Range of Microbial Disease Complexes with *Meloidogyne* Species and Role of Botanicals in Management

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Abstract

Plant diseases are economically very important. The increasing realization of role of plant niche environment particularly the rhizosphere has triggered the application of management strategies to manage soilborne diseases below threshold. Among these regulatory strategies, one important aspect is to break the pathogenic symbioses as disease complexes. The present chapter has been divided into two parts: the first part focuses on the important soil pathogens in the vicinity with host plants with the role of edaphic climate in their association as *disease complexes*, while the second one deals with the changing strategy of soil environment using eco-friendly botanicals to discourage formation of disease complexes.

16.1 Introduction

Fear for survival drives the interactions of life forms. With reference to host crop, however, it may either be negative or positive. The ability of the parasite to interfere with one or more essential functions of the plant determines its potential to elicit disease. This potential or virulence is a decisive factor for the survival or establishment of pathogen or parasite in its host. The external climate (aerial environment and/or edaphic) strengthens disease signaling. Therefore, virulence potential of a pathogen or its inoculum potential is basically determined by the niche environment.

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Further complexity in disease pyramid is brought by ecosystemic dissection of interactants. The three principle components, i.e., pathogen, host, and environment, emerge through intra- and inter-ecosystemic interactions to decide the potential of interaction. The pathogen lives in a community of microbes, say, in rhizosphere with other pathogenic and nonpathogenic interactants. Potency of infection depends upon the inoculum level and virulence of pathogen which is further regulated by the environment, which in case of soil might be decided by soil texture, chemical composition, temperature, and moisture level. Host plant itself naturally grows in the community of several other weeds and plants which forms chemical (allelopathic), physical, or specificity barrier for pathogen. Interaction of microbial community may antagonistically interact (often used as biocontrol agent) or naturally may positively interact to form disease complex (Zacheo et al. 1977). The phenomenon of pathogenic interaction "one at a time" may or may not be excluded by cross-resistance or cross-sensitivity.

16.2 Soil Environment

Soil is not a pure culture of microorganisms, and it bears various potential pathogens, symbionts, and free living beneficial microbes at various stages of growth. Ecologically, soil is a very complex and still unexplored body where millions of microorganisms continuously interact negatively and positively or remain neutral. Most of these microorganisms which belong to kingdom Monera (prokaryotes) and Protista (simple eukaryotes) are r-selected species with high adaptive value. Fluctuating environment of soil causes successive alterations in microbial communities which include soil moisture, temperature, oxygen availability, and nutrient status. However, selective buildup or subsidence of one or some microbial species/strain among inhabiting microorganisms is aided by the efficiency to metabolize host exudates facing stressful regime in vicinity which provides the opportunity to competitively exploit the available feast. Several abiotic factors (environment) that are responsible for the stress of host include high or low temperature stress, water logging or hypoxic stress, draught, salinity, mechanical stress (injury), or natural senescence. A set of microclimatic or niche factors may determine the natural selection of species or strain build inoculums, for example, primary inoculum level, composition of host exudates (allelochemicals, volatile organic compounds), availability of antagonists, soil pH, and physical structure of soil. Among soilborne pathogens, a significant role of nematodes and fungi has been demonstrated in the development of plant diseases in crop plants around the globe which includes lentils, cotton, peanuts, brinjal, chickpea, soybean, potato, tomato, etc. (Back et al. 2002; Koike et al. 2003).

16.3 Important Soilborne Plant Pathogens

Soil is a good medium for the rich culture of plethora of microorganisms. The plant is said to be healthy when it carry out its physiological functions to the best of its genetic potential. Under natural conditions, there are numerous microorganisms and environmental factors which alter the normal physiological functions of the plant that compromise its genetic potential and disease development. The series of invisible and visible responses of plant cells and tissues to pathogenic microorganisms or environmental factor imparts adverse changes that lead to partial impairment or death of the plant or its part. The plant pathogenic microorganisms, such as viruses, fungi, protozoa, and nematodes, usually cause diseases in plants by disturbing the metabolism of plant cells through enzymes, toxins, growth regulators, and other substances they produce. Soil consists of nutritional availability for host growth, presence of niche microbes and their secretions, host exudates, and other abiotic factors. These environmental conditions may favor one or more pathogens which further cooperate or antagonize each other. The hidden half of plant, i.e., roots, is more prone to negative interaction of microorganisms than shoots which cooperatively assists each other to develop host pathogenesis. An array of microbes could interact negatively with host crop in its rhizosphere region. Often herbaceous plants with soft root tissues infested by a number of soilborne pathogenic bacteria, fungi, nematodes, and insects are generally vegetable crop plants. These include bacteria, actinomycetes, mollicutes, protozoans, fungi, nematodes, and crustaceans. In a natural soil environment, there lie several microorganisms, i.e., nearly 10^6–10^8 bacteria, 10^6–10^7 actinomycetes, 5×10^4–10^6 fungi (cfu), 10^5–10^6 protozoa, and 10^4–5×10^5 algae in 1 g of field surface soil (Gottlieb 1976), whereas c. 1×10^7 nematodes in 1m^2 of fertile soil (Richards 1976). Most of these microorganisms are saprophytic with little or no disease potential on plant; most others under favorable soil conditions initiate plant diseases, for instance, pathogenic fungi or root-knot nematodes.

A significant development of disease complex formation in plant pathology has occurred after the 1960s including nematodes with fungi, bacteria, and viruses. Nematode has been seen to facilitate disease development under normal conditions caused by pathogenic fungi and bacteria through synergistic or additive relations. Thus, two pathogens are required to induce disease, where primary pathogen induces changes in host inviting secondary pathogen to participate actively to exacerbate the pathogenesis. Interactions involving bacteria as secondary host are few as compared to fungi. Among bacteria, likewise fungi, wilt- and rot-causing bacteria are studied in more detail.

16.4 Root-Knot Nematodes

Nematodes are ubiquitous and cosmopolitan parasites of vascular plants, causing substantial crop damage. Although various species exploit all parts of the plant, roots are the major target. Nematodes deploy a broad spectrum of feeding strategies, ranging from simple grazing to the establishment of complex cellular structures (including galls) in host tissues (Bird and Kaloshian 2003). Plant parasitic nematodes are capable of producing recognizable disease symptoms on suitable susceptible hosts (Agrios 2005). These were first reported in roots of greenhouse-grown cucumbers by Berkeley in 1855, England. Plant parasitic nematodes belonging to 15 genera have been reported to cause heavy losses on okra (Bhosle et al. 2004). Root-knot nematode is one of the most harmful nematode pests of crop production in tropical and subtropical regions causing extensive economic damage worldwide (Sikora and Fernandez 2005; Hussain et al. 2011; Mukhtar et al. 2013). These nematodes are obligate root parasites of more than 2000 plant species comprising herbaceous and woody plants of mono- and dicotyledons (Hussey 1985).

The primary inoculum level of nematode population in soil is regarded as key determinant of root infestation and is phloem/cell sap herbivory if host is available in vicinity. Availability of host attracts juveniles through chemotaxis through the exudation of root secretions. Possible effector molecules are also released by nematodes to discourage surface-induced defense activation in host. Soil temperature, moisture, pH, aeration, and plant exudates are other determining factors of nematode fecundity, life span, and activity in soil. For different crops and their respective varieties, the threshold nematode population required to initiate pathogenicity has been worked out by several workers (Khanna and Jyoti 2004; Chand 2004; Ekenma and Chidera 2005; Ansari and Azam 2005; Khan et al. 2006; Khan et al. 2008; Kankam and Adomako 2014). Increasing the nematode inoculum level resulted in corresponding increase in number of galls and nematode population buildup. The reduction in growth parameters and nematode infestations was found to be proportional to the inoculum level. Besides abovementioned factors, availability of heavy metals in soil also has adverse effect on soil nematode population.

16.5 Root-rot Fungi

High moisture and temperature of soil environment increase root respiration and rapidly deplete the rhizospheric oxygen. Such reducing environment with high biological oxygen demand supports the perpetuation of necrotrophic fungi especially rotting fungi. Among the soilborne fungal diseases, damping off of seedlings, root rot, and wilt of adult plants are caused by several species of *Fusarium*, *Pythium*, *Rhizoctonia*, and *Verticillium* (Kuprashvili 1996; Jacobsen 2006; Lucas et al. 1997) and are widely distributed throughout the world. *Rhizoctonia solani* is one of the most widely distributed and destructive soilborne plant pathogenic fungi, originally described by Kuhn, 1858 on potato. Occurrence and virulence of *R. solani* depend upon various factors like soil texture, moisture, and temperature (Gill et al. 2000; Gill et al. 2001). It flourishes through vegetative hyphae and sclerotia to cause serious plant diseases (Sneh et al. 1996), for instance, leaf blight, leaf spots, root rot, shoot rot, fruit rot, damping off etc., and has broad host range (Anderson 1982; Lemanczyk 2010). Fungal sclerotia are the structures which survive under adverse environmental conditions for many years. According to a survey, contribution of fungal diseases toward total yield loss of important crops in India is 18–31% (Grover and Gowthaman 2003).

16.6 Bacterial Associations with Nematodes

Nematodes play significant role in carrying pathogenic bacteria and development of disease complex. Nematode predisposes the host to these bacterial diseases providing wounds as entry points for bacteria. For instance, root-knot nematode *M. incognita*-induced wounds in host facilitate the disease complex formation inviting the bacteria *Pseudomonas solanacearum* and *M. hapla* to *Agrobacterium tumefaciens*. The association produces disease symptoms in host different than those produced by either of the pathogen alone. Nematode attaches to bacteria, its body surface binding to cuticle. The nematode *Anguina tritici* in wheat and *A. funesta* in ryegrass produces black seed galls. With bacterial species *Clavibacter*, the nematode causes spike blight with spikelets bearing bacterial mass rather than grains. Grains also produce toxins fatal to sheep and cattle and cause a disease called annual ryegrass toxicity in cattle. Similarly, the presence of *M. incognita* in tomato and brinjal exacerbates the bacterial wilt caused by *Pseudomonas solanacearum* even in resistant varieties. Some of the bacterial genera are specifically carried by their nematode hosts. Species of *Anguina* and *Aphelenchoides* also vector bacterial parasites to aerial parts of plant. The coinfection of nematode juveniles of *A. tritici* with bacterium *Clavibacter tritici* results into yellow ear rot of wheat. *A. tritici* causes ear cockle of wheat. The interaction and carrying of bacteria with nematode are essential steps for disease complex development. The mode of bacterial attachment to nematode juveniles and the nature of their association may differ. The detailed knowledge of mechanism of interaction, however, is still lacking; recent work for early bacterial-nematode interaction is discussed in forthcoming text.

16.7 Plant Disease Complexes

Soil is the pool of numerous diverse pathogens which could potentially infect plant. Nevertheless, these pathogens are host specific with specific host range. A successful pathogenic infection, inhabiting rhizospheric common niche, relies on host exudes which induces upsurge of inoculum density and competitive exclusion of other antagonists. Alternatively, several environmental conditions and host responses attenuates this inoculum potential resulting into partial or complete disease failure. It is now evident that several pathogenic fungi, like those of other non-pathogenic symbioses or complex organisms, undergo facilitative co-operation to overcome "'failure of nutrient acquisition" or pathogenesis to ensure their survival and growth.

16.7.1 Nematode-Fungi Disease Complex

From the primary inoculum of root-rot fungi, viz., *Pythium*, *Rhizoctonia*, *Macrophomina*, and *Fusarium*, the secondary inoculum level rapidly builds up the feeding level which results in sloughing off of root epidermal peels. Alternatively, root herbivory of nematodes under favorable temperature and moisture conditions accelerates the infection by biotrophic fungi providing additive opportunity of infection in nematode-damaged roots. Counter-infection of root-rot fungi in nematode-infested roots contributes to the severity of the disease that adversely affects the host growth and yield output. Therefore, primarily nematode-resistant varieties were screened to discourage formation of nematode-fungi disease complex.

It was long been known that diseases in crop plants were the result of a complex interaction of host, pathogen, and prevailing environmental conditions. In the rhizosphere of a plant root, millions of opportunistic microorganisms inhabit in sharing ecological niche. A significant role of soilborne pathogens has been attributed globally in the successful development of disease. A disease complex is produced through interactions between two or more organisms. Studies have shown that under a set of environmental conditions, independent infections by root-rot fungi or nematodes have suboptimal disease response in their host plants as compared to their complexed or associative efforts (Bergeson 1972). Most common interactive associations of plant nematodes have been shown with viruses (Khan 1993), bacteria, insects (Sitaramaiah and Pathak 1993; Ryss et al. 2011), and fungi (Back et al. 2002). Many species of plant parasitic nematodes predispose the plants to fungal and bacterial infections, and thus, the plants may suffer greater damage from concomitant infection.

The association of nematode with fungi on host could fall under synergistic, additive, or antagonistic interactions with respect to negative or disease development in host. The synergistic association results into enhanced fungal infections due to adverse physiological effects on host plant by nematode parasitism (Golden and Van Gundy 1975; Starr and Aist 1977). Nematode-fungal disease complexes, especially those involving *Meloidogyne* spp., are common on many crops (Golden and Van Gundy 1975; Diomande et al. 1981; Abawi and Barker 1984; Starr et al. 1989; Safiuddin and Shahab 2012). Synergistic association of *M. incognita* and *R. solani* on okra or tomato roots was better colonized by *R. solani* in the presence of *M. incognita* compared to plants exposed to *R. solani* alone (Golden and Van Gundy 1975). Siddiqui and Husain (1991) reported a similar effect of *M. incognita* on the colonization of chickpea roots by *Macrophomina phaseolina*.

The frequency of involvement of nematodes and fungi in disease complexes is reflected in the number of crops, and the most destructive nematode species in the world is *M. incognita* that has been frequently reported in disease complexes. Brodie and Cooper (1964) reported that the mechanical wounding of cotton seedlings failed to increase the susceptibility to either *R. solani* or *P. debaryanum*. He also found that sporangial production of *P. debaryanum* was almost ten times greater in the presence of sap exuded from root-knot galls produced by *M. incognita* than in the presence of sap from healthy roots. These observations indicate that the nematodes create better environment for fungal development, perhaps by increasing the available nutrient supply. Batten and Powel (1971) observed that root rot was more extensive in prior inoculation of *M. incognita* to *R. solani* in the roots of tobacco plants than those where nematode and fungus were introduced either simultaneously or separately or even when *R. solani* was added after artificial wounding. Histological examination of galled roots after inoculation with *R. solani* revealed

Table 16.1 Disease complex of root pathogenic nematode and fungus forming complex with their host plants

Nematode	Pathogenic fungus	Host plant	Reference
Meloidogyne javanica	*F. oxysporum* f.sp. lentil	*Lens culinaris*	De et al. (2001)
Meloidogyne incognita	*Thielaviopsis basicola*	*Gossypium hirsutum*	Wheeler et al. (2000)
Meloidogyne incognita	*Rhizoctonia solani*	*Arachis hypogaea*	Abdel-Momen and Starr (1998)
Meloidogyne incognita	*Rhizoctonia solani*	*Solanum lycopersicum*	Arya and Saxena (1999)
Meloidogyne arabicida	*F. oxysporum*	*Coffea arabica*	Bertrand et al. (2000)
Heterodera glycines	*Phytophthora sojae*	*Glycine max*	Kaitany et al. (2000)
Heterodera glycines	*F. solani*	*Glycine max*	Rupe et al. (1999)
Globodera rostochiensis	*Rhizoctonia solani*	*Solanum tuberosum*	Back et al. (2000)
Pratylenchus thornei	*F. oxysporum* f.sp. ciceri	*Cicer arietinum*	Castillo et al. (1998)
Pratylenchus thornei	*Rhizoctonia solani*	*Cicer arietinum*	Bhatt and Vadhera (1997)
Pratylenchus neglectus	*Verticillium dahliae*	*Solanum tuberosum*	Hafez et al. (1999)
Pratylenchus penetrans	*Verticillium dahliae*	*Mentha arvensis*	Johnson and Santo (2001)
Rotylenchulus reniformis	*F. oxysporum* f.sp. pisi	*Pisum sativum*	Vats and Dalal (1997)
Rotylenchulus reniformis	*Phytophthora palmivora*	*Piper betle*	Jonathan et al. (1997)

extensive fungal colonization in the root-knot susceptible cultivar 'Dixie Bright 101' when *M. incognita* preceded *R. solani*. *Rhizoctonia solani* is normally non-pathogenic on mature tobacco roots but may cause severe losses when present with well-established root-knot nematode infections. Hazarika and Roy (1974) studied the interrelationship between *R. solani* and *M. incognita* on eggplants (*Solanum melongena* L.), and they showed that the number of galls on roots and the number of egg masses were significantly greater in plants inoculated with nematode and fungus together than inoculated with nematode alone. Moreover, the growths of eggplant were not affected significantly by the attack of *M. incognita* or *R. solani* alone or in combination (Table 16.1).

16.7.2 Nematode-Bacteria Disease Complex

Most of the potentials of pathogenic nematode-prey interaction were done in animal systems. *Caenorhabditis elegans* has been much used to study microbial pathogenesis (Kim 2013). This nematodes-bacteria interaction could involve the transition from prey-predator to host-pathogen relationship. Bacteria may here work as food or pathogen or initially prey and later may become pathogenic (Garigan et al. 2002; Cabreiro and Gems 2013). Alternatively, the hologenome theory states that the two are holobiont, the evolutionary unit (Rosenberg and Zilber-Rosenberg 2011). The nematode could take up bacteria through digestion or external adherence (Ingham et al. 1985) that may facilitate it for further dispersal. In some other bacteria, surface pili or fimbriae may facilitate its adhesion to nematode surface (De Oliveira-Garcia et al. 2003). Mohan et al. (2001) identified heparin-binding domain (HBD) and gelatin-binding domain (GBD) of *M. javanica* second-stage juveniles which have important role in surface attachment of *Pasteuria penetrans* endospores to cuticle of nematode at first-stage infection.

16.8 Disease Management Through Organic Amendments

For the control of root-knot nematode (*Meloidogyne* spp.) and root-rot fungus, chemical control still remains to be one of the most outstanding methods in terms of immediate results, but there are many reports where chemicals (nematicides and fungicides) have been found to contaminate the soil and ultimately the underground water and thus are potentially toxic to human being (Alam and Jairajpuri 1990; Kookana et al. 1998; Komarek et al. 2010). Due to the hazardous effect and high cost of the chemicals, there has been a growing interest to find out the alternative and eco-friendly means for managing the disease caused by the pathogens. Organic and bioorganic amendments are generally used to increase the agricultural productivity (Abdel-Aziez et al. 2014) and their suppressive effect on plant parasitic nematodes (Khan and Haque 2011) and fungus (Dubey et al. 2007) and also for nematode and fungus both when they parasitized concomitantly (Mokbel et al. 2007; Akhtar and Siddiqui 2008). Organic soil amendments have been found effective to suppress the noxious nematodes to varying extent depending upon the nature of organic matter (Oduor-Owino 2003; Yadav et al. 2013). A number of indigenous plant products have been identified to be toxic to nematodes. The beneficial effects of organic amendments are due to certain nematicidal compounds that are released during decomposition of organic additives in soil, and similarly biological agents produce antagonistic substances against nematode and fungi (Amin and Sequeira 1966; Khan and Saxena 1997; Siddiqui et al. 2002; Ashraf and Khan 2010). Amending the soil with farmyard manure and commonly available plant parts and products of neem, mahua, castor, mustard, and linseed in the form of oil cakes and dry leaves, seeds, seed kernel, seed coat, seed powder, etc. is one of the common methods used against plant parasitic nematodes, especially in India. The organic matter is an important component of soil, and the value of decomposition of organic amendment is an important factor in reduction of nematode infection which was first demonstrated by Linford et al. (1938).

16.8.1 Through Plant Residues/Green Manures

Organic matter serves as a primary source of nutrients for nematophagous fungi and nematode as a secondary source (Nicolay and Sikora 1991). The organic matter is an important component of soil, and the value of decomposition of organic amendment is an important factor in reduction of nematode infection, which was first demonstrated by Linford et al. (1938). Infection of *M. javanica* on tomato was reduced by incorporating oil cakes and their formulations (Goswami and Vijayalakshmi 1986; Khanna et al. 1987; Ahmad 1989; Darekar et al. 1990; Goswami 1993; Tiyagi and Alam 1995; Javed et al. 2008).

The use of green manures and plant residues before planting has long been considered as an effective control (Lumsden et al. 1983). Organic amendments are not only safe to use but also have the capacity to improve soil structure and fertility. These control strategies are now directed toward the use of natural products. Bioactive products of plants are being less persistent in environment and are safe for mammals and other nontarget organisms. Amending the soil with farmyard manure and commonly available plant parts and products of neem, mahua, castor, mustard, and linseed in the form of oil cakes and dry leaves, seeds, seed kernel, seed coat, seed powder, etc. is one of the common methods used against plant parasitic nematodes, especially in India. The increased efficacy of organic matter in the form of oil cakes in combination with inorganic fertilizers may be attributed to the fact that organic matter could provide the required nutrients such as zinc, iron, copper, manganese, etc. which help in plant metabolism through the supply of important micronutrients in the early growing phase of the plants. Organic matters like oilseed cakes act as a nutrient reservoir, and upon decomposition, a large number of organic products are released slowly in the soil in which root absorbs the ionic forms during their growth period leading to the higher yields. Use of different plant residues for organic amendment to decrease root pathogenic disease was well reviewed by Spadaro and Gullino (2005), Oka (2010), and Ntalli and Caboni (2012).

16.8.2 Plant-Derived Phytochemicals

Because of the adverse effect of synthetic pesticides, the interests turned toward the use of pesticides of natural origin or biopesticides. The adverse effects of chemical pesticides included negative impact on environment, toxicity to nontarget organisms including humans, and resistance development in insect population. Several plant extracts and their active constituents have been tried for the efficacy against root-knot nematodes and even root-rot fungi (Khalil 2013). Different plant parts such as leaves, seeds, flowers twigs, or stems or the residues of plants have been used for soilborne disease management. The different plant species which have been found effective were neem, castor, mahua, soybean, carnation, sunflower, sesamum, mustard, karanj, etc. (Table 16.2).

Table 16.2 Selected crop plants with phytochemicals active against root-knot nematodes

Plant species	Phytochemicals	Active against	References
Azadirachta indica	Limonoids (nimbin, azadirachtin, salannin)	*M. javanica*	Devakumar et al. (1985) and Akhtar (2000)
Tagetes species	Polythienyls, myristic, and dodecanoic acids	*Memoidohyne* spp.	Gommers and Bakker (1988) and Debprasad et al. (2000)
Artemisia species	Flavonoids	*Ditylenchus dipsaci*, *M. incognita*	Timchenko and Maiko(1989) and Dias et al. (2000)
Chrysanthemum spp.	–	*M. javanica*	Bar-Eyal et al. (2006)
Crotalaria spectabilis	Monocrotaline	*M. incognita*	Fassuliotis and Skucas (1969)
Mucuna pruriens	Alcohols	*M. incognita*,	Nogueira et al. (1996)
Ricinus species	Lectins (ricin)	*M. incognita*, *M. arenaria*	Rodrıguez-Kabana et al. (1989) and Ritzinger and McSorley (1998)
Brassica spp.	Glucosinolate, isothiocyanates, nitriles	Weeds, bacteria, fungi, nematodes	Kirkegaard et al. (1993), Matthiessen and Kirkegaard (2006), and Mumm et al. (2008)
Sorghum drummondii	Cyanogenic glycoside, dhurrin	*M. hapla*	Widmer and Abawi (2000, 2002)
Secale cereale	Hydroxamic acid	*M. incognita*	McSorley and Dickson (1995) and Zasada et al. (2005, 2007)
Quillaja saponaria	Saponins, polyphenols	*Meloidogyne* spp., *Xiphinema* spp.	San Martin and Magunacelaya (2005)
Pennisetum glaucum	S-compounds	Nematodes	Rodriguez-Kabana et al. (1965)

16.8.3 Disease Management Through Organic Amendments

Infection of *M. javanica* on tomato was reduced by incorporating oil cakes and their formulations (Goswami and Vijayalakshmi 1986; Khanna et al. 1987; Ahmad 1989; Darekar et al. 1990; Goswami 1993; Tiyagi and Alam 1995; Javed et al. 2008). Singh et al. (1990) determined the effect of neem, castor, and mustard cakes against *M. incognita* on tomato cv. Pusa Ruby under pot experiment. They reported that neem cake alone was highly effective against nematode followed by castor and mustard cakes, respectively. However, a mixture of neem + mustard and neem + castor cakes was more effective than neem cake alone. Alam (1991) studied the effect of mahua, castor, mustard, neem, and groundnut oil cakes singly and in different combinations against *M. incognita*, *T. brassicae*, *R. reniformis*, *H. indicus*, and *T. filiformis*, on tomato, brinjal, chili, okra, cabbage, and cauliflower under field conditions. He reported that all the treatments singly and in different combinations significantly reduced the population of plant parasitic nematodes. Mahua cake was phytotoxic to all the test crops except brinjal, whereas other cakes improved plant growth significantly. Mojumdar and Mishra (1993) studied the effect of neem cake and seed kernel/seed coat as single, full dose, or split doses to soil naturally infested with *M. incognita* on chickpea under pot conditions. They found that all the treatments were effective to reduce the number of root galls significantly. However, treatment with neem seed kernels was most effective when applied as full dose. Abid et al. (1995) studied the effect of neem dry leaves powder, seed powder, and neem cake at 2, 4, and 6 g/750 g soil against *M. javanica* on okra under pot conditions. They reported that all the treatments enhanced the plant growth and reduced gall formation as compared to untreated control. Maximum reduction in root-knot index was observed with oil cake followed by seed powder. Rao and Goswami (1996) determined the efficacy of organic amendments, viz., groundnut, karanj, mahua, mustard, and neem cakes, an inorganic amendment, attapulgite-based clay dust (ABCD), and carbofuran for comparison on root-knot development caused by *M. incognita* and growth of cowpea. They observed that the reduction in root-knot development was significantly high in mustard, neem cakes, carbofuran, and ABCD treatments, the least effect being found with groundnut cake. The plant growth was greatly improved in mustard, and neem cakes amended soil followed by karanj, mahua cakes, and ABCD, respectively.

Several workers achieved success by using organic matter (Baby and Manibhushanrao 1996; Bailey and Lazarovits 2003), straw of several crops (Osunlaja 1990; Alam et al. 2002), leaves, stems, seeds (Tariq et al. 2006 & Tariq et al. 2008; Ahmed et al. 2009), seaweeds (Sultana et al. 2005), aqueous extracts of plant parts (Alam et al. 2002; Dawar et al. 2007; Emmanuel et al. 2010), oil cakes, and plant products and their formulations (Jeyarajan et al. 1987; Ehteshamul-Haque et al. 1998; Dubey et al. 2009) against root-rot fungus. Use of plant residues and organic amendment has been recognized as an effective way of achieving substantial population reduction of plant-pathogenic life forms like fungi, bacteria, nematodes, etc. (Patrick and Toussoun 1965). Plant residues or organic amendments have been reported to check the population of the pathogens through a variety of mechanisms (Sayre et al. 1964; Patrick and Toussoun 1965; Cook 1977; Sitaramaiah 1990).

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