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Antagonistic plants as a tool of nematode management

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Abstract
Plant parasitic nematodes are nearly microscopic worm shaped organisms. The damage caused by them ranges from negligible injury to total destruction of the plant. The extent of direct damage by the plant parasitic nematodes to the crops depends on several factors. Overall average annual loss of the world's major crops due to the damage of plant parasitic nematodes was estimated to be 12.3%. The present practices of nematode management mostly rely on the combined use of various cultural and biological methods, which aimed at long-term nematode management considering the ecological and economic conditions. Among such management practices the use of various antagonistic plants is found to be quite effective. Plants like *Crotolaria,* marigold (*Tagetes* spp.), Neem (*Azadirachta indica*), species of *Brassica* have already been identified as having antagonistic effects to the plant parasitic nematodes. This review highlights the effect of different antagonistic plants against plant parasitic nematodes and the efficient ways for their incorporation.

Keywords: Antagonistic plants, nematode management, plant parasitic nematodes, yield loss

Introduction
Plant parasitic nematodes cause significant damage to a wide range of crops each and every year. Nematode infestation reduces the yield as well as quality of the produces. For sustainable production of food, effective management of nematode is very essential. Antagonistic plants play a great role in nematode management. Plants considered to be antagonistic are those that negatively affect the population of nematodes, like trap plants, unfavorable hosts and those containing nematicidal/nematostatic compounds in their tissues, which can be released into the external environment or act only within the plant (Ferraz and Valle, 1997 cited by Moreira *et al*., 2015) [8, 22]. These plants not only serve to control the infestation of plant parasitic nematode, but can also be used as green cover, organic matter, or for improving the general quality of the soil (Moreira *et al*., 2015) [22].
Various nematicidal substances can be isolated from the antagonistic plants. The botanicals of the antagonistic plants can provide novel compounds that nematodes are not yet able to inactivate. Moreover these are less concentrated than the pure compounds which make them less toxic than the pure ones. They are also more biodegradable as compared to the pure compounds. This makes them environment friendly. Many crops have already been identified as having the anti-nematode properties but their proper effective incorporation methods are yet to be determined. This paper reviews the commonly available plants having the anti-nematode properties and their different utilization methods which have already been studied.

Marigold (*Tagetes* spp)
Marigold is a very popular ornamental crop. It is found to be having nematicidal compounds and have been widely utilized for the nematode management purpose. It specially controls root-knot nematode, *Meloidogyne* spp. Marigold releases a nematicidal compound called alpha-tertheinyl, which reduces the nematode population. Alpha-tertheinyl is released only by active living marigold roots and gets inactivated in exposure to near ultra violet light when taken out of the soil. That is why it is not advisable to incorporate the marigold plant extracts. For effective nematode management, marigold should be planted as cover crop before planting the main crop. It should be planted at least two months prior to the desired crop. In order to get long lasting effect on nematode population, marigold cultivation should be done every year before planting of the main crop. Dense planting provides better results.
Vergel *et al.* (1979) [39] found significant reduction on the plant parasitic nematode population in the rhizosphere of tomato plants when grown in combination with marigold (*T. erecta* and

T. patula). Siddiqi and Alam (1987) [32] found that *T. minuta* reduces the infestation of root-knot nematode, *M. incognita* in tomato and brinjal. Abid and Maqbool (1990) [1] found that there was less number of galls in the tomato inoculated with *M. javanica* when grown with *T. erecta* in comparison to the plants grown without *T. erecta*. Prasad *et al.* (1992) [24] found that there was reduced number of plant parasitic nematode population (*Meloidogyne* spp, *Hoplolaimus indicus* and *Tylenchulus vulgaris*) in the brinjal field, which was intercropped with *Tagetes* spp. Walia and Gupta (1997) [42] found that leaves extract of old marigold plants inhibited the hatching of second stage juveniles (J_2) as compared to control. Verma and Ali (1999) [40] studied the effect of marigold intercropped with pointed gourd in *M. incognita* infested field. They found that there was reduced number of galls and egg masses on the root system of pointed gourd. They also found that marigold variety Saffron Spice was most effective in reducing galls and the least effective variety was Yellow Gate. Sundararaju (2003) [35] conducted an experiment at the banana field on banana cv. Nendran (AAB) infested with root-lesion nematode, *Pratylenchus* and found that there was maximum reduction in root-lesion index and nematode population when *T. erecta* was grown as intercrop. Verma (2006) [41] studied the effect of intercropping of marigold (*T. erecta*) with field pea (*Pisum sativum* cv. Jayanti) against root-knot nematode infestation. The increase in yield over the control (without marigold intercropping) reached 24.4% and number of galls and egg masses were also significantly less.

Sunn hemp (*Crotolaria juncea*)

C. juncea has number of beneficial qualities. It is mostly used as green manuring crop to increase soil organic matter and nitrogen content. In addition, it is particularly versatile for nematode management. *Crotalaria juncea* is a poor host to many important plant-parasitic nematodes, including *Meloidogyne incognita* (McSorley, 1999; Santos and Ruano, 1987) [21, 31], *M. javanica* (Araya and Caswell-Chen, 1994; McSorley, 1999; Silva *et al.* 1990) [3, 21, 34], *M. arenaria* (McSorley, 1999) [17], *Rotylenchulus reniformis* (Caswell *et al*., 1991; Silva *et al*. 1989; Wang *et al*., 2002) [5, 33,44], and *Pratylenchus brachyurus* (Charchar and Huang, 1981) [6]. *C. juncea* enhance the activity of some nematode antagonistic microorganisms when incorporated into the soil (Quiroga-Madrigal *et al*., 1999; Rodrı´guez-Ka´bana and Kloepper, 1998; Wang *et al*., 2001) [25, 30, 43]. Sunn hemp produces monocrotaline, which is toxic to many plant parasitic nematodes (Rodriguez-Kabana *et al*., 1992; Wang *et al*., 2001; Jourand *et al*., 2004) [30, 43, 13]. Marahatta *et al.* (2012) [19] found that *C. juncea* suppressed the population of reniform nematode, *R. reniformis* and weeds while enhancing free living nematode population which are involved in nutrient cycling. Patel and Dhillon (2017) [23]. studied the allelopathic properties of *C. juncea* and time period for better degradation for the management of root-knot nematode, *M. incognita* found that maximum galling index and decrease in growth parameters were observed when degradation period was given of 10 days or after. This indicates that *C. juncea* requires 10-20 days for decomposition due to which the availability of nutrients and release of allelopathic products happens to occur after 10 days.

Neem (*Azadirachta indica*)

Neem is known to contain effective nematicidal properties. The extracts of seed, leaves, roots and bark generally contain chemical compounds, some of which are found to be effective against nematodes. Nemato-toxic compounds of the neem plant, especially the azadirachtins, are released through volatilization, exudation, leaching and decomposition. Hasan and Saxena (1974) [10] found that soil amended with oil cakes greatly suppressed the hatching of *Meloidogyne incognita* juveniles, where neem oil cakes and mustard cakes found to be most effective followed by groundnut, mahua and castor cakes. Hussain and Masood (1975) [12] studied the effect of various plant extracts on larval hatching of *M. incognita* and reported complete inhibition of hatching of eggs of *M. incognita* in the leaf extracts of *A. indica* (L.) and *Chenopodium anthelmenticum* (L.). Devakumar *et al.* (1985) [7] found that nematicidal principles form neem were highly active against root-knot nematode, *M. incognita*. Lee (1990) [17] studied the effect of *Melia azedarach* on *M. incognita* and found that seed and leaf extracts of *M. azedarach* inhibited the hatching of eggs and embryonic development of root-knot nematode. Akhtar and Mahmood (1997) [2] used neem oil based formulations against *M. incognita* as seed treatment and bare root dip treatment as varying degrees of success. Sundararaju and Kumar (2000) [36] reported that there was significant increase in yield and reduction in population of *Pratylenchus coffeae* on banana when banana plants were treated with 50 percent of N applied by neem cake. Sudararaju *et al.* (2003) [35] studied the efficacy of various botanicals against root-lesion nematode, *P. coffeae* on banana. They found that among the applied botanicals *A. indica*, *Calotropis procera*, *Datura stramonium*, *Crotolaria juncea* and *Vitex negundo* were found to be superior and effective in reducing the nematode population and increasing the yield significantly.

***Brassica* spp.**

Brassicaceae family plants are found to have potential nematicidal properties when used as biofumigant. They produce glucosinolates. These glucosinolates compounds breaks down into various allelochemicals and incorporated into soil and it controls soil borne pests and nematodes (Hafez and Sundararaj, 2001; Lazzeri *et al*., 2004; McSorely *et al*., 1997; Riga *et al*., 2004) [11, 16, 20, 26]. The fumigant effect of decomposing Brassicaceae plants is believed to be the result of chemical reactions that result in the formation of biologically active products (Underhill, 1980) [38]. Riga *et al*. (2011) [28] conducted a greenhouse experiment and field trials in three seasons, they found that Brassica green manures in combination with half the recommended rate of 1,3-dichloropropene (1,3-D, Telone) reduced root knot nematode, *Meloidogyne chitwoodi* to below detection levels, and reduced lesion nematodes, *Pratylenchus penetrans* and stubby root nematodes, *Paratrichodorus allius,* to below economic threshold levels. Karavina *et al.* (2015) [14] carried out an experiment at glasshouse to determine the efficacy of different glucosinolate sources (rape, radish, mustard and cabbage) and brassica formulations (cake, extract and unmacerated) in suppressing *M. javanica* population on tomato. The results showed that mustard was the most effective brassica in controlling nematodes, while cabbage, radish and rape significantly reduced *M. javanica* population when compared to the untreated control.

Lantana camara

Lantana camara is an invasive weed usually found on the road side and fallow land. Many people have reported the nematicidal properties of this weed. Begum *et al.* (2000) [4] isolated two new constituents, lantanoside and lantanone and

the known compounds linaroside and camarinic acid from the aerial parts of *L. camara*. Lantanoside, linaroside and camarinic acid were tested for their nematicidal activity against *Meloidogyne incognita*. The results showed 90, 85, and 100% mortality, respectively, at 1.0% concentration. Ghimire *et al.* (2015) [9] studied the nematicidal potency of various concentrations of *L. camara* leaf extract. It was found that 50% concentration of *L. camara* leaf extract at 48 hrs and above was found detrimental to root-knot nematode. Karim and Samsi (2019) [15] studied the efficacy of *L. camara* and *Parthenium hysterophorus* against *M. incognita*. Between two plant species, *L. camara* was found to be more effective causing 83% mortality at 40% concentration of extracts and *P. hysterophorus* caused 81.5% mortality of the nematode at the same concentration (40%).

Conclusion

Nematodes are one of the most devastating pests of wide range of crops. The efficacy of different antagonistic plants in nematode management has been found to be fruitful. Still there are many plants whose efficacy is yet to be explored against nematode. There must be suitable incorporation methods to get the best results. Farmers should also be made aware of the utilization of these antagonistic plants to have a sustainable production.

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