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Nematodes associated with organic farming systems and their management strategies: A review

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Abstract
Plant protection is extensively engaged in conversation with organic growers both National and world level, yet organic agriculture faces the same plant-parasitic nematodes (PPNs) issues as conventional farming. The main motto and basis of organic agricultural system is to maintain the health of soil and its food web. Along with maintaining soil fertility, the farmers also want to maintain good microbial population required for nutrient recycling. This makes the application of organic matter in the form of composts and manures that will decrease the pest populations and incorporation of cultural practices like crop rotations. It also helps in addition of nutrients to the soil. The ultimate goal of organic agriculture is to improve the plant health; hence amending the soil with organic matter is the basic factor for soil ecosystem management, which directly or indirectly increases the crop yields. In organic farming systems, nematodes are becoming a hindrance in the profitable productions and it is very difficult to control in these systems, as chemicals are not supposed to be employ. Worldwide estimates of crop losses are about 12.3 % annually of food and fiber, due to nematodes. Different studies had conducted on organic and conventional farming systems. It has proved that genera of plant parasitic nematodes attacking organic farming are similar to that in conventional farming. Such as, root knot (*Meloidogyne* spp.), cyst (*Heterodera* and *Globodera* spp.), and reniform nematode (*Rotylenchulus reniformis*). Therefore, in this review article, we discussed different management strategies for PPN management in organic farming.

Keywords: Plant parasitic nematodes, predatory nematodes, organic farming and management

Introduction
Nematodes belonging to the phylum Nematoda are bilaterally symmetric round worms, which are microscopic in size and cannot, seen with naked eyes. They are one of the abundant groups of animals, which require a thin film of moisture for their survival. They are obligate parasites, which feeds mainly on plant roots with above ground symptoms of stunting, yellowing, wilting and deteoration of fruit quality, which are often confused with nutrient or water deficiency (Stirling, 1991). In general, soils including organic farms both the ectoparasites and endoparasites are found (Chen *et al*., 2012) [4].

Organic agriculture refers to growing of crops without the incorporation of synthetic pesticides and fertilizers and it is defined by the International Federation of Organic Agriculture Movements (IFOAM) as “A production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effect. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved” (IFOAM, 2009). It is based on minimal use of off farm inputs and on management practices that restore, maintain, or enhance ecological harmony. The primary goal of organic agriculture is to optimize the health and productivity of interdependent communities of soil life, plants, animals and people (National Organic Standard Board, 1997).

Nematode problems associated with organic farming
We briefly review of plant parasitic nematode associated with organic farming system and their management. The important plant parasitic nematodes, which are of greater importance, are sedentary endoparasites of the family Heteroderidae that includes the cyst nematodes e.g. *Heterodera spp.* and *Globodera spp*, root knot nematodes *eg*. *Meloidogyne* spp. and migratory endoparasites of the family Pratylenchida *eg*, *Pratylenchus* spp. The nematode problems in organic farming are same as observed in conventional farming, as in organic farming the synthetic chemicals are restricted to apply hence left with limited options for the

nematode management. The overall losses caused by nematodes are 12% annually of food and fiber but the overall losses incurred by nematodes in organic farming systems has not been estimated till today. Hence, to manage nematodes in organic farming the farmers employ the practices such as crop rotation, use of cover crops, resistant varieties and soil amendments. Plant parasitic nematodes act as predisposing agents as their feeding creates entryways into roots for secondary pathogens as well as plant viruses (Rowe and Powelson, 2002) [32].

Symptoms caused by plant parasitic nematodes

Nematodes exhibit two types of symptoms, above ground and below ground. The above ground symptoms observed are non-specific and may be produced due to several other reasons. The symptoms are stunting, yellowing, wilting, dieback, *etc*. Some nematodes directly attack the above ground plant parts and produce the symptoms like dead or devitalized buds, crinkling and curling of leaves, gall formation, necrosis, discolouration and leaf spots or leaf lesions. Below ground symptoms induced are root galls by *Meloidogyne* spp., *Xiphinema* on roses, stubby roots by stubby root nematode, *Trichodorus* and *Paratrichodorus*, root lesions caused by *Pratylenchus* spp., root rot by *Ditylenchus* spp., excessive root branching and swellings by *Heterodera* spp. in cereals.

Left: Overview of Paddy field infected with rice root knot nematode, *Meloidogyne graminicola*

Right: Spindle shaped galls of Rice caused by *Meloidogyne graminicola*

Right: Roots of Potato encountered with Potato cyst nematodes

Left: Wheat fields infested with cereal cyst nematode, *Heterodera avenae*

Left: Compound galls formed by *Meloidgyne incognita* in gerbera

Right: Roots of cucumber plant infested with root knot nematode

Management aspects in organic farming Cultural practices

a) Crop rotation

Nematode movement is restricted in soil as they cannot move long distance hence it is very easy to reduce the nematode population below they reach damage threshold levels. Due to continuous availability of food to the nematode by growing the same host crops for years will increase their population above the threshold levels hence, planting the non-host crop in between will remove the food source for PPNs. The effectiveness of crop rotation depends upon the following factors like nematode species present in the field, host range and ability of nematodes species to survive in the field without any food source. In addition, the design of a successful cropping system depends on economics (Ferris and Noling, 1987) [7]. Cyst nematodes have narrow host range hence non-host crops can easily be selected compared to lesion nematodes that have a wider host range. In the southeastern United States, rotation of peanut with maize or sorghum for management of *M. arenaria* is unattractive because of the low economic value of these crops (Rodriguez-Kabana *et al*., 1989) [31], but 3-year sequences of peanut and soybean found to be profitable (Rodriguez-Kabana *et al*., 1988) [30].

Crop rotation also increase the diversity and stability of microorganisms present in the rhizosphere. Sethi and Gaur (1986) [34] had reviewed the crop rotation principles in nematode management. The different types of crops employed in crop rotation not only improves the soil structure but also helps in increasing the nutrient cycling that results in higher yields for main crop and provides good returns to the organic farmers. Crop rotation will be effective only if rotated with crops belonging to different families like Cucurbitaceae, Poaceae and Brassicaceae, which are non-hosts to most of the nematodes (Wang *et al*., 2004) [44]. Crop rotations are applicable to both reducing nematode populations as well as reduction in plant diseases and insect pests. Root knot nematode is a serious pest of number of vegetable crops and beans and so it is very difficult to manage by crop rotation with non-host crops like grains, as resistant or highly resistant varieties are not available. Whereas the rotations can be easily applicable for cyst nematodes. *Globodera rostochiensis* as it confines itself only to the members of family Solanaceae with potatoes as the preferred hosts but the cultivation of non-host crops like carrot, cauliflower, beans, French beans, cabbage and cauliflower during autumn reduces the cyst population to the greater extent.

A non-host crop, cotton can be rotated with peanut for the management of *M. arenaria* (Rodriguez-Kabana *et al*., 1987) [27]. Maize with soybean for management of *H. glycines* (Schmitt, 1991), rotations with legumes or other non-hosts are used against *H. avenae* on cereal crops (Brown, 1987) [2], alfalfa rotations are useful against *H. schachtii* on sugarbeet (Weischer and Steudel, 1972) [46], and many other examples of successful crop rotations are available in literature (Good, 1968; Johnson, 1982; Trivedi and Barker, 1986) [10, 13, 40]. The effect of non-host crop depends upon type of crop selected as in some cases, favorable effects from crop rotation can persist for several seasons (McSorley and Gallaher, 1993) [16], and while in other instances rotation effects may lessen after a single season (Rodriguez-Kabana and Touchton, 1984) [26]. In perennial crops, it is essential to evaluate economics of management practices over the life of the crop, since short-term evaluations may show a loss during the initial years when the crop is just established (Ferris and Noling, 1987) [7]. With the long rotations employed against cyst nematodes, it may be necessary to project nematode populations and yields over many years to assess profitability of proposed crop sequences (Jones and Kempton, 1978) [14].

b) Application of soil organic amendments

Since in organic agriculture, as discussed above, the application of synthetics are not permitted, the animal and plant by products are employed in the soil, which not only controls nematodes but also enhances the nutrient supply, increases the organic matter levels, improves the soil structure and texture and improves the plant health. There are two types of organic amendments (i) amendments that are cultivated and applied in the soil, *in situ* such as cover crops, trap crops, green manures, *etc*. and (ii) amendments applied from outside such as animal or composted yard manures. McSorley (2001) has reviewed in detail regarding several mechanisms for the probable cause of nematode suppression using organic amendments. The organic amendments enhance the naturally occurring antagonists or microorganisms such as bacteria, fungi and even predatory nematodes. Amending the soil with deoiled non-edible seed cakes of neem, karanj, mahua, castor, *etc*. is beneficial as they release ammonia that is directly lethal to nematodes and improve the soil fertility and organic matter content (Oka, 2010, Rodriguez-Kabana and Ivey, 1986, Rodrioguez- Kabana *et al*., 1987) [22, 28].

The main constraint that remains with this is high dose of applications *i.e.* more than 20 quintals per hectare. This can be resolved if it is applied in combination with other management practices or multiplying bioagents in FYM such as *Trichoderma, Paecilomyces, Aspergiluis, Bacillus, Pseudomonas, Actinomyces, etc*. which help in controlling soil borne PPNs. In 2007, Oka *et al*. studied the efficacy of organic amendments, with or without soil solarization, for the control of the root-knot nematodes *M. incognita* and *M. javanica* in organic farming systems in pot. Container and greenhouse experiments and was observed that combinations of the amendments with soil solarization were more effective than the amendments or soil solarization alone in reducing nematode populations and galling indices in most cases. It assumed that high soil temperatures and accumulation of ammonium/ammonia in these treatments seemed to be involved in controlling root-knot nematodes.

c) Cover crops

The main purpose of the cover crops such as grasses and legumes is to improve the soil fertility and soil structure nutrient recycling, to provide fresh organic matter, control weeds and other pests and to prevent the soil from erosion. Commonly the crops employed for this purpose are sunhemp (*Crotolaria juncea* L.) against root knot nematode (Wang *et al*., 2004) [44], sudan grass/ sorghum against root knot nematode (McSorley *et al.,* 1995) [17], velvet bean against root knot nematode (Queneherve *et al.,* 1998) [24], pearl millet against root knot nematode and lesion nematode (Belair *et al*., 2005) [1], etc. Along with this, marigold especially the root exudates also attained quite attention in suppression of several genera of PPNs (Siddiqui and Alam, 1987) [35]. The selection of the cover crop mainly depends on the two things *viz.* economics and adaptability to local conditions. At the same time, it should be poor host or non-host for plant parasitic nematodes prevalent in that particular area. They should be applied as mulches that may be less detrimental as soil food web and help in suppressing the nematodes. In addition, organic farmers should take care in selection of cover crops because selected cover crop may be resistant to one species but may be susceptible to other nematodes. (Wang *et al.,* 2008) [45]

Cover crops secrete allelochemicals, which are plant-produced compounds that effect the behavior of other organisms within the plant environment. For *eg.* Sorghum or Sudan grass contain the chemical called '*dhurrin*' which degrades into hydrogen cyanaide and acts as a nematicide (Wider and Abawi, 2000) [47]. Other allelochemicals that act as nematode antagonistic compunds are glucosinolates, polythienyls, cyanogenic glycosides, alkaloids, lipids, terpenoids, steroids, triterpenoids, phenolics, *etc*. which are released by plants like castor, chrysanthemum, pea, velvet bean, sesame, crotolaria, indigo, sudan grass, tephrosia, *etc*. Sunhemp containing monocrotaline is a popular nematode suppressive cover crop. Details are given in Table 1.

d) Application of botanicals

We have already discussed about the nematode suppressive cover crops like marigold, sesame, castorbean etc. but there are few plants whose extracts or essential oils are used as nematicides, which are considered as first generation pesticides and has been reviewed by Ntallii and Caboni, 2012. Under organic agriculture, many of the plant products are used but for nematode management availability in large quantities is the main limitation.

Table 1: List of botanicals containing active component and its chemical classes

Chemical classes of botanical nematicides	Active component	Derived from
Aldehydes and ketones	aldehyde benzaldehyde	*Eucalyptus meliodora*
	p-anisaldehyde, benzaldehyde, trans-cinnamaldehyde, pulegone, and furfural	*Ailanthus altissima, Melia azedarach*
Alkaloids	2,5-Dihydroxymethyl-3,4-dihydroxypyrrolidine – (pyrrolidine alkaloid)	Loncocarpus and Derris
	1,2-Dehydropyrrolizidine	*Chromolaena odorata*
	saponins and flavonoids	*Morinda lucida*
	flavonoids	*Acacia gummifera, Ceratonia siliqua, Ononis natrix, Tagetes patula*, and *Peganum harmala*
Cyanogenic glycosides	dhurrin	Sudangrass
	linamarin and lotoaustralin	cassava roots
	furostanol glycosides	*Dioscorea deltoidea*
	flavone-C-glycosides, namely, schaftoside and isoschafto side	Schott tubers
Glucosinolates and Isothiocyanates	allyl isothiocyanate	Brassica and Sinapis sp.
Limonoids, Quassinoids, and Saponins	tetranortriterpenoid limonoid	*Azadirachta indica*
	Quassinoids	Simaroubaceae family (*Quassia amara, Cassia camara*, and *Picrasma excelsa*)
	Saponins - medicagenic acid	*Quillaja saponaria*
	saponins	*Medicago sativa, Cestrum parqui*
	Triterpenic saponins	seeds of *Madhuca indica* and fruit pericarp from *Sapindus mukorossi*
Organic acids	pomolic acid, lantanolic acid, lantoic acid, camarin, lantacin, camarinin, and ursolic acid	*Lantana camara* Linn. var. *aculeata*
	nonessential amino acid L-3,4-dihydroxvphenylalanine (L-Dopa)	*Mucuna* spp.
Phenolics, Flavonoids, and Quinones	p-hydroxybenzoic acid, vanillic acid, caffeic acid, ferulic acid, and a quercetinglycoside, 7-glucoside	root leachate of L. *camara*
	methyl esters, and thiophenes (including α- terthienyl)	*Tagetes patula* L.
	magnolol and honokiol	*Magnolia tripetala*
Piperamides	capsaicin	*Capsicum frutescens*
Polyacetylenes and Polythienyls	polyacetylenes and polythienyls	*Tagetes* species
Terpenes	monoterpenes (C10), sesquiterpenes (C15), hemiterpenes (C5), diterpenes (C20), triterpenes (C30), and tetraterpenes (C40).	*Carum carvi, Foeniculum vulgare, Mentha rotundifolia*, and *Mentha spicata*
	2- undecanone	*Ruta chalepensis*
	Ascaridole	*Croton regelianus* and *Chenopodium ambrosioides*

e) Application of bio control agents

Exploitation of biocontrol agents is another option for organic growers in controllong PPNs along with cultural practices. The main limitation in this aspect is augmentative release of biocontrol agents. However, there are few commercial biocontrol agents such as bacterial and fungal pathogens available in market for organic growers. The efficacy of biocontrol agents is important in terms of no. of propagules (CFU- colony forming units) present per cc/g in the biocontrol agent's culture being used for fortification of FYM.

1 Bacterial pathogens

In soil rhizosphere, inside or outside roots various saprophytic bacteria are present that proved to be antagonistic to nematodes. The most commonly and widely studied group of beneficial bacteria that is present in plant zone is PGPR (plant growth promoting rhizobacteria), that enters the root zone, colonize and become endophytic (Hallman *et al*, 2001) [12]. Several bacterial species such as *Bacillus subtillis*, *B. sphaericus* and *Pseudomonas fluoresecens* are harmful to PPNs. Tian *et al.,* 2007 [38] has reviewed the different mechanisms proposed by rhizobacteria that release the nitrogenous compounds to nematodes inducing the systemic resistance to plants. *Pasteuria penetrans*, which is gram-positive, obligate endoparasitic bacteria on knot nematode as this can mass-produced on the nematode hosts (Sayre and Starr, 1985; Sterling 1984, Trudgill *et al.*, 2000) [33, 36, 41]. However, the main drawback lies with this is a high application rates in a large scale cropping systems. This problem can be resolved as they can effectively use in nursery bed treatment for managing *M. graminicola* in rice, seed treatment or its application along with castor cake in the root zone twice a year in fruit orchards like pomegranate.

2 Fungal pathogens

These parasites are of two types *viz.* obligate and facultative. Obligate fungal parasite are *Catenaria auxilarius* and *Nematophthora gynophila* which use their spores to initiate infection by adhering to the body of the nematode or being ingested and penetrating into the gastrointestinal tract (Kerry and Krump 1980) [15]. While the facultative parasites grows saprophytically in the soil producing the specialized spores or trapping structures such as rings knobs, nets, etc. and kill the nematodes by trapping them which inclues *Dactylella*, spp. *Dactylaria candida*, *Arthobotrys botryospora*, *Paeciliomyces lilacinus*, *Verticilium chlamydopsporium* and *Hirsutella rhossiliensis*. (Hallman *et al*., 2009 and Sterling, 2014) [11, 37]. But the main drawback that lies with this its performance in field which is limited by several biotic and abiotic factors like soil temperature, moisture, pH, texture etc., that affects their survival and establishment in the fields after applied commercially. In nematode control aspects, the fungal bioagent known as *Trichoderma viride* can be used as seed treatment along with neem seed powder kernel extract against *Rotylenchulus reniformis* in cowpea. Both the bacterial and fungal bioagents can be applied in combination like *P. fluorescens* and *T. viride* for seed treatment in lentil. For application, *T. harzianum* should have a minimum of 2×10^8 CFUs per cc, while *P. fluorescens* should contain 2×10^8 cells per cc. Recommendations included in package of practices of AICRP (All India Coordinated Research Project on Nematodes in Agriculture) regarding exploitation of biocontrol agents is soil application of *T. viridae* @ 20 g/m^2, mixed with neem cake/FYM/ vermicompost @ 100 g/m^2 in the beds for the management of root knot nematodes in tomatos grown in protected cultivation.

f) Soil solarization

Apart from nematodes in organic farming, plants are also infected by insects, fungi, weeds, etc., which are also soil borne like root knot nematode. Hence, anaerobic soil management practices as if flooding, soil solarization, *etc*. should employed. Nematodes especially root knot nematodes are controlled better using organophosphorus nematicides. Nevertheless, application in large quantity will lead to residual problems. So, this should replace with less destructive and non-chemical alternative methods like soil solarization. This should be involved in package of practices *i. e.* Integrated pest management (IPM). Most of the organic growers skip this simple technique. Solarization is farmer friendly approach as this method is cheap, easy possess ability, excellent chemical resistant, flexible, free from odor and toxicity.

Soil solarization is the use of plastic traps placed on the surface of the soil to a level that kills the soil borne pathogens, weeds and other soil dwelling pests (Gaur & Perry, 1991) [8]. This technique is applicable in areas with high summer temperatures, *i.e.* effective only where summers are predictably sunny and warm. Solarization is well documented as an appropriate technology for the control of soil borne pathogens and nematodes but the economics in purchasing and applying plastic restricts its use in high value crops. Polythene reduces the heat convection and water evaporation from the soil to the atmosphere. This forms the water droplets on the inner surface of the polythene film as a result its transmissivity to the long wave is highly reduced, resulting in better heating which will increase the thermal sensitivity of resting structures (Mehrer. 1979, Mehrer and Katan, 1980) [19].

This is done on smooth beds, which are free from debris or clods. The large clods should be broken up to enhance the heat conduction in soil. The soil surface should slightly moistened and covered with the transparent thin polythene sheet of 25-30 µm of thickness for 2-4 weeks period to heat the non-cropped soils and make the temperature lethal to nematodes (Gaur & Dhingra, 1991) [9]. Bricks should place the edges or heavy objects so that plastic cover is held tightly in place from blowing away. Control by solar heating is high in upper 30 cm of the soil and is very effective for shallow rooted and short season plants. As a result, this technique is not effective for those nematodes, which are residing in deeper soils *i.e*. below 12 inches soil because nematodes are mobile and can recolonize soils quickly. Hence, this application therefore requires yearly application. Soil solarization effectiveness depends upon total sunshine hours, soil type, soil moisture, soil texture, colour of soil, nematode species, thickness and transparency of polythene sheet *etc*. The thin polythene sheets are more effective than thick sheets due to better radiation transmittance. Black polythene sheets gets, heated by itself and is therefore less efficient in heating the soil than the transparent ones. The maximum temperatures attained in upper layer of soils.

Soil solarization is quite compatible with other methods of control like application of pesticides or bio pesticides and these combinations have been reported to prolong the efficacy of solarization. Low application of fungicides, herbicides, etc. can combined with soil solarization to achieve better pest control. The elevated temperatures, seems to increase the activity of the above active compounds. It can also be combined with the application of crop residues, green and animal manures and inorganic fertilizers. These materials will release the volatile compounds in the soil that kill the pests by stimulating the growth of beneficial soil organisms. *eg*, root knot nematode can almost be completely controlled by combining the above two techniques resulting in larger yields.

Summer solarization is very effective in managing nematodes in poly houses. During peak summers of every year the crop debris should be removed, thoroughly ploughed, surface should be leveled, slightly watered and covered with the transparent polythene sheet. For 2-3 weeks the polyhouses should not be opened and in the mean time the nursery preparation or bio control agents multiplication should be carried out. This technique is so effective that if it is done timely and precisely, there will be no need for the farmers to go for chemical applications. The availability of soluble organic matter and minerals like nitrate, ammonium, calcium chloride and magnesium ions were increased following solarization (Chen and Katan, 1980; Chen *et al*., 1981 and Chauhan *et aI*., 1988) [5, 6, 3]. The electrical conductivity of the soil solution is also increased though the rise may be greater in uncovered soil due to evaporation of moisture and upward toxic movement in the soil. Physical properties of soil viz., soil porosity and water holding capacity as well as chemical properties viz., total nitrogen, available nitrogen, phosphorus and potash were also increased in solarized soil compared to non-solarized soil (Patel, 1994) [23]. Thus, the increased solubilization of organic matter and enhanced availability of nutrients improve plant growth directly and may also increase their tolerance to pathogens.

The main drawback that lies with this method is that it is possible only in tropical and subtropical regions of the world and is economical in disinfecting small areas like nursery beds for producing nematode free seedlings, polyhouses and microplots. For example, the transparent plastic film of 25 µm thickness laid on the slightly irrigated soil two weeks during the month of May/June is recommended to control root knot nematodes and weeds in the nurseries growing tomato/capsicum/cucumber to increase the transplantable seedlings.

Picture: Field leveling and giving slight irrigation before application of plastic sheet

Picture: After application of plastic sheet, sealing the polyhouses by dropping the polythene cutains

Conclusions

Across the globe there is increasing concerns regarding food safety and environmental protection, hence there is demand for organically grown food. The success of the organic farm lies in the disease management, that depends on the exclusive agronomic practices and natural pesticides that has been discussed in this chapter to manage plant parasitic nematodes which is really a challenging aspect to the organic growers as feasible control methods are not available till todays date. Hence, the research aspects should more focused on the developing resistant or tolerant cultivars, which should at the suit the local conditions and satisfy the economic issues of the growers. Research and surveys should focused on the occurrence of parasitic nematodes in organic farms and the reactions of the nematodes on cultural practices, which will serve as valuable information in the science of nematology.

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