hydrogen sulfide have been shown to be toxic to plant-parasitic nematodes (52,105). The addition of organic matter to soil often improves conditions for growth of plants which may increase their tolerance to nematodes. Such amendments may enhance the development of biocontrol organisms as well as providing plant nutrients.

Some organic amendments are inexpensive and may offer an effective means of nematode control in small plots. Green manure crops in combination with promising biocontrol agents have potential for nematode control on a large-field basis. More research is needed in different parts of the world to identify and characterize locally available amendments and the impact of antagonistic microorganisms as related to potential nematode control.

TIME OF PLANTING

Different environmental factors affect nematode populations, so the timing of crop establishment is important. Most pathogenic nematodes are inactive during the winter months because low temperatures inhibit their activities. Autumn-sown wheat, barley, and rye generally support lower nematode populations than their spring-sown counterparts in Europe (49). In Australia, early-sown crops of wheat (April/May) are less severely damaged by *H. avenae* and produce better yields than late-sown (June/July) crops (22,70). A delay of the planting date in California until soil temperatures are below 18 C was suggested as a means of maximizing the effectiveness of wheat in rotations as a nematode-pest-management tactic for suppressing root-knot nematodes (95). Minimum root-knot damage on *Cicer arietinum* L. (chickpea) was noted when sowing was done in November and December (40).

The selection pressure imposed by long-term early planting may result in adaptation to the lower temperatures. Studies with three *Globodera rostochiensis* (Wollenweber) Behrens populations revealed that populations at early planting sites penetrated roots and developed more quickly than "normal" populations (53). These results support the hypothesis that the annual practice of early planting and harvesting to control losses caused by *G. rostochiensis* in Scotland is selecting a nematode population adapted genetically to the prevailing production conditions (53).

FALLOW

Fallow is a simple method used to control nematode populations by starvation (82). The aim of fallowing is to free land of all vegetation, including weeds, for varying periods of time by frequent tillage (disking, plowing, harrowing, or by applying herbicides to prevent plant growth) (8). Beneficial effects of fallow were demonstrated in control of *Meloidogyne* spp. (19,92,93,125), *Pratylenchus* spp. (19,34), *Rotylenchulus reniformis* Linford and Oliveira (17), and *Paratrichodorus minor* (Colbran) Siddiqi (19). This tactic should reduce the population levels of all plant-parasitic nematodes. Nevertheless, it may be less effective in arid climates than in those with high rainfall, as nematodes inhabiting arid regions often survive via anhydrobiosis.

Populations of nematodes change during different seasons of the year, depending on the type of crop present. Populations of several parasitic species attacking forage crops declined steadily in fallow field soil during the fall, then remained constant during winter and declined sharply again in the spring (68). Research on field production of tomato transplants in southern Georgia (56) indicated that fallow was the most effective means of reducing nematode populations. Populations of *Quinisulcius acutus* (Allen) Siddiqi and *H. dihystera* (Cobb) Sher increased in a subtropical agroecosystem under all management practices tested except fallow (69).

Fallowing has several limitations in controlling all species of plant-parasitic nematodes. Cyst nematodes survive relatively long periods in the absence of hosts. As indicated earlier some nematodes are tolerant of desiccation and/or high temperature, e.g. *Pratylenchus brachyurus* (Godfrey) Filipjev and Schuurmans Stekhoven (37). Fallow land does not contribute to farm income, and the physical structure of the soil may be adversely affected. Bare fallowed soil also is subject to greater erosion, whereas weed fallow may support continued nematode reproduction.

FLOODING

Flooding has long been used to control plant-parasitic nematodes (21,51,123). In a naturally occurring infestation, only 23% of root-knot nematode juveniles survived beyond 2 to 5 days in saturated soil compared to 76% survival in soil at 29% saturation (86). Reduction of nematode populations by flooding may be due to high moisture level (26), less aeration in soil (124), low pH, and the development of toxic substances (52). Pronounced reduction of nematode numbers was noted in non-sterilized, water-saturated soil as compared with sterilized, water-saturated soil, indicating the possible importance of microbial activity (51,52). *Pratylenchus penetrans* survived more in soils with high rather than low moisture tensions (119).

Temperature may affect the survival of the nematode in flooded soil. *Meloidogyne incognita* may survive for weeks at low temperatures, but declines rapidly at 20-30 C in fallowed or flooded pots under controlled conditions (93). Survival of nematodes was inversely correlated with temperature (4 to 30 C) regardless of genus (85). Although time of flooding may not influence nematode control in the roots (25), two cycles of flooding are more effective than one (85). Flooding or irrigation can disseminate plant-parasitic nematodes, and could conceivably intensify associated problems (36). In addition, flooding large areas often is impractical and will not provide the level of control needed in severe nematode infestations (85).

DESTRUCTION OF RESIDUAL CROP ROOTS

The concept of early destruction of root-knot infected crop roots was proposed by Bessey in 1911 (13). This approach has been refined to facilitate the control of *Meloidogyne* spp. and several other pests on tobacco (87). This practice, including cutting stalks, plowing roots out and exposing them to the sun with repeated discing, limits the number of life cycles completed and greatly accentuates the decline of *Meloidogyne* spp. after harvest (11). This tactic is effective primarily with crops that have a perennial growth habit and has limited benefits on true annual crops. In contrast, use of "no-till" practices may result in the number of nematodes remaining at abnormally high levels in the root zone (118). Thus, one should be cognizant of the differing impact of various crop-management practices on nematode communities.

SANITATION, QUARANTINES AND CERTIFIED PLANT MATERIALS

Sanitation and the use of nematode-free planting stock are effective means of nematode control (6). These tactics are especially important for perennial crops, including woody ornamentals, trees, and small fruits. Nematodes can be spread by many means through movement: soil; infected host plants; aerial parts of plants including the seed; farm equipment; animals; and by rain, flood water, and wind. The recent trend of growing plants, especially woody ornamentals, in containers (often in non-soil media) should greatly reduce nematode problems in these systems.

Several countries now resort to the use of exclusionary measures against specific plant diseases and pests (7). These exclusionary or quarantine measures are basically of two types: restrictive and prohibitory. The restrictive type of quarantine requires presentation of a certificate indicating that the plant or soil material has originated from an uncontaminated area, or that the material has been treated to eliminate the pest. In prohibitory quarantine, soil or other carriers which might harbor a harmful nematode are prohibited from entering a specific area (8). The effectiveness of quarantines in limiting nematode problems is debatable. The USA quarantine on the golden nematode, *G. rostochiensis,* appears to have been very effective as this pest has a very restricted distribution in that country. A similar USA quarantine on the soybean cyst nematode, *H. glycines,* resulted in failure. The divergent means of spread of this nematode may have been largely responsible for this failure.

CONCLUSION

Cultural practices may be used effectively against nematodes, resulting in increased crop yields. Although these practices have been employed by farmers for many years, our understanding of the parameters affecting their efficacy is limited. Present circumstances and available information greatly increase the need for a multifaceted approach to control plant-parasitic nematodes. Life histories, population dynamics, host ranges of nematodes, and the efficiency and susceptibility of primary hosts must be characterized before recommending any practices. Cultural practices involving limited expense may prove most useful for farmers in developing and developed countries because chemical control is becoming increasingly expensive and less reliable than in the past. Their potential is such that they should lead to partial alleviation of problems imposed by the recent loss of the more effective nematicides and the increasing problems with resistant cultivars being parasitized by new races of target nematode species, especially as a result of monoculture.

It is unfortunate that farmers and their advisers have frequently neglected cultural practices after the introduction of effective pesticides. Crop scientists must develop a renewed awareness of the value of these simple tactics and integrate them into an overall management system. This change should minimize the threat of pesticides to the environment and lessen general pollution hazards.

Future integrated nematode-control programs should be focused heavily toward management via cultural practices where practical. Control tactics that could be key components of such systems are: 1) use of nematode-free planting stock or seeds; 2) employment of effective, weed-free crop rotation; 3) destruction of residual infected crop and/or weed hosts as soon as possible after harvest (may need nonhost cover crop to minimize soil erosion); 4) alternate nonhosts, resistant cultivars and susceptible cultivars where possible, and 5) exploit dry seasons, where they occur, by using fallow and/or nonhost crops and weed-host control. This integrated approach can be reasonably economical and reduce the dependence on nematicides.

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