Review

Management of plant parasitic nematodes by means of organic amendment

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(Reçu le 10/03/2018; Accepté le 11/04/2018)

Abstract

Plant parasitic nematodes (PPN) are one of the major biological constraints in various economically important crops across the world. The use of nematicides as an effective means for the control of PPN can be environmentally hazardous. Alternatively, the utilization of organic amendments has been proposed as a suitable and economically feasible method for managing plant parasitic nematodes. In this review we provide information from across multiple studies on the use of soil organic amendment as a promising approach for suppressing plant parasitic nematodes, enhancing plant productivity, and promoting global food security.

Keywords: Nematodes, organic amendment, crops, nematicides.

Gestion des nématodes phytoparasites au moyen d'amendements organiques

Résumé

Les nématodes phytoparasites constituent l'un des principales contraintes biotiques dans la production de différentes cultures dans diverses régions du monde. L'utilisation de nématicides comme moyen efficace de lutte contre les NPP peut être dangereuse pour l'environnement. Alternativement, l'utilisation des amendements organiques a été proposée comme méthode appropriée et économiquement réalisable pour la gestion des nématodes phytoparasites. Dans ce travail, nous fournissons des informations provenant de multiples études sur l'utilisation de l'amendement organique du sol comme une approche prometteuse pour supprimer les nématodes phytoparasites, améliorer la productivité des plantes et promouvoir la sécurité alimentaire mondiale.

Mots-clés: Nématodes, amendement organique, cultures, nématicides.

INTRODUCTION

Plant parasitic nematodes (PPN) are one of the major biological constraints in the production of various economically important crops, distributed across the world and cause large losses. The annual global loss in horticultural crops due to PPN has been estimated at 8.8-14.6% of total crop production, equivalent to 100-157 billion US dollars (Abad *et al*., 2008; Nicol *et al*., 2011). These nematodes can be managed by cultural practices, chemical nematicides and resistant cultivars.

In intensive crop production systems, PPN have been controlled mainly by nematicides and chemical soil fumigants for decades. However, in recent years, several nematicides have been withdrawn from the market due to environmental and human health concerns. In addition, nematicides often do not provide long-term suppression of the pathogen.

In many cases, crop losses are reduced by the annual application of expensive and highly toxic soil fumigants or non-fumigant nematicides. These chemicals cause serious health and environmental hazards and therefore their application is not sustainable. In addition, the economic cost of chemicals is a major obstacle for many farmers. Therefore, there is a need for alternate management options against PPN.

Presently, researchers have diverted their attention to manage PPN through the use of organic amendments (Linford, 1939, Faruk *et al*., 2001) as one of the most promising solution to manage plant parasitic nematodes (Linford, 1939) and to improve soil fertility and structure.

In the last few years, there has been an increasing interest in using soil amendments and other composted materials to suppress plant parasitic nematodes (Akhtar and Malik, 2000). Organic amendments can be divided into two broad categories: (i) amendments that are cultivated *in situ* and are incorporated into the soil such as green manure, cover crops, crop residues, industrials wastes (oil seed cakes) or town wastes (ii) amendments transported from elsewhere into the field such as composted animal manure and composted yard material or animal waste.

MANAGEMENT APPROACH OF PPN

Compared to other pathogens, PPN are sometimes difficult to control because they live in the soil and possess a great ability to attack almost every part of the plant. Soil organic amendments can be successfully employed for the control of PPN. Many types of organic amendments such as nematicidal plants, compost, protein-rich wastes, animal and green manures have been examined for their effect on suppressing PPN (Oka, 2010). The use of organic amendments can reduce disease caused by nematodes directly by affecting soil properties and indirectly by improving plant growth, changing root physiology and enhancing populations of antagonistic microorganisms, and productivity (Adegbite and Adesiyan, 2005).

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NEMATICIDAL ACTIVITY OF PLANT EXTRACT

Most studies worldwide have focused on root-knot nematodes (*Meloidogyne spp.*; RKNs) that attack more than 2000 plant species causing galls on roots (Jones *et al.,* 2013). Thirteen new species of *Meloidogyne* have been identified in the last decade, totaling more than 100 recognized species in the genus (Elling, 2013) but only four *Meloidogyne* species (*M. javanica*, *M. arenaria*, *M. hapla* and *M. javanica*) are considered major plant pests worldwide (Hunt and Handoo, 2009).

Yield losses due to RKNs frequently cited for vegetables are 10 % (Koenning *et al*., 1999). For example, Sasser and Carter (1985) reported yield losses of 22-30 % on tomato due to *Meloidogyne incognita*. In Western Anatolia-Turkey, *Meloidogyne* spp. caused up to 80 % yield losses in processing tomato-growing areas (Kaskavalci, 2007). Similarily, yield losses that attained 30% in three highly susceptible vegetables crops (melon, egg-plant and tomato) have been reported by Sikora and Fernandez (2005). Verdejo-Lucas *et al*., (1994) reported yield reduction of 61% in tomato due to the density in soil of 4750 juveniles of 250 cm^{-3} of *M. javanica*.

Use of plant and their products is one of the economical and safe methods for controlling root-knot nematodes. These methods are low cost, easy to apply and also have the ability to improve soil texture and fertility (Feizi *et al*., 2014). Several plant-based products have been involved in plant–nematode interactions. These compounds include nematotoxicants, hatching inhibitors or stimulants, attractants and repellents (Chitwood, 2002). Toxic substances to parasitic nematodes have been identified in several plants (Akhtar and Malik, 2000; Oka, 2010). Different plant extracts have been evaluated in different studies for their nematicidal properties (Akhtar, 1999; Alam *et al*., 2002). Among plant extracts, cruciferous plants (*Brassica carinata, Brassica rapa*), velvet bean (*Mucuna spp*.), sunn hemp (*Crotalaria juncea*), *Eucalyptus*, marigold (*Tagete* spp.), Rakshak gold (a neem-based product), castor bean (*Ricinus communis*) and *Chrommelina* have been used successfully for controlling root-knot nematodes (*Meloidogyne* spp.) (Wang *et al*., 2002; Alam *et al*., 2002; Hooks *et al*., 2010; Mokrini et *al*., 2010; Umar *et al.,* 2010; Ansari *et al*., 2016). Several studies showed decreasing densities of root-knot nematodes after application of various types of organic plants (Table 1).

Adegbite (2003) reported that plant extracts that contain flavonoids and alkaloids were found to have ovicicidal property to *Meloidogyne* eggs. Jourand et *al.* (2004) reported that the use of leaf extract from *Crotalaria virgulata* reduced significantly root galls caused by root-knot nematodes (*Meloidogyne incognita*) in tomato. Plant extracts of thyme (*Thymus vulgaris*), *Eucalyptus* spp., sweet wormwood (*Artemisia obsinthium*), fennel (*Foeniculum vulgare*), peppermint (*Mentha spicata*) reduced hatching activity of *Meloidogyne incognita* (Ibrahim et *al*., 2006). A number of nematicidal compounds including phenolic and salicylic acids, were reported by Shaukat et *al.* (2002) in the aqueous extract of powdered shoot of *Argemone mexicana,* which caused mortality of *M. javanica*. In addition, Ali et *al.,* (2002) reported a significant mortality *in vitro* of *M. javanica* resulting from the use of the methanolic extracts of *Lantana camara.*

Several studies have shown the efficacy of many neem preparations to manage plant-parasitic nematodes, including root-knot nematodes (Chitwood, 2002; Adegbite and Adesiyan, 2005; Bharadwaj and Sharma, 2007; Oka et *al*., 2007; Ntalli et *al*., 2009; Mokrini et *al.,* 2010). In addition, several researchers reported high mortality of RKN by using different aqueous extracts of neem preparations (Aziz et *al*., 1995; Khurma and Singh, 1997; Akhtar, 2000). Fatoki and Oyedumade, (1996) showed that amendment of soil with neem leaves reduced significantly *Meloidogyne* in soil population. Ojo and Umar (2013) showed that the powder of cocoa bean reduced nematode population of *M. javanica* in tomato. Ashoub et *al*. (2010) showed that jojoba oil cakes can inhibit significantly *M. incoginta* reproduction, galls formation and egg masses production. Dongre and Sobita, (2013) showed that the extracts from Bael (*Aegle marmelos*), Eucalyptus (*Eucalyptus globus*), Congress grass (*Parthenium argentatum*) and Neem (*Azadirachta indica*) were found to be most effective in reducing the population of rice root knot nematode, *Meloidogyne graminicola* in rice and they concluded that these extracts increased the growth of the plants. Similarly, extracts of several plants including neem, castor bean, crotalaria, sesame (*Sesamum indicum*) and velvet bean, have been reported to be effective in controlling nematodes (Araya and Caswell-Chen, 1994; Chitwood, 2002; Alashalaby and Noweer, 2003).

Several studies were reviewed by Thoden et *al*. (2011) in which *Meloidogyne* spp. populations were increased by using several organic amendments and they explained this result by the interaction between several factors including the number of application per year, nematode community, soil infestation level and finally the composition of organic amendment. Goswami (1993) showed that populations of *Meloidogyne incognita* associated with cowpeas were lower in soil amended with *Azadirachta indica* than in dried and autoclaved soils. Several species of marigolds extracts (*Tagetes* spp.) including African marigold, *T. erecta*, the French marigold, *T. patula*, and the South American marigold, *T. minuta* were tested against several plant parasitic nematodes. These are effective in controlling nematodes (Bridge, 1996). Rangaswamy and Reddy (1993) reported that leaf extracts of *Tagetes patula* and indian mustard significantly reduced root galling and egg mass production of *Meloidogyne incognita* in green house trials. Several studies showed that the use of *Artemisia dracunculus, A. verlotorum, A. absinthium* reduced populations of both *M. incognita* (Dias *et al.,* 2000) and *Ditylenchus dipsaci* (Tim-chenko and Maiko, 1989).

NEMATICIDE ACTIVITY OF BOTANIC OIL

Several essential oils from medicinal and botanical plants have been found to be effective for controlling several plant parasitic nematodes including root-knot nematodes

Table 1: Different botanical plant extracts used for controlling plant-parasitic nematodes

Plant extracts	Used Plant Parts	Target nematode	Crops	Reference
Tagete erecta	Flower and root	*Meloidogyne incognita*	Tomato	Sankari Meena *et al*. (2010)
T. patula, T. erecta, T. minuta	Root	*Meloidogyne incognita*	-	Cannayane and Rajedran (2002)
T. erecta	Flower and root	*Meloidogyne incognita*	Tomato	Sankari Meena *et al*. (2010)
Melia azedarach	Leaves, seed	*Meloidogyne incognita*	Sunflower, Tomato, Cucumber	Singh et *al*. (2001); Mokrini et *al*. (2010); Nafiseh katooli et *al*. (2010)
Azadirachta indica	Leaves and seed	*Meloidogyne incognita*	Sunflower	Singh et *al*.(2001); Bharadwaj and Sharma (2007)
Tagete erecta ***Neem***	Leaves	*Meloidogyne javanica* *M. incognita*	Tomato Soybean	Abid and Maqbool (1991); Walia et *al*. (1994); Atungwu et *al*. (2009)
Argania spinosa	Oilcake and leaves	*Meloidogyne spp.*	Melon and cucumber	Azim (2005)
Murraya koenigii L	Leaves	*Meloidogyne incognita*	Tomato	Usman and Siddiqui (2011)
Vitex negundo L.	Leaves	*Meloidogyne incognita*		Usman and Siddiqui (2011)
Calotropis procera	Leaves	*M. incognita;*	Tomato	Tiyagi et *al*. (2009)
Thevetia peruviana	Leaves	*M. incognita;*	Tomato	Tiyagi et *al*. (2009)
Argemone maxicana and Solanum xanthocarpum	Leaves	*M. incognita; Rotylenchus reniformis*	Eggplant, cauliflower	Ajaz and Tiyagi (2003)
Karanj *(Millettia pinnata)* and Moutard	-	*M. incognita*	Tomato	Goswami and Meshram, (1991)
Subabool *(Leucaena leucocephala L.)*	Leaves	*M. javanica*	Tomato	Walia et *al*. (1994)
Gylricidia maculata, Ricinus communis, moringa oleifera	Leaves	*Radopholus similis*		Jasy and Koshy (1992)
Moringa oleifera	Leaves	*M. incognita*	Eggplant	Murslain et *al*. (2013)
Brassica campestris L.	Leaves	*M. chitwoodi; M. javanica*	Potato, Tomato	Mojtahedi et *al*.(1991); Oduor-Owino et *al*.(1993)
Bitter leaf and Cashew	Leaves and seeds	*M. incognita*		Umar and Aji (2013)
Castor bean *(Ricinus communis L.)*	Seed	*Meloidogyne spp.*	Tomato	Mokrini, (2005), Adomako and Kwoseh (2013)
Hunteria umbellata	Leaves	*M. incognita*	Cashew (*Anacardium occidentale*)	Okeniy et *al*. (2014)
Calotropis procera; Datura stramonium, Ricinus communis		*M. javanica*	Brinjal	Nandal and Bhatti (1990)
Cymbopogon citratus; Acacia alata; Acalypha ciliata; Ocimum gratissimum	Leaves	*M. incognita*		Olaniyi et *al*. (2005)
Bael *(Aegle marmelos)*, Jatropha *(jatropha curcas)*, Eucalyptus *(eucalyptus globus)*		*M. graminicola*	Rice	Mukesh and Sobita (2013)
Mexican marigold *(Tagetes minuta)*, Lantana *(Lantana camara)*	Leaves	*M. incognita*	Tomato	Taye et *al*. *(*2013)
Baker tree *(Milletia ferruginea)*	Seeds	*M. incoginta*	Tomato	Taye et *al*. (2013)
Calotropis	Seeds	*M. incognita; M. javanica*	*Cicer arietinum*	Maheswari et *al*. (1997)
Datura stramonium; Azadirachta indica; Crotolaria juncea	Leaves	*M. incognita*	Mulberry	Nelaballe and Mukkara (2013)
Datura fastuosa, Bougainevillea glabr, Calotropis gigantia, Ocimum sanctum, Allium cepa	Leaves	*M. incognita*	Pigeon pea	Upadhyay et *al*. (2007)
Datura stramonium	Leaves	*M. javanica*		Parihar et *al*. (2012)
Cassia tora* and *Morus alba	Leaves	*M. incognita*	Chickpea	Tanweer et *al*. (2009)
Crotalaria virgulata	Leaves	*M. incognita*	Tomato	Jourand et *al*. (2004)
Chrysanthemum coronarium	-	*Meloidogyne spp.*	Tomato	Bar-Eyal et *al*. (2006)
Cassava peelings, cocoa pod husk and rice husk	-	*Meloidogyne spp.*	Cowpea	Egunjobi and Olaitan (1986)
Turmeric *(Curcuma longa)*; Marwa tulsi *(Origanum majorana)*, Mint *(Metha arvensis)*	Leaves	*M. incognita*	-	Goel et *al*. (2017)
Wild spinach *(Solanum nigrum L.)*, Ivy gourd *(Coccinia grandis)*	Seeds and leaves	*M. incognita*	Tomato	Asif et *al*. (2016)
***Tagete patula*, Indian mustard**	Leaves	*M. incognita*	Tomato	Rangaswamy et *al*. (1993)

in vegetables (Oka *et al*., 2000; Park *et al*., 2005; Sivakumar and Gunasekatan, 2011; Table 2). The essential oils *Foeniculum vulgare*, *Mentha rotundifolia*, neem, azadirachtin and nimbin, salannin showed the highest nematicidal activity in vitro and those from *Coridothymus capitatus* and *Origanum vulgare* reduced significantly root-galling caused by RKN of cucumber seedlings when mixed with sandy soil (Akhtar, 2000; Oka *et al*., 2000). Abd-Elgawad and Omer (1995) reported that the essential oils of four medicinal plants *Mentha spicata, vulgaris, Majorana bortensis* and *Mentha longifolia* increased nematode mortality. Meyer *et al*., (2008) showed that volatiles of clove oil reduced the number of *Meloidogyne incognita* in vitro. Similarly, Neem oil based formulation controlled *Meloidogyne incognita* associated with tomato and chickpea (Javed *et al*., 2008; Akhtar and Mahmood). Pendey (2000) reported that the oils of *Eucalyptus citriodora,* and *Ocimum basilicum* had significant impact on the control of *Meloidogyne incognita*, however these three oils were highly toxic even at lower concentration (250 ppm). Nafiesh *et al*., (2010) concluded that castor bean and chinaberry reduced the population of *M. incognita* in soil (Nafiesh Katooli *et al*., 2010). Vouyoukalou and Stefanoudaki (1998) showed that egg masses and root galling caused by both *M. javanica* and *M. incognita* were reduced after application of waste water from the olive oil to the soil. The same result was also obtained when fresh olive was incorporated into the soil (Rodriguez-Kabana *et al*., 1992; 1995). Goswami (1993) showed that the mustard oil-cake affected the mortality of *M. incognita*.

ANIMAL MANURE AND ITS COMPOSTS

Composted animal manures have been evaluated in several studies for their capacity to control various plant parasitic nematodes (Akhtar and Mahmood, 1996; Renčo *et al*., 2009; 2011; D'Addabbo *et al*., 2011). A positive relation between the application of compost and the control of PPN was reported in several studies (McSorley and Gallaher, 1996; Everts *et al.,* 2006). Kerkeni *et al.,* (2007) reported that different composts prepared from poultry, sheep, cattle and horse manures reduced significantly the population of *Meloidogyne incognita* and galling index on tomato roots due to the presence of predatory nematodes. De Jin *et al.,* (2005) showed that compost contains chitinolytic bacteria producing enzymes, like chitinase, that suppress plant parasitic-nematodes in tomato plants and reduce their population. They concluded that the level of nematode suppression depends on several factors including the maturity of the final product, the type of composting process, the application rate and the nematode species (Rivera and Aballay, 2008; McSorley, 2011).

Numerous studies have reported the effect of microorganisms on nematode suppression in soils after application of animal manures (Oka, 2010; Kaplan and Noe, 1993). Wachira *et al.,* (2009) showed that the number of fungi increased in soil resulting from application of chiken manure. Ismail *et al.,* (2006) obtained highest suppression of *Rotylenchulus reniformis* with lower C/N ratio in soil amended with composts. Gonzalez and Canto-Saenz, (1993) reported that chicken and steer manures reduced the numbers of citrus nematodes and potato cyst nematodes and increased their yields. El Hajji and Horrigne-Raouani (2012) reported that incorporation of cattle manure (70 T/ha) improved potato growth and decreased the multiplication rate of *M. javanica.*

CONCLUSION

Accumulating evidence show that the use of soil organic amendments, such as green manures, animal manures, composts or slurries, has the potential to be part of plant health management scheme by improving soil quality and suppressing plant-parasitic nematodes. The beneficial effects of organic incorporation have been generally considered to be due to increase in soil nutrients, improvement in soil physical and chemical properties, and direct or indirect stimulation of predators and parasites of phytoparasitic nematodes; though some recent studies reported an increase of plant-parasitic nematodes after the use of organic amendments. Further research is needed to determine the mechanisms that underpin suppression of plant-parasitic nematodes. Overall, organic amendments hold significant promise for effectively promoting sustainable agriculture. Their use as a means for managing plant parasitic nematodes can be synergistically improved by making combination with other cultural and biological nematode management strategies.

Table 2: Different oil cakes used against plant-parasitic nematodes

Botanical oils	Target nematode	Crops	Reference
Chinaberry and castor bean	*Meloidogyne incognita*	Cucumber	Katooli *et al*., (2010)
Clove	*M. incognita*	-	Meyer *et al., (*2008)
Neem	*M. incognita*	Tomato; Chickpea	Akhtar and Mahmood (1997); Javed *et al., (*2008)
Mustard, neem and groundnut	*M. incognita*	Eggplant	Alam *et al.,* (1980)
Neem, castor, sunflower	*M. incognita*	Chichpea	Tiyagi and Ajaz (2004)
Groundnut, Sunflower and Soybean	*Plant parasitic nematodes*	Chichpea	Rizvi *et al*., (2012)
Brassica s*pp.*	*Tylenchulus semipenetrans*	Citrus	Sinha and Neog (2002)
***Melia azadirachta* and *Brassica* spp.**	*M. incognita*		Katooli *et al*., (2010)
Neem	*M. incognita*		Dourado *et al*., (2013)
Clove	*M. incognita*		Meyer *et al.,* (2008)
Fennel, apple mint, syrian oregano and oregano	*Meloidogyne spp.*		Oka (2000)
Neem, cotton, linseed	*M. incognita*	*Vigna mungo*	Rehman *et al*., (2014)
Neem, mustard, cotton	*M. javanica*	Brinjal	Barihar *et al*., (2015)
Castor, neem, *Simarouba glauca*	*M. graminicola*	Rice	Prassad *et al.,* (2005)

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