

PLANT PARASITIC NEMATODE IN INDONESIA - SITUATION MANAGEMENT-RESEARCH

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Abstract

Plant parasitic nematodes cause significantly a yield loss in plant production in Indonesia. It is very difficult to control due to their habitat in the soil. As tropical country, the nematodes found more diverse every agriculture soil and it is very difficult to control. As reported by the potato grower the constraint factor in potato production cause *Globodera rostochiensis* in central potatoes production. *Meloidogyne* spp reported found almost plant production in many crop and control could not bring successfully in reduce the problem in the field. *Radopholus* sp and *Pratylenchus* sp infected both main crop banana and coffee, The infested soil is difficult to control due to some nematode known broad host spectrum, migrated horizontally and vertically in soil rhizosphere. Recommended control cover agronomic, pesticide, adding organic amendments and biological control with beneficial antagonist. Research intensively carry out not just validation of plant parasitic nematode in Indonesia, but also ecology, biology and developed control effectively.

Introduction

Geographically Indonesia in tropical country is known as rich and diverse in natural resources. Economically it has important for developing agriculture sectors additionally about 80% people already worked in that sector. The constraint factors in plant production are plant pests and diseases both during planting time and post harvest. The plant parasitic nematodes present a threat to improving agricultural production and quality and it is difficult to control with conventional systems. Some products of agriculture are oriented for export constraint factors with product quality and continuity supply because plant pests and diseases particularly nematode.

Plant-parasitic nematodes must be addressed in crop production and integrated pest management (IPM) systems if agriculture is to meet the world demands for increasing food and fibre production. On a worldwide basis, annual crop losses due to nematode damage have been estimated to average 12.3 percent (Sasser and Freckman, 1987), amounting to some US\$77 million annually. The data available indicate that similar losses occur in the Near East (Maqbool, Hashmi and Ghaffar, 1988; Saxena, Sikora and Srivastava, 1988). For example, estimated losses for vegetable crops due to nematode-related disease complexes in Egypt amounted to some 15 percent in 1986, with losses for field crops ranging from 5 to 20 percent (Eissa, 1988). Nevertheless, the subtle

nematode symptoms and signs are often confused with nutrient deficiencies and other maladies, resulting in nematodes being overlooked by agricultural scientists as well as growers.

The concept of combining compatible tactics for controlling nematodes predates that of IPM. In 1889, Atkinson discussed a range of nematode-management tactics that is surprisingly similar to those available today. Tactics discussed for controlling root-knot nematodes include: sterilization of the soil by starvation (including the use of non-host plants); the potential of trap crops; composts; nematicides; and soil amendments such as hardwood ash and potash. The early work of Cobb (1918) on sampling nematode communities provided a basis for the development of improved tactics and strategies essential for integrated pest management (Barker, 1985a). The following statement was offered by Tyler in 1933:

Nematode Status

Plant parasitic nematode is one of the organisms continue to threaten agricultural crops. In Indonesia, 26 species of plant parasitic nematodes infecting various food, horticulture, and estate crops (black pepper, patchouli, ginger, tobacco, and coffee) have been identified. Amongst those, *Meloidogyne*, *Pratylenchus*, *Radopholus* and *Globodera* are the most destructive nematodes in Indonesia. World economical crop losses caused by nematodes may reach 80 billion US \$. Because of unavailable data, crop losses due to nematodes in Indonesia have not been estimated. Nematodes problem in Indonesia became serious in the year 2003, when potato plantation in Sumber Brantas, Kota Baru, East Java was attacked by golden cyst nematoda (*G. rostochiensis*). This nematode now has spread in the provinces of West, Central and East Java, as well as North Sumatera, and caused 32%-71% crop losses approx. of Rp 2 trilyun.

In addition, a number of nematodes are disseminated with crop seeds, including *Anguina tritici* on wheat and *Ditylenchus dipsaci* on alfalfa and a number of other crops. In tropical rain forest has been described plant parasitic nematodes namely *Tylenchus*, *Xiphinema*, *Aphelenchoides*, *Pratylenchus*, *Psilenchus*, *Tetylenchus*, *Rotylenchulus*, *Trichodorus*, *Longidorella*, *Longidorus*, *Radopholus*, *Tylenchulus*, *Nothotylenchus*, *Radophloides*, *Paratylenchus*, *Apratylenchoides*, *Hoplotylus*, *Scutellonema*, *Zygotylenchus*, *Heterodera*, *Malenchus*, *Micoletzkyia*, *Ditylenchus*, *Aglenchus*, *Atetylenchus*, *Allotylenchus*, *Hoplolaimus*, *Telotylenchus*, *Antarctylus*, *Acontylus*, *Paratrophurus*, *Belonolaimus*, *Hemicycliophora*, *Discocriconemella*, *Discotylenchus*, *Rotylenchus*, *Histotylenchus*, *Tylenchorhynchus* and *Tylodorus*

Nematode Management

Government-regulated quarantines have had varying levels of success in different countries (Barker, 1985b; O'Bannon and Esser, 1987; Taylor, 1986). For example, the quarantines for *Globodera rostochiensis* and *Heterodera zea* have been success stories to date in the United States (Barker, 1985). In contrast, the quarantine for the soybean-cyst nematode, *Heterodera glycines*, failed in that country. This failure may have been a result of the nematodes being more widely disseminated than initially realized as well as having several effective means of dispersal. Internal quarantines developed by the European and Mediterranean Plant Protection Organization have focused on

Aphelenchoides besseyi for rice and strawberry, *Ditylenchus destructor*, *G. rostochiensis* and *G. pallida* on potato, *Radopholus citrophilus* on citrus, and *Xiphinema americanum* on a range of crops (EPPO, 1982). More recently, *Bursaphelenchus xylophilis* has been a focal point concerning the importation of wood products in a number of countries. Other nematodes that have limited distribution and are threats to certain crops include *Meloidogyne chitwoodi* and *M. nataliei* (Barker, 1985b). Further spread of these and other highly aggressive nematodes is undoubtedly a concern in most Near East countries.

At a more practical level, certified plant material, nematode-free planting stock and clean farm equipment should be standard IPM practices. This issue is particularly important for vegetatively propagated crops such as banana, potato, and crops for which seedlings are transplanted. *In vitro* propagation of banana has proved to be an effective means of providing clean planting stock and should reduce the need for nematicides (Sarah, 1989).

Nowadays, various components of control methods have been obtained, such as the use of resistant or tolerant varieties, cultural practices (fertilizer, organic matter, rotation, cover crops), botanical pesticides (neem seed powder, castor meal), biological agents (*Arthrobotrys*, *Pasteuria penetrans*), chemical pesticides, as well as quarantine (to protect nematodes spreading from infected to uninfected area). As the most important part of the development of Integrated Pest Management (IPM), control strategy of nematodes must be conducted integrately and ecofriendly based on the precise concept through combining of some control method components, supported by operational and technical prudents. Operational prudent includes training program, research and development through the coordination of government and private institution as well as farmers. Technical prudent includes control of existency (surveillance) of nematodes, the development of disease caused by nematodes, and its spreading.

A well-planned combination of practices will go much further for control of nematodes than any of the recommended treatments alone". Tyler also stated that the presence of nematodes (root-knot) in any soil can best be determined by examining the roots of susceptible plants which have been growing for at least three weeks in warm, moist conditions. For attempted eradication of root-knot nematodes, the author suggested the following:

1. Burning of residues two or three times if possible, each preceded by digging or ploughing.
2. Dry fallow with frequent ploughing.
3. One or two well-irrigated trap crops, completely destroyed two or three weeks after sprouting.
4. Moist fallow during warm weather, without weeds.
5. Resistant crops in rotation, kept free of weeds.
6. Repetition of steps 4 and 5.

The relative youth of the science of nematology and the availability of effective, relatively inexpensive nematicides hampered the development of integrated management systems in this discipline. During the last two decades, however, much progress has been made in characterizing damage functions and thresholds for major nematode-crop combinations, the study of general population dynamics and simulation models for key nematodes, and the development of improved management tactics (Barker, Schmitt and Imbriani, 1985; Duncan, 1991; Ferris and Noling, 1987). In addition, considerable

progress has been made in elucidating the roles of nematodes in disease/pest complexes, and their interactions with symbionts.

Currently, most nematode management programmes focus on tactics involving the reduction of the initial nematode population density and/or the suppression of their reproduction during the season. Most nematode management tactics also have the inherent feature of limiting damage associated with the target crop. In contrast, tolerant crop cultivars may be damaged little economically while supporting relatively high nematode reproduction. With the diminishing availability of a single strategy or tactic for nematode management, a combination of two or more compatible tactics in an integrated system is becoming more critical than in recent years when nematicide usage was the primary measure for nematode control.

Fortunately nematodes have a number of characteristics that limit their long-distance dispersal, including their restricted active movement, obligate parasitism, narrow host ranges of many species, sharp population declines in the absence of hosts, and survival depending on environmental conditions and crop management practices. Thus, long-distance dispersal of these parasites is largely passive and by chance. Key means of dissemination include movement of soil on equipment and plant parts, crop transplants, water, animals and contaminated containers such as burlap bags. Measures for avoiding dissemination and establishment of new nematode problems should be a component of national or regional nematode IPM programmes.

Six general tactic categories may be placed under this strategy: crop eradication; rotation; vertical resistance; chemical nematicides; biological control; and physical treatments to reduce nematode population densities. This strategy includes some of the oldest and most recently developed tactics that have been used in carefully developed IPM systems.

Although eradication is a longstanding tactic for nematode management, it is very difficult to achieve success for field infestations. Fumigation or heat treatments, for example, may eliminate all nematodes in upper soil layers, but those occurring at depths of 0.3 to 1.0 m below the soil surface will generally escape and eventually move back into the plough layer. In contrast, nematode infestations in confined environments, including greenhouses and container-propagated plants, can be eliminated through standard sanitation procedures.

A wide range of cultural practices have varying levels of efficacy in nematode management. These include clean planting stock, crop rotation, inter- and intracropping, cover/trap crops, soil amendments, fallow, time of planting/harvesting, and general farm hygiene and culture. Such non-chemical tactics are especially important for low-value crops (Brown, 1987).

This is one of the oldest and most effective tactics for managing plant-parasitic nematodes (Nusbaum and Ferris, 1973). The goal of rotation is to bring about a striking population decline of the target nematodes that will facilitate the subsequent crop to grow and produce an acceptable yield. Crop rotation and cropping systems are similar concepts which are sometimes confused. Crop rotation is the fixed yearly sequence and spatial arrangement of crops, or the alternation of crops and fallow, on a given land area (Nusbaum and Ferris, 1973). Alternate crops in rotation may be planted or natural. In contrast, a cropping system is the sequence of growing crops and the required technologies for their production. Thus, cropping systems cover all kinds of crop

sequences, including monoculture, whereas crop rotation indicates an inflexible cycle or a fixed sequence of crops (Nusbaum and Ferris, 1973).

The study of cropping systems should include quantitative analysis of the relationships among crops and pests, and general management tactics which may be deployed in that system (Noe 1986; Noe, Sasser and Imbriani, 1991). The crop system may be spatial or temporal. Thus nematode populations may respond to individual crops as well as the arrangement of the crops over space and time (Table 6). To maximize the efficacy of rotation and cropping systems in nematode management, the short- and long-term effects of cropping systems, spacing and associated interactions with biotic and abiotic environmental factors on crop yields must be better understood. Research addressing these issues should include potential effects of the general environment (Noe and Sikora, 1990), associated weeds and other plant pests in cropping systems and development of appropriate crop rotations.

Nusbaum and Ferris (1973) gave two key principles for crop rotation: the reduction of initial nematode population levels necessary to permit the subsequent crop to complete its growth before severe attack; and the preservation of competitive, antagonistic and/or predacious nematodes and other organisms at population densities that allow effective buffering of the pathogenic species. Shifts in nematode populations and communities may be characterized numerically through the application of the concepts that define host status and by various population models. For example, good hosts have a high equilibrium density (E) and maximum rates of reproduction (a) (Seinhorst, 1970; Nusbaum and Ferris, 1973). In contrast, these parameters would be low for poor hosts or non-hosts. The relative host sensitivity is defined or indicated by the tolerance limit (T) (Seinhorst, 1970). The utilization of these quantitative concepts for target nematode species for a primary host and associated crops is necessary for the development of effective rotation systems.

Much knowledge is essential for quantifying nematode-host interactions and the development of specific recommendations for crop-rotation systems. Such data must include nematode species and race or biotype, their host ranges, host efficiency and susceptibility of crops to be included in the rotation, associated weeds, general population dynamics, and information on the relationships between population densities and crop loss (Nusbaum and Ferris, 1973). Other critical information includes the effects of abiotic environmental parameters on nematode population dynamics and associated disease complexes and possible pesticide interactions.

The level of success in nematode management through crop rotation may vary with the year, target nematodes and associated plant pathogens, location, weed hosts present, and the nature and length of the rotation (Trivedi and Barker, 1986). Publications that give host ranges, including weeds, for various nematodes are available (Goodey, Franklin and Hooper, 1965; USDA, 1960). Details on the host ranges of given nematodes are beyond the scope of this discussion. Nevertheless, the non-hosts and poor hosts tabulated for given nematodes in Table 7 may serve as a starting point for developing effective crop rotations for IPM purposes.

Non-host crops have been used for developing effective rotation programmes for nematodes such as *Meloidogyne* spp., *Heterodera* spp., *Ditylenchus* spp., *Belonolaimus* spp. and *Pratylenchus* spp. (Trivedi and Barker, 1986). Rotation systems that involve two to four years of non-host crops generally give excellent results managing these

nematodes. For cropping systems in the Near East, this may involve several crop sequences of non-hosts between the production of a susceptible host during such a two- to four-year period. For example, groundnuts, cotton, potato and a range of vegetables or perennial crops, such as alfalfa, may be grown between crops of maize as a means of limiting damage to the latter by *H. zea*. Effective crop rotations for *Meloidogyne* spp., with their broad host range, are more difficult to develop. However, a number of crops important in the Near East may be considered as a nucleus for rotations involving species of *Meloidogyne*. Cotton is a non-host for *M. arenaria* which attacks groundnut, and the latter is a non-host for *M. incognita* which attacks cotton. Some cultivars of wheat are also poor hosts for both of these nematodes. Thus, such limited information can be used as a starting-point for rotation systems for these important crops where sufficient land is available.

Much information on the distribution of major nematodes, their host ranges and potential management options, including rotation, is becoming available for Near East countries (Al-Hazmi, 1988; Maqbool, Hashmi and Ghaffar, 1988; Luc, Sikora and Bridge, 1990; Ibrahim and Rezk, 1988; Ibrahim, Rezk and Ibrahim, 1988; Saxena, Sikora and Srivastava, 1988). Also, more comprehensive data on potential weed hosts are becoming available (Montasser, 1990).

Inter- and intracropping is a widely used practice in several countries. Various types of mixed cropping and asynchronous temporal planting (Table 6) may limit nematode damage as outlined by Raymundo (1985). Definitive data on these practices are rather limited.

Cover/trap crops and antagonistic plants are useful for reducing nematode populations as well as conserving soil and often improving soil texture (Nusbaum and Ferns, 1973; Trivedi and Barker, 1986). In localities where land availability permits, the use of cover crops, especially plants that serve as trap crops or offer other suppressive effects on nematode populations, should be considered (Table 8). Carefully selected cover crops may serve as living mulches and provide multiple pest control (National Academy of Sciences, 1991).

Organic amendments offer considerable potential for restricting populations of plant-parasitic nematodes (Stirling, 1991; Jairajpuri, Alam and Ahmad, 1990; Trivedi and Barker, 1986). Soil amendments with oilcakes, green manure, mature crop residues, chitin-containing materials, hemicellulose and farm manures may provide varying levels of nematode suppression. Leaves of neem (*Azadirachta* spp.) and products thereof provide nematicidal and other pesticidal activity (National Academy of Sciences, 1992a). A chitin-based preparation was recently released as a nematicide in the United States. Unfortunately, this product failed to provide acceptable levels of nematode suppression. A combination of green manure crops or other organic amendments with promising biological control agents may have potential for nematode management on a large-field basis (Abu-Laban and Saleh, 1992; Bansal, Walia and Bhatti, 1988; Trivedi and Barker, 1986).

Fallow is a simple tactic for reducing nematode populations through starvation, as suggested by Tyler in 1933. The goal with this practice is to free the soil of all vegetation for varying periods of time, often by frequent tillage. Theoretically this tactic should be more effective in hot, arid climates than in cooler regions that have high rainfall. However, a number of nematode species inhabiting dry habitats may survive for

extended periods through anhydrobiosis. Also, cysts of *Heterodera* or *Globodera* spp. may be tolerant to desiccation and/or high temperatures and survive for prolonged periods in the absence of host plants. Additional disadvantages of this tactic include the problems of increased soil erosion, adverse effects on soil structure, and the fact that this practice fails to contribute directly to farm income.

The time of planting/harvesting may be utilized to exploit differential environmental effects on nematode populations versus crop growth and maturity. For example, early planting of crops such as wheat, barley, rye, chickpea and potato has restricted associated nematode damage in some instances (Brown, 1987; Duncan, 1991; Trivedi and Barker, 1986). Because of the prevailing temperatures and the conditions required for optimum growth of most crops, this approach often is impractical.

Overall farm hygiene and culture may also play a key role in limiting crop damage caused by plant-parasitic nematodes. The typical nutrient deficiencies resulting from root damage and impaired uptake effected by nematode parasitism may be offset, in part, by proper nutrition, moisture and protection from adverse conditions (National Academy of Sciences, 1968; Brown, 1987; Trivedi and Barker, 1986). Adequate potassium levels may enable a number of plants to tolerate large populations of nematodes. Ammonium sources of nitrogen have been shown to suppress a number of nematodes, including *H. glycines*. Based on research with *D. dipsaci* on alfalfa, high calcium levels may increase host resistance to nematodes. The integration of crop management and compatible cultural tactics might be viewed as the basic foundation for successful nematode control and crop production (Trivedi and Barker, 1986).

This type of resistance in plants to pathogens, including nematodes, theoretically falls under the strategy of reducing initial inoculum level (Vanderplank, 1963). This situation clearly is true for resistant cultivars that function in large part as trap crops. (The main discussion on resistance is given under the strategy of suppressing nematode reproduction below.)

Nematicides available on the world markets (Sasser, 1989) may be classified as fumigants and non-fumigants, and considerable research is focusing on the development of novel compounds. The properties that are responsible for soil fumigants being excellent nematicides may result in their being placed under regulatory review (Bird, 1987). To date, DBCP, EDP and DD have been withdrawn from United States markets through the action of regulatory agencies. In addition, 1,3-D has been removed from current use in California, and there is a risk that methyl bromide will be removed from the United States markets. The latter compound has been implicated as an agent that damages the ozone layer. Although a range of non-fumigant nematicides have acceptable levels of efficacy, most of these compounds have been detected in groundwater (Bird, 1987). In addition, some reports have focused on the microbial breakdown of some of these materials in soil, especially under continuous usage (Wu, Stachyra and Viglierchio, 1992).

In spite of the problems associated with nematicides, they comprise an important tactic for many nematode IPM systems, especially for high-value crops. As indicated by Sasser (1989), the procedure for selecting a nematicide should include procurement of information on efficacy and capacity to enhance yields of the primary crop or crops in a specific region. Sasser (1989) and Thomason (1987) provide details on nematicide safety and environmental issues, related economics and additional problems concerning

factors in selecting and using these materials, their methods of application and dosage and use on annual or perennial crops.

Increasing interest in this important nematode management tactic is reflected in two recent books (Stirling, 1991; Jairajpuri, Alam and Ahmad, 1990). As we gain greater understanding of the ecology and biology of nematode antagonists, parasites and predators, they undoubtedly will become important in an integrated approach to managing plant-parasitic nematodes as suggested by Stirling (1991).

The concept of physical means of reducing nematode populations was considered by Atkinson (1889), Bessey (1911) and Tyler (1933). Postharvest ploughing or discing can result in a 90 percent or greater reduction of nematode populations (Fig. 7; Jain and Bhatti, 1989). The prevailing high temperatures in much of the Near East may add to the effectiveness of this tactic during much of the year.

Heat solarization may be an effective nematode management tactic for small land plots in some regions of the Near East. For example, Saleh, Abu-Gharbieh and Al-Banna (1989) showed that a combination of the application of solar-heated water and solarization (with a plastic cover) resulted in a decline of 96 percent in populations of *Meloidogyne javanica* in Jordan. With this treatment, soil temperatures at 10 to 20 cm depths reached 60° and 56°C, respectively, whereas a maximum temperature of 46°C was achieved with solarization alone. Still, the addition of a nematicide or another tactic may be needed to achieve this level of control in some regions (Greco *et al.*, 1990). The likely differential sensitivity of different nematode species to high temperatures should be considered in using this tactic. For example, *M. javanica* can tolerate temperatures of 50°C up to three hours or more, whereas *M. hapla* and *M. incognita* are killed in much shorter times at this temperature. Solarization also provides some multiple pest control (National Academy of Sciences, 1991).

Flooding has been evaluated periodically for decades as a means of reducing nematode populations (Duncan, 1991; Trivedi and Barker, 1986). At high temperatures, and especially with organic amendments, this treatment can be effective in reducing nematode levels. In contrast, flooding plants such as cranberries under extremely cool conditions may have little impact on parasitic nematodes. Because of the extensive use of irrigation in much of the Near East, the potential of delivery of nematode antagonists or parasites with the water warrants careful study.

Host-plant resistance will provide an increasingly important contribution to the solution of many nematode problems (Roberts, 1992). With the enhanced availability of germplasm that has nematode resistance genes and rapidly advancing molecular-transfer techniques, resistant cultivars should become a primary management tactic in nematode IPM. This approach will become more critical as chemical nematicides become more restricted. The striking returns from deployment of some nematode-resistant cultivars reflect the great potential of this management tactic. For example, Bradley and Duffey (1982) in an economic analysis concluded that the soybean cultivar Forrest, resistant to *M. incognita* and *H. glycines*, gave a US\$400 million return over a six-year period (the cost of development of this cultivar was US\$1 million).

A number of reviews on the development and deployment of host-plant resistance are available (Roberts, 1992). Except for the stem nematode *D. dipsaci*, most of the available host resistance is limited to species that have sedentary feeding habits. This situation probably results from three factors: the reproductive activity of these

sedentary nematodes can be assessed more readily than migratory endoparasites or ectoparasites; the intimate host-parasite relationship of sedentary nematodes is more likely to be controlled genetically than those of migratory species; and the real or perceived importance of the maladies induced by sedentary nematodes results in much greater research on host resistance than for other feeding groups.

The list of highly effective host-plant resistances to given nematodes is rather limited (Roberts, 1992). This listing is restricted to only seven nematode genera on a relatively narrow range of crops. Still, some resistance has been developed for other nematodes, including *Pratylenchus* spp., *Nacobus aberrans*, *Rotylenchulus reniformis*, *Radopholus citrophilus*, *Xiphinema americanum* and *Criconemella xenoplax*.

The deployment of host-resistant cultivars has been accomplished largely on a regional basis (Roberts, 1992). A world survey by Sasser and Freckman (1987) indicated that at least some nematode-host resistance or tolerance is available on one or more crops in all regions surveyed. In Africa, however, only four crops were reported to have tolerance or resistance: bean, cowpea, tomato and yam. The resistant host lists for other geographic regions is somewhat longer and South America had the most extensive list with 26 plant species. The list for Asia was intermediate with 18 crop plants exhibiting some nematode resistance.

The available host resistance to nematodes also has some limitations. For example, resistance to *Meloidogyne* spp. in bean and tomato plants is heat-sensitive, and thus may fail in hot production regions at lower latitudes (Roberts, 1992). In addition, crop cultivars with resistance to *Meloidogyne* spp. are often susceptible to other associated nematode species. The latter limitation is not a serious restriction in fields that have a primary dominant or target nematode species. However, the restricted deployment of host-plant resistance in the large African continent reflects a critical regional and worldwide need for greater collaboration between nematologists and plant breeders in the development and deployment of this important tactic for reducing nematode problems.

Available host-plant resistance to nematodes should be deployed in carefully developed cropping systems. Monocultures with resistant cultivars frequently result in the appearance of biotypes of the target nematode that circumvent the resistance (Young, 1992).

Supplemental chemical nematicides have come to the forefront in some regions as a means of suppressing the increase of nematodes on high-value crops such as groundnut or citrus (Thomason, 1987). Repeated applications of low dosages through trickle irrigation may suppress nematode multiplication, resulting in the growth of a healthy crop.

Tolerant cultivars of suitable host species grow and yield well in spite of nematode parasitism (Oostenbrink, 1972). Although such hosts have near-normal shoot and root growth, nematode population densities build up to levels that often severely damage subsequent susceptible crops. For example, maize may support relatively high reproduction of *M. incognita* or *M. arenaria*, and still produce near-normal yields. Thus, such crops should be examined carefully before placing them in rotations with highly susceptible crops. A few plant breeders and nematologists are working to combine host-plant resistance and tolerance to nematodes. Resistant/tolerant cultivars clearly would

have an advantage in that some resistant cultivars may be severely stunted by high population densities of the target nematode.

As indicated earlier, Tyler (1933) suggested that two or more management tactics be combined to develop effective control programmes for root-knot nematodes, and also stated that the value and permanence of chemical or cultural treatment would be increased when followed by a wet fallow or resistant crop, with particular attention to the control of weed hosts. As highly efficacious, inexpensive chemical soil treatments have been removed from the market, the integration of available management tactics and the maximizing of the potential of cropping systems must receive much greater attention (Noe, Sasser and Imbriani, 1991; Roberts, 1993).

To date, most IPM nematology research has focused on population biology, host phenology, modelling, damage functions and overall pest management decision-making (Bird, 1987; Roberts, 1993). Progress in these areas has clearly facilitated the development of better management programmes as well as enhancing our understanding of nematode-host interactions. Nevertheless, the integration and assessment of combinations of potentially compatible nematode management strategies and tactics have received only limited attention. This situation has developed, in large part, from heavy reliance on the use of nematicides, rotations where practical and resistant cultivars when available. The integration of host resistance and nematicides with other compatible tactics should minimize potential problems of loss of efficacy of given compounds or the appearance of nematode biotypes that attack resistant cultivars.

Integration of nematode management may be considered at two levels: within nematology; and across pathogen/pest disciplines. Within the context of nematodes, the application of multiple management tactics may be done over time or simultaneously, or both (Roberts, 1993). The temporal approach focuses on season-to-season or year-to-year integration of tactics relevant to cropping cycles. This cycle of integration of tactics might focus on crop rotation with non-hosts, resistant cultivars, or both, with additional strategies such as nematicides, cultural practices or biological control being added as they become available. This approach could involve different control tactics on different crops for given years. The second approach described by Roberts (1993) for integrating nematode-control components, involved simultaneous use of two or more tactics. This approach requires compatibility among the tactics to be deployed.

Numerous examples of single and multiple pest/pathogen successes could be cited (Duncan, 1991; Luc, Sikora and Bridge, 1990). Combinations of host resistance and tolerance, nematicides and rotations of resistant and susceptible potatoes with non-host rotation crops have provided a successful integrated management programme for the potato-cyst nematode (Roberts, 1993; Trudgill, 1987). A rather different system focusing host resistance, crop rotation, residual host-root destruction immediately after harvest, and an appropriate nematicide where warranted, has proved to be highly successful for *Meloidogyne* spp. and certain fungi, bacteria, insects and weeds on tobacco in North Carolina (Melton, 1991).

Roberts (1993) also offered a theoretical but practical framework for the integration of nematode management tactics with only partial efficacy (Fig. 9). This example depicts four hypothetical control tactics, A-D, with each having an efficacy of 66 percent. Thus, stepwise, residuals of the initial nematode population levels per successive tactic would be 34, 11.6, 2.9 and 1.3 percent, respectively. Information on

the damage threshold for the target nematodes and the efficacy of the integrated management tactics deployed, would be essential to determining the number of the types of treatments necessary to achieve satisfactory crop yields. For highly aggressive nematode species such as *M. arenaria* on groundnut, an even greater number of these types of tactics might be required in a management programme. Clearly, more information on the potential interactions of available management tactics, whether antagonistic or synergistic, or simply additive effects, will be critical for the integration of nematode control strategies and tactics.

Plant Parasitic Nematode Research

Much progress has been made in characterizing nematode communities and in the assessment of some management tactics in the Near East. Research opportunities remain in these areas as well as in developing related damage functions/thresholds and the integration of compatible strategies/tactics. Candidates for this integration include rotation/cropping systems, resistant cultivars, fallow/destruction of residual infected roots, solarization, nematicides and soil amendments/biological control. Carefully developed research-extension priorities, and the use of some type of data/decision-support system, should facilitate the development and deployment of effective IPM programmes. Long-term IPM goals and priorities might focus on interdisciplinary IPM (all pathogen and pest groups) and sustainable crop-production systems with critical inputs from experts in technology development/transfer, institutional resources/training, and economic/social/cultural components.

Promising new technologies for nematode diagnosis and identification, critical to IPM, are on the horizon. In addition, novel management weapons, including transgenic plants with nematode resistance and/or biological control genes, new safer nematicides and more effective biological control agents should be forthcoming. Improved data management and decision-support systems should facilitate the integration of new and traditional IPM strategies and tactics.

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