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Oil-Cake Amendments: Useful Tools for the Management of Phytonematodes

Aisha Sumbul, Rose Rizvi, Irshad Mahmood and Rizwan Ali Ansari
Section of Plant Pathology and Nematology, Department of Botany, Aligarh Muslim University, Aligarh, 202002, India

Corresponding Author: Aisha Sumbul, Section of Plant Pathology and Nematology, Department of Botany, Aligarh Muslim University, Aligarh, 202002, India

ABSTRACT
In the present review, an attempt was made to compile the data available across the world befitting the management practices of phytonematodal disease using oil-cakes. Some of the data of oil-cakes have also been shared herein, which were applied along with other beneficial microbes, such as; bacterium and fungi. Analyzed data propounded that utilization of oil-cakes against economically important nematode problems, such as *Meloidogyne* spp. are very enthusiastic. Oil-cakes have been used by different workers in different forms such, as crude oil-cake, aqueous extracts, powdered oil-cake etc and both *in-vitro* as well as *in-vivo* studies were carried out to see the effect of oil-cakes on phytonematodes. The oil-cakes such as mustard, neem, castor, karanj, groundnut, mahua and sesame gave their best to manage the disease in glass house and in field condition as well. Currently, researchers are looking for ecofriendly and biodegradable alternatives to chemical pesticides for the control of phytonematodes. Present review concluded oil-cakes to be the best option so far against phytoparasitic nematodes not only because of its ease of availability but also economical feasibility for the growers/farmers entrepreneurship. However, mechanisms of action of oil-cakes in relation to PPN is very less understandable and therefore yet to be fully explored.

Key words: Oil-cakes, plant parasitic nematodes, neem

INTRODUCTION
Plant parasitic nematodes are one of the major biological constraints in the production of various economically important crops, distributed across the world and cause huge losses. The annual global loss in horticultural crops due to PPN has been estimated as 8.8-14.6% of total crop production and 100-157 billion US dollars worldwide in terms of money (Sasser and Freckman, 1987; Koenning *et al*., 1999; Abad *et al*., 2008; Nicol *et al*., 2011). Phytonematodes are obligate parasites and mainly attack the underground parts of the plants such as roots, bulbs, corms, rhizomes etc and incite hindrance with water uptake and transport. Some PPN can also infect aboveground parts such as leaves, buds, flowers etc. Phytonematodes not only have negative impact on plant growth but also interfere in the nodulation, nitrogen fixation and suppress the overall yield of plants. In addition to direct harm, nematodes also affect the plant health indirectly. They act as virus-vectors and also make the plant vulnerable to attack by several other pathogens such as bacteria and fungi. Presence of root-knot nematode makes the *Fusarium* wilt resistant cultivar of cotton susceptible to fungi (Atkinson, 1892).

The control of PPN is a big challenge before the researchers as well as policy makers as they inhabit the soil along with other beneficial/non-target organisms (Akhtar, 1997). Most of the times damages caused by phytonematodes are confused with nutritional deficiency and thus are difficult to deal with. Currently, major methods of controlling PPN are by the use of chemical nematicides, cultural practices and the growing of resistant cultivars. Today, in order to meet the growing demands of vigorous cultivation, application of chemicals has enormously been increased, which has resulted not only in the contamination of ground and surface water but has also interfered with soil biota. In a view of avoiding possible health and environmental hazards, the use of many prevalent nematicides like Dibromochloropropane and Ethylene dibromide have been totally banned. Methyl bromide, the most effective and widely used fumigant for soil-borne diseases and weeds, including nematodes has already been prohibited in some countries and its complete withdrawal from the market is being planned for most countries by international agreements (Anonymous, 1997). Such circumstances, as deregistration of many pesticides and contamination of the biosphere have inducted the need for newer methods to manage nematode problems and subsequently improving crop productivity. Now the growers are forced to use the options of nematode control which do not cause pollution or otherwise lead to undesirable side effects such as deterioration of environment, hazard to human health and harmful effects on non-target organisms (Duncan, 1991) and involve the materials which are biodegradable in nature (Tiyagi and Ajaz, 2004).

Organic farming has strongly attracted the growers, being an important priority area in view of the growing demand for safe and healthy food and long term sustainability that concern on environmental pollution associated with indiscriminate use of pesticides (Renco, 2013; Tiyagi *et al*., 2015). Though the use of chemical inputs in agriculture are inevitable to meet the growing demand for food in the world, there are many opportunities in selected economically important crops and surrounding habitats where organic production can be encouraged to meet the domestic demand. Organic sources are effective option as a source of macro and micronutrients and have required potential to improve yield and to save environment from chemical fertilizers. One important change resulting from the addition of organic matter is a potential increase in available nutrients, including an increase in organic carbon (Guidi *et al*., 1988), potassium, calcium and magnesium (Bengston and Cornette, 1973; Duggan and Wiles, 1976; May *et al*., 1973). Organic matter can also change the level of available nitrogen in the soil.

Organic amendment is of paramount importance in the management of plant diseases also. It can result in control of plant-parasitic nematodes (Siddiqui *et al*., 1976; Alam, 1991), by improvements of soil structure and fertility, alteration of the level of plant-resistance, release of nemato-toxic compounds and instigating the activities of microorganisms that are antagonistic to phytonematodes (McSorley and Gallaher, 1995; Pera *et al*., 1983; Oka, 2010). A number of organic additives of plant origin, including oil-cakes, chopped plant parts and seed dressing made from plant extracts, have been used to control nematodes (Muller and Gooch, 1982; Tiyagi *et al*., 1988; Akhtar and Alam, 1993). Present review article is a step towards the direction to update the available information on the use of oil-cakes in the management of PPN as much as possible to our best knowledge.

UTILIZATION OF OIL-CAKES IN CONTROLLING PLANT PARASITIC NEMATODES

Amongst various organic amendments, the oil-cakes of several plants have been found to be effective against phytonematodes (Goswami *et al*., 2007; Ashraf and Khan, 2007). Oil-seed cake refers to a compacted mixture of the meal remaining after vegetable oils has been extracted from seeds such as cotton seed and groundnut etc. These are rich in protein and minerals and are valuable as poultry and other animal feed. Oil-cakes from certain seeds such as castor beans and tung nuts are toxic to various kinds of harmful microbes and are used as fertilizers rather than feed. It is of common practice among food and vegetable growers to use oil-cakes as a source of plant nutrients and to control nematodes. Oil-cakes can be applied to the soil directly in the form of powder or pellets, watered and allowed to decompose. As the decomposition time increases, their nematicidal effect increases. Seeds of plants can also be treated with extracts of oil-cakes before sowing in order to protect the crop from nematodes.

This trend is recently receiving greater interest among nematologists, providing effective control against the target nematode and avoiding environmental pollution (Singh *et al*., 1980; Burman *et al*., 1995; Youssef and El-Nagdi, 2010; El-Sherif, 1984; El-Sherif *et al*., 2006, 2010).

Effect of oil-cakes on survival of nematodes *in-vitro*: Nematicidal properties of aqueous extracts of oil-cakes or soil amended with oil-cakes in the absence of plants have been proved to be challenging. Water soluble fractions of oil-cakes extracted from neem, mahua, groundnut and castor were toxic to nematodes like *Hoplolaimus indicus*, *Rotylenchulus reniformis* and *Tylenchorynchus brassicae* and inhibited the larval hatching of *M. incognita* (Khan *et al*., 1974a). Similarly, the larval hatching of *M. incognita* was suppressed significantly by boiled extracts of mustard and cotton oil-cake up to 99.92 and 99.38% in water. Eggs of *M. incognita* were found to be more vulnerable to oil-cakes (neem, karanj, mahua, groundnut, cotton, linseed, sesamum and kokam) and fungicide (Ceresan wet and Aureofungin-sol) treatment than larvae (Lanjeswar and Shukla, 1986). Neem cake extract was found to be most effective in killing *M. incognita* larvae (Gowda and Setty, 1978; Gowda and Gowda, 1999) whereas, mustard cake extract proved to be most effective in controlling *Hoplolaimus indicus* (Deshmukh and Prasad, 1969). However, greater concentrations of oil-cake extract shown best results due to the presence of higher nematotoxic compounds.

Nematode suppression by oil-cakes in soil: Previous results have shown that application of oil-cakes has achieved a lot of success in controlling nematodes in the soil. Goswami *et al*. (1993) reported that decomposed products of groundnut, mahua, mustard, karanj and neem oil-cakes affected the mortality of *M. incognita*. Mustard cake was found to be most nematotoxic even from the first week. In another experiment, Khan and Goswami (1995) showed that the mortality of *M. incognita* juveniles increased with increasing decomposition period of neem cake up to 20 days, thereafter showing a decline. Gutpa and Kumar (1997) found that groundnut and mustard cakes reduced the populations of *Tylenchorynchus* spp. and *Helicotylenchus* spp. in pot experiments. Interestingly, reduction level increased at higher dosages and the longer periods of treatment. Effect of temperature on decomposition of margosa cake and on the survival of *Tylenchorynchus elegans* was assessed by Sitaramaiah (1979). He reported that nematode population was significantly reduced in the amended soil at 20°C and above. Nagesh *et al*. (2001) reported that supplementing neem oil-cakes with inorganic fertilizers as nitrogen, phosphorus and potassium, had an additive effect on the mycelial growth and sporulation of *P. lilacinus*, increasing the antagonistic potential of *P. lilacinus* against *M. incognita* (Table 1).

Table 1: Documented suppression of phytonematodes by the use of different oil-cakes

Crops	Oil-Cakes	Nematodes	References
Black gram (*Vigna mungo*)	Castor	*Rotylenchulus reniformis*	Kannan *et al*. (1987)
	AMF (*Glomus fasciculatum*)+neem, mahua, castor and groundnut	*Meloidogyne incognita*	Sankaranarayan and Sundarababu (1997)
Chickpea (*Cicer arietinum*)	Neem, castor, groundnuts, linseeds, sunflower and soybean	*Meloidogyne incognita*	Tiyagi and Ajaz (2004)
	Neem, karanj	*Meloidogyne incognita*	Yadav *et al*. (2005)
	Neem	Plant parasitic nematodes	Pandey and Singh (1990)
	Pseudomonas fluorescens+neem, castor, linseed, groundnut, sunflower and soybean	Plant parasitic nematodes	Rizvi *et al*. (2012)
Cow pea (*Vigna unguiculata*)	Cotton, sunflower	*Rotylenchulus reniformis*	Yassin and Ismail (1994)
	Neem	Plant parasitic nematodes	Latif *et al*. (1999) and Umar and Simon (2008)
French bean (*Phaseolus vulgaris*)	Neem	*Rotylenchulus reniformis*	Padhi and Misra (1987)
Lentil (*Lens culinaris*)		Plant parasitic nematodes	Tiyagi *et al*. (2001)
Mung bean (*Vigna radiata*)	Mustard, neem, castor and duan	PPN (*M. incognita*, *Rotylenchulus reniformis*, *Tylenchorhynchus brasscae*, *Helicotylenchus indicus*)	Tiyagi and Alam (1995)
	Neem	*Helicotylenchus*, *Tylenchorynchus* and *Pratylenchus*	Prasad *et al*. (1974)
Pigeon pea (*Cajanus cajan*)	Neem, mustard, linseed	*Heterodera cajani*	Singh (2004)
	Neem, sesamum, mustard, cotton and castor	*Heterodera cajani*	Meena *et al*. (2009)
Soybean (*Glycine max*)	Mustard, neem, linseed, mahua and castor	*Meloidogyne incognita*	Mishra and Gupta (1997)
Maize *(Zea mays)*	Neem	*Tylenchorhynchus*, *Helicotylenchus* and *Pratylenchus*	Prasad *et al*. (1974)
Rice (*Oryza sativa*)	Castor, neem and *Simarouba glauca*	*Meloidogyne graminicola*	Prasad *et al*. (2005)
Wheat (*Triticum aestivum*)	Neem	*Tylenchorhynchus*, *Helicotylenchus* and *Pratylenchus*	Prasad *et al*. (1974)
	Fertinemakil (neem cake+fungicide)	Plant parasitic nematodes	Khan *et al*. (2007)
Cabbage (*Brassica oleracea* var. *capitata)*	Mahua, castor, mustard, neem and groundnut	Plant parasitic nematodes	Alam (1991)
Cauliflower (*Brassica oleracea* var. *botrytis*)	Mahua, castor, mustard, neem and groundnut	Plant parasitic nematodes	Alam (1991)
Chilli (*Capsicum annum*)	Mahua, castor, mustard, neem and groundnut	*Meloidogyne incognita*	Alam *et al*. (1980)
	Mahua, castor, mustard, neem and groundnut	Plant parasitic nematodes	Alam (1991)
	Groundnut, sesame, mustard and duan	*Meloidogyne incognita*	Trivedi *et al*. (1978)
	Pasteuria pentrans+neem, castor, mustard and citrullus	*Meloidogyne incognita*	Chaudhary and Kaul (2013)
Egg plant (*Solanum melongena*)	Mahua, castor, mustard, neem and groundnut	*Meloidogyne incognita*	Alam *et al*. (1980)
	Mahua, castor, mustard, neem and groundnut	Plant parasitic nematodes	Alam (1991)
	Neem, groundnut and castor	*Meloidogyne incognita*	Khan *et al*. (1974b)
	Mustard	*Meloidogyne incognita*	Husain *et al*. (1984)
	Undi	*Meloidogyne incognita*+ *Fusarium solani*	Mittal and Goswami (2001)
	Fennel, sesame and anise	*Meloidogyne incognita*	El-Sherif *et al*. (2006)
	Paecilomyces lilacinus+groundnut, neem, linseed, castor	*Meloidogyne javanica*	Ashraf and Khan (2010)
	VAM+neem	*Meloidogyne incognita*	Borah and Phukan (2004)
	AMF+neem, mustard and castor	*Meloidogyne incognita*	Bhardwaj and Sharma (2006)
Okra (*Abelmoschus esculentus*)	Mahua, castor, mustard, neem and groundnut	Plant parasitic nematodes	Alam (1991)
	Neem, groundnut and castor	*Meloidogyne incognita* and *Tylenchorynchus brassicae*	Khan *et al*. (1979)
	Neem, castor, mustard and rocket salad	*Rotylenchulus reniformis*	Anver and Alam (1996)

Table 1: Continue

Crops	Oil-Cakes	Nematodes	References
	Castor, neem, mustard, groundnut and duan	(PPN) *Hoplolaimus indicus*, *Rotylenchulus reniformis*, *Tylenchulus filiformis*, *Tylenchorynchus brassicae* and *Meloidogyne incognita*	Siddiqui and Alam (1987)
	Neem, mustard and castor	*Meloidogyne incognita*	Ram *et al*. (2009)
	Groundnut, castor, sunflower and linseed	*Meloidogyne incognita*	Ganaie *et al*. (2011)
	Mustard	*Meloidogyne incognita* and *Meloidogyne javanica*	Patel *et al*. (1985)
Pointed gourd (*Trichosanthes dioica*)	Neem	*Meloidogyne incognita*	Chakraborti (2000)
Potato *(Solanum tuberosum)*	Neem	*Meloidogyne incognita*	Sharma and Raj (1987)
Squash *(Cucurbita* spp.*)*	Sesame	*Meloidogyne incognita*	Youssef and El-Naghdi (2010)
Tomato (*Solanum lycopersicum*)	Mahua, castor, mustard, neem and groundnut	*Meloidogyne incognita*	Alam *et al*. (1980)
	Mahua, castor, mustard, neem and groundnut	Plant parasitic nematodes	Alam (1991)
	Mustard	*Meloidogyne incognita*	Hameed (1968)
	Neem	*Meloidogyne incognita*	Goswami and Swarup (1971), Verma (1986), Bhattacharya and Goswami (1987b), Goswami and Vijaylakshmi (1986) and Jacob and Illaque (1998)
	Groundnut and Karanj	*Meloidogyne incognita*	Goswami and Swarup (1971)
	Neem,	*Meloidogyne incognita*	Gowda and Setty (1978)
	Castor, mustard, neem, mahua and groundnut	*Hoplolaimus indicus*, *Tylenchorhynchus brassicae*, *Helicotylenchus indicus* and *M. incognita*	Singh *et al*. (1980)
	Castor	*Meloidogyne incognita*	Akhtar and Alam (1990) and Roldi *et al*. (2013)
	Castor and Neem	*Meloidogyne incognita*	Parveen and Alam (1999)
	Olive	*Meloidogyne incognita*	Albakhi *et al*. (2004)
	Neem and jatropha	*Meloidogyne incognita*	Kalairasan *et al*. (2007)
	Neem and groundnut	*Meloidogyne incognita*	Bhattacharya and Goswami (1987a)
	Neem and karanj	*Meloidogyne incognita*	Darekar *et al*. (1990)
	Cotton, flax, olive, sesame and soybean	*Meloidogyne incognita*	Radwan *et al*. (2009)
	Castor and mustard	*Meloidogyne javanica*	Abid and Maqbool (1991), and Javed *et al*. (2007)
	Neem	*Meloidogyne javanica*	Lopes *et al*. (2009)
	Castor	*Meloidogyne javanica*	Abbasi *et al*. (2005)
	Neem	*Pratylenchus penetrans* and *Meloidogyne hapla*	Goswami and Meshram (1991)
	Mustard and karanj *Paecilomyces licinus*+ neem, castor, flax, groundnut and mahua	*Meloidogyne incognita*	Khan and Saxena (1997)
	Pasteuria penetrans+neem	*Meloidogyne incognita*	Javed *et al*. (2008)
	Pasteuria penetrans+ *Paecilomyces lilacinus*+neem	*Meloidogyne incognita*	Reddy *et al*. (1997)
	Trichoderma harzianum+neem	*Meloidogyne incognita*	Kumar and Khanna (2006)
	Neem, mustard, castor+AMF	*Meloidogyne incognita*	Bhardwaj and Sharma (2006)
Acid lime (*Citrus aurantifolia*)	*Paecilomyces lilacinus*+Neem	*Tylenchorynchus semipenetrans*	Reddy *et al*. (1991)
Banana (*Musa paradisiaca*)	Neem	*Pratylenchus goodeyi*	Musabyimana and Saxena (1999)

Table 1: Continue

Crops	Oil-Cakes	Nematodes	References
	Neem	*Meloidogyne incognita* and *Helicotylenchus multicinctus*	Jonathan *et al.* (2000)
	Carbofuran+*Trichoderma viridae*+neem	*Radopholus similis*	Harish and Gowda (2001)
Tangerine (*Citrus reticulata*)	Neem, sesame, soybean, cotton	*Tylenchorynchus semipenetrans*	Mohammad *et al.* (1980)
Papaya (*Carica papaya*)	Neem	*Meloidogyne incognita*	Srivastava (2002)
Miscellaneous			
Berseem (*Trifolium alexandrium*)	Neem	Plant parasitic nematodes	Hasan and Jain (1984) and Azmi *et al.* (2000)
Bajra (*Pennisetum typhoides*)	Neem	Plant parasitic nematodes	Hasan and Jain (1984)
Betelvine (*Piper betle*)	Neem	*Meloidogyne incognita*	Jagdale *et al.* (1985) and Acharya and Padhi (1988)
	Neem	*Meloidogyne incognita, Rotylenchulus reniformis Hirschmaniella mucronata, Hoplolaimus indicus* and *Dorylaimus* spp.	Sivakumar and Mariuthu (1986)
Groundnut (*Arachis hypogaea*)	Neem	*Meloidogyne arenaria*	Vaishnava *et al.* (1993)
Japanese mint (*Mentha arvensis*)	Neem	*Meloidogyne incognita*	Pandey (2000)
Subabul (*Lucaena leucocephala*)	Neem	*Meloidogyne incognita*	Azmi (1990)
Sugarcane (*Saccharum officinale*)	Neem	*Meloidogyne incognita, Pratylenchus coffeae* and *Helicotylenchus dihystera*	Jonathan *et al.* (1991)
Tea (*Camellia sinensis*)	Neem	*Meloidogyne incognita*	Bora and Neog (2006)
Tobacco (*Nicotiana tabacum*)	Neem	*Meloidogyne incognita*	Gowda *et al.* (1985) and Ravindra *et al.* (2003)
Tulsi (*Ocimum basilicum*)	Neem	*Meloidogyne incognita*	Haseeb *et al.* (1988)

ROLE OF OIL-CAKES IN SUPPRESSING PLANT PARASITIC NEMATODES ON CROP PLANTS PULSE CROPS

Pulses, the food legumes have been grown since millennia and have been a vital ingredient of human diet in India and across the world. These are important crops due to their high protein and essential amino acid content as well as their pivotal role in crop rotation due to their ability to fix atmospheric nitrogen and increase soil fertility. It is estimated that approximately 40-60 million Mt of atmospheric nitrogen is fixed by cultivated legume plants annually (Smil, 1999), which is important not only for agriculture, but also for the environment because nitrogen fixation can supplement the use of synthetic nitrogen fertilizers which require a large amount of energy input during production that can contribute to environmental pollution. Pulses are the second most important group of crops after cereals.

Pulses are found to be constantly associated with PPN which cause enormous losses both quantitatively and qualitatively (Khan, 2008). The nematodes that most widely infest pulse crops include root-knot nematode (*Meloidogyne incognita*), cyst nematodes (*Heterodera glycines*, *H. cajani*), reniform nematode (*Rotylenchulus reniformis*) and root lesion nematode, (*Pratylenchus thornei*) (Ali and Singh, 2007). Average yield losses caused by PPN on a worldwide basis are estimated to be 13.7% in chickpea (*Cicer arietinum*), 10.9% in field bean (*Phaseolus vulgaris*) and 13.2% in pigeonpea (*Cajanus cajan*) (Sasser and Freckman, 1987).

A number of reports on using oil-cakes, to control PPN infesting pulse crops are available. When black gram (*Vigna mungo*) seedlings infected with 2,000 freshly hatched larvae of *M. incognita* were treated with castor oil-seed cake, it suppressed the nematode population and egg masses significantly (Kannan *et al.*, 1987). Neem oil-cake (at 2 t ha^{-1}) suppressed *Rotylenchulus reniformis* population by 86.2% and increased the growth of French bean (*Phaseolus vulgaris*)

(Padhi and Misra, 1987). Cotton and sunflower oil-cakes effectively controlled population of *Rotylenchulus reniformis* on cowpea (*Vigna unguiculata*) and gave the vigorous plants (Yassin and Ismail, 1994). Similar results of nematode control on cowpea were found with neem cake amended soil by Latif *et al*. (1999) and Umar and Simon (2008). Application of neem cake was found effective when applied 15 days prior to sowing of chickpea seeds (Pandey and Singh, 1990). On chickpea roots, the reduction of *M. incognita* population and enhancement in plant growth by the application of oil-cakes of neem, castor, groundnut, linseed, sunflower and soybean (Tiyagi and Ajaz, 2004) and by neem and karanj oil-cakes (Yadav *et al*., 2005) has been reported. Oil-cakes also gave positive results in control of cyst nematode, associated with pigeonpea (*Cajanus cajan*). Anver (2003) found that oil seed cakes of neem, castor, mustard and duan proved effective in reducing the nematode multiplication and consequently increased the bulk density of woody stem of pigeonpea. Harm caused by nematodes was further reduced by the addition of *Paecilomyces lilacinus* along with oil cakes. Singh (2004) evaluated the efficacy of two nematicides, phorate, carbofuran and oil-cakes of linseed, mustard and neem in controlling cyst nematode on pigeonpea. Maximum plant growth was obtained in treatments with neem cake followed by mustard cake, carbofuran, linseed and phorate whereas, maximum reduction in nematode population was recorded by both nematicides followed by neem cake, mustard cake and linseed cake respectively. When amended well with soil and allowed for decomposition, oil-cakes of neem, sesamum, mustard, cotton and castor were found significantly effective in plant growth promotion and in suppression of cyst nematode population on pigeonpea (Meena *et al*., 2009). Highest nitrogen fixing ability of leguminous crops is attributed to their root nodule forming capacity with rhizobia. The PPN mainly attacking roots interferes with their nodule forming capacity, thereby affecting their nitrogen fixing ability and thus reducing plant growth. Reduction in number of nodules in nematode infested plants has been reported by many investigators (Malek and Jenkins, 1964; Shafi *et al*., 2002; Khan *et al*., 2005). In most of the cases studied, it was seen that oil-cakes may be helpful in increasing root nodule forming capacity of leguminous crops and in turn enhancing plant growth and suppress nematode population. Mishra and Gupta (1997) reported that oil-cakes of 5 mustard, neem, linseed, mahua and castor significantly improved plant growth of soybean (*Glycine max*) that may be due to reduced root-knot infection, increase in root nodulation per root system as well as nodule weight and/or release of nitrogen and other nutrients from oil-cakes. In addition, residual effect of oil-cakes in controlling PPN is also observed by many workers. Population of PPN (*Meloidogyne incognita*, *Rotylenchulus reniformis*, *Tylenchorhynchus brassicae*, *Helicotylenchus indicus* etc.) was significantly reduced by the application of oil-cakes of neem, castor, mustard and duan on mungbean plants (Tiyagi and Alam, 1995). A multifold increase in plant growth parameters and residual effects on subsequent crop, chickpea was also observed. Similar results on plant growth parameters of lentil and control of PPN are reported by Tiyagi *et al*. (2001). The residual effects of different oil-cakes (neem, castor, linseed, groundnut and duan) were also noted in the subsequent crop, mungbean, in the next growing season.

The AM fungi help in improving phosphorus status of plants that results in improved plant growth and ability to resist nematode attack. Oil-cakes are reported to provide suitable substrate for VAM colonization, thus helping the plant indirectly to defend them against PPN. Sankaranarayanan and Sundarababu (1997) recorded greatest reduction in root-knot nematode population infesting black gram when AM fungus (*Glomus fasciculatum*) was inoculated to the plants after treatment of the soil with oil-cakes of neem, mahua, castor and groundnut. Goswami *et al*. (2007) reported the control of root-knot nematodes on pulse crops to a great extent when oil-seed cake of karanj along with Farm Yard Manure (FYM) was used as substrate for enhancing VAM colonization. This treatment constituting karanj oil-seed cake+FYM+VAM fungus (*Glomus fasciculatum*) proved best in controlling root-knot nematode and also in improving plant growth.

Efficacy of different oil-cakes in improving plant growth is reported to be enhanced by the presence of plant growth promoting rhizobacteria *Pseudomonas fluorescens* in case of chickpea (Rizvi *et al*., 2012) and on mungbean (Tiyagi *et al*., 2011). Significant improvement in growth parameters of mungbean plants seemed to be due to reduction in disease incidence and might caused by growth promoting substances of *P. fluorescens*. Most effective combination of *P. fluorescens* was with neem cake.

Cereal crops: Cereals constitute the world's most important source of food. Amongst cereals, rice, maize and wheat occupy the most prominent position in terms of production, acreage and source of nutrition, particularly in developing countries. It has been estimated that about 70% of the land cultivated for food crops is devoted to cereal crops. The global population is projected to increase steadily to around 9 billion by 2050 and with this, demand for the staple cereals like rice; maize and wheat will increase (Dixon *et al*., 2009).

The cereal crops are considerably susceptible to nematode attack and show yield losses of economic value. The most common nematodes attacking cereals include root-knot nematode, *M. graminicola*, stem nematode, *Ditylenchus angustus*, cereal cyst nematode, *Heterodera avenae*, seed gall nematode, *Anguina tritici*, stunt nematode, *Tylenchorynchus vulgaris* etc. Average yield losses on cereals due to nematode infestation ranges from 7-22% (7-19% in wheat, 10-22% in rice, 6-10% in maize, 17-77% in barley and 3-32% in oat) (Khan and Jairajpuri, 2010).

Extensive work has not been done on the control of PPN by using oil-cakes on cereals. However, a few reports indicate the potential of oil-cakes in controlling nematodes on cereals. Prasad *et al*. (1974) reported that neem seed cake along with some other organic amendments was effective in controlling *Helicotylenchus*, *Tylenchorynchus* and *Pratylenchus* populations on wheat and subsequent crops, mung and maize. Furthermore, piludi and mustard cake showed significant depressing effects on population of stunt nematode (*Tylenchorynchus vulgaris*) than other treatments. Prasad *et al*. (2005) assessed the effects of seed cakes of castor, neem and *Simarouba glauca* at the rate of 2.5 and 5.0 g kg^{-1} soil as soil treatments on the growth of rice and population of *M. graminicola*. Neem cake was found to be most effective in reducing egg masses of the nematode on rice plants. Fertinemakil, a pesticide combination of neem cake and a fungicide, was found to be effective in reducing nematode populations and increasing root length on wheat (Khan *et al*., 2007).

Vegetable crops: Vegetable crops are among the most susceptible host for nematode infestation and are usually worst affected by them (Sharma *et al*., 2006; Anwar *et al*., 2007; Singh and Khurma, 2007), because of their soft and succulent plant body and their cultivation under the conditions such as high soil moisture that favor nematode infestation. Nematodes attack almost all the plant parts including roots, stem, leaves, inflorescence, flowers, bulbs and corms (Webster, 1972), causing severe damage to crop both quantitatively as well as qualitatively. Important nematodes that mainly attack the vegetable crops include *Globodera*, *Meloidogyne* spp., *Belonolaimus longicaudatus*, *Radopholus similis*, *Trichodorus* spp., *Pratylenchus* spp., *Rotylenchulus reniformis* and *Paratrichodorus* spp. Yield losses due to PPN in vegetable crops may reach up to 5-43%. Several reports of nematode control on vegetables through the use of oil-cakes are available. Singh and Sitaramaiah (1973) reported that oil-cakes of margosa, peanut, castor, mustard, linseed, mahua and coconut showed varying degree of success in reducing

Meloidogyne javanica infection on vegetable crops. The possible mechanism of nematode control was found to be direct as well as indirectly through improved health of the plant host and alterations in root physiology leading to greater resistance to infection. Alam *et al.* (1980) found that when tomato, chilli and eggplant were transferred from the soil amended with oil-cakes of mahua, castor, mustard, neem and groundnut to unamended soil and later inoculated with 1000 *M. incognita* larvae, fewer larvae penetrated the plant and less galling occurred. Also, the plants reared in amended soil had increased level of total free phenols. Alam (1991) reported that in field trials oilseed cakes of mahua, castor, mustard, neem and groundnut singly or in different combinations significantly controlled populations of plant-parasitic nematodes on tomato (*Lycopersicon esculentum* Mill.), eggplant (*Solanum melongena* L.), chilli (*Capsicum annum* L.), okra (*Abelmoschus esculentus* Moelch), cabbage (*Brassica oleracea capitata* L.) and cauliflower (*Brassica oleracea botrytis* L.). Except mahua cake, which was phytotoxic to all test crops (excepting eggplant), other cakes improved plant growth significantly. However, when mixed with other cakes, mahua cake lost its phytotoxicity.

Among vegetable crops, the most studied one is tomato that is found to be heavily infected with root-knot nematodes (*Meloidogyne* spp.) in the tropics, temperate and subtropical regions (Taylor and Sasser, 1978; Whitehead, 1997; Sikora and Frnandez, 2005). Suppression of the most common species of root-knot nematode, *Meloidogyne incognita* population, reduced galling and egg mass production and improved plant growth parameters is reported by amending the soil with composted oil-cakes (D'Errico and Di Maio, 1980) including mustard cake (Hameed, 1968), neem cake (Goswami and Swarup, 1971; Verma, 1986; Bhattacharya and Goswami, 1987b; Goswami and Vijaylakshmi, 1986; Jacob and Illaque, 1998), groundnut and karanj cake (Goswami and Swarup, 1971), castor cake (Akhtar and Alam, 1990; Roldi *et al*., 2013), castor and neem cakes (Parveen and Alam, 1999), Olive cake (Albalkhi *et al*., 2004) and neem and jatropha cakes (Kalaiarasan *et al*., 2007). Neem and groundnut cakes were more effective in unsterilized soil than in sterilized soil, leading to increased plant growth response and low nematode population in tomato (Bhattacharya and Goswami, 1987a). Dosages of neem oil-cake above 4% w/w were found to be phytotoxic, but at 4% it significantly increased host plant growth and reduced root galling and populations of *M. incognita* in tomato. Application of neem and karanj oil-cakes at 400 kg ha^{-1} was the most effective in suppressing the root-knot nematode population in tomato (Darekar *et al*., 1990). Jacob and Illaque (1998) observed that neem cake was more effective than neem dust in reducing root-knot nematode population in tomato. Oil-cakes of cotton, flax, olive, sesame and soybean at the rate of 5, 10, 15, 20 or 50 g kg^{-1} soil against *Meloidogyne incognita* infecting tomato and found that *M. incognita* population in the soil and root galling were significantly suppressed with these cakes at all rates. The highest reduction in galls was noted in plants treated with sesame cake whereas the lowest with olive cake (Radwan *et al*., 2009).

Bare-root dip in the extracts of oil-cake of castor and mustard significantly reduced root-knot infection caused by *Meloidogyne javanica* on tomato and eggplant. The damaging effects of the nematode were masked by bare-root dip treatments as shown by improved plant growth in both the test plants (Abid and Maqbool, 1991). Javed *et al.* (2007) reported that the protective and curative soil application of neem oil-seed cake significantly reduced the number of egg masses and eggs per egg mass of *M. javanica* on tomato roots. Similarly, castor oil-cake, at the application rate of 0.5% reduced the number of eggs/plant by 18% on tomato plants (Lopes *et al*., 2009). In greenhouse trials, Abbasi *et al.* (2005) found that 1% neem cake (mass/mass soil) caused a reduction in the number of *Pratylenchus penetrans* and *Meloidogyne hapla* in tomato roots by 67-90%. In the field, same dose of neem cake was found to reduce the number of lesion nematodes by 23% in corn roots. Possible cause of decrease in nematode population and enhanced plant growth may be the reduced penetration of nematode juveniles inside the root due to oil-cake application. Akhtar (2000) explained that azadirachtin is the major nematotoxic compound present in neem which is released through volatilization, exudation, leaching and decomposing of the plant parts, that causes significant inhibition of nematode reproduction and multiplication. Alam *et al.* (1980) reported that fewer juveniles penetrated the roots of the tomato plants raised in neem cake amended soil as compared to untreated control. Goswami and Meshram (1991) reported that mustard and karanj cakes, when compared with carbofuran, showed improved plant growth response and enhanced efficiency in inhibiting penetration of *M. incognita* juveniles in tomato roots.

The PPN are also found to be associated with okra (*Abelmoscus esculentus*) roots and are reported to be controlled with the application of oil-cakes. Application of oil-cakes of neem, groundnut and castor significantly suppressed several nematode species, including *T. brassicae* and *M. incognita* in okra rhizosphere and also increased the populations of saprophytic fungi, including *R. solani* and *F. oxysporum* (Khan *et al.*, 1974a, b). Patel *et al.* (1985) reported the significant management of root-knot nematodes by the use of mustard cake on okra. Application of neem, castor, mustard and rocket salad oil-cakes suppressed the population of root-knot nematode and the reniform nematode (*Rotylenchulus reniformis)* in okra and improved the plant growth and water absorption capacity of its roots (Anver and Alam, 1996). Siddiqui and Alam (1987) found that the oil-cakes of castor, neem, groundut, mustard and duan integrated with deep ploughing were highly effective in reducing population of PPN viz., *Hoplolaimus indicus* Siddiqui, *Rotylenchulus reniformis* Linford and Oliveira, *Tylenchorynchus brassicae* Siddiqi, *Tylenchulus filiformis* Butschli and *Meloidogyne incognita* inhabiting the rhizosphere of okra. The residual effect of oil-cakes remained even after a period of six months as the PPN was suppressed in the subsequent crop, tomato. Reduced population of root-knot nematode (*Meloidogyne incognita*) and improvement in plant growth parameters of okra by amending the soil with neem, mustard and castor cakes is reported by Ram *et al.* (2009) and through the application of groundnut, castor, sunflower and linseed cakes is reported by Ganaie *et al.* (2011).

Eggplant (*Solanum melongena*), one of the most important host of PPN, mainly root-knot nematode, is also reported to be treated with oil-cakes of neem, groundnut and castor (Khan *et al.,* 1974b), mustard (Husain *et al*., 1984), undi (*Callophyllum inophyllum*) (Mittal and Goswami, 2001), fennel, sesame and anise (El-Sherif *et al*., 2010) in order to reduce the population of phytophagous nematodes and to enhance the plant growth.

Reports on the control of root-knot nematodes on other vegetable plants such as on chilli by cakes of groundnut, sesame, mustard and duan (Trivedi *et al*., 1978), on squash by sesame cake (Youssef and El-Nagdi, 2010), on potato by neem cake (Sharma and Raj, 1987) and on pointed gourd by neem cake (Chakraborti, 2000) are also available. Various studies were conducted in order to determine the efficacy of oil-cakes in comparison to inorganic nematicides in controlling PPN on vegetable crops. Uniformity of results was not recorded, as in some cases oil-cakes were found more effective than nematicides while in others nematicides gave better results than oil-cakes. Response of systemic nematicide, aldicarb was superceded by neem cake treatment (Bhattacharya and Goswami, 1987a, b) and carbofuran by mustard and karanj cake treatment (Goswami and Meshram, 1991) against root-knot nematode on tomato. Neem cake at 80 q ha^{-1} was found to be more effective than carbofuran at 2 kg a.i. ha^{-1} in reducing root-knot nematode population and enhanced plant growth on tomato (Jain and Gupta, 1997). In contrast, aldicarb gave better results in comparison to neem cake on potato (Sharma and Raj, 1987) and carbofuran was better than neem cake on okra (Abuzar and Haseeb, 2006).

Combining bio-control agents with oil-cakes have proved to be significant in controlling PPN on vegetable crops. Khan and Saxena (1997) reported that combining oil-cakes of neem, castor, flax, groundnut, mustard and sesame in soil with *P. lilacinus* resulted in enhanced plant growth and decreased population build up of nematodes and root gallings on tomato. Groundnut cake with *P. lilacinus* proved to be most effective. These amendments increased the parasitism of *P. lilacinus* on root-knot nematodes and thus reducing disease incidence. Similarly, Javed *et al*. (2008) observed that there was significantly less root-galling and enhanced plant growth when *Pasteuria penetrans* combined with neem cake was applied as a management system for root-knot nematode on tomato. Highest improvement in plant growth and best protection against *M. javanica* on eggplant was obtained by the integration of *P. lilacinus* with groundnut cake followed by neem cake, linseed cake, castor cake and mahua cake and by integrating *C. oxysporum* with neem cake followed by groundnut cake, linseed cake, castor cake and mahua cake (Ashraf and Khan, 2010). Comparative efficacy of *Pasteuria penetrans* under the influence of organic amendments of four oil-cakes namely neem, castor, mustard and citrullus against the populations of *Meloidogyne incognita* in chilli was studied by Chaudhary and Kaul (2013), which concluded that combination of castor and *P. penetrans* showed greater reduction in galling index (84.75%) and final population (85.74%) over the *M. incognita* control than other treatments. In addition, plant growth parameters were also significantly improved.

Integration of neem cake with *P. penetrans* (28×107 spores m^{-2}) + *P. lilacinus* (20 g inoculums m^{-2}) gave maximum increase in plant growth parameters and number of seedlings per bed in tomato plants infected with *Meloidogyne incognita.* Parasitism of *M. incognita* females was highest in the treatment neem cake + *P. penetrans* while egg parasitism was highest in the treatment neem cake + *P. lilacinus* (Reddy *et al*., 1997). Application of *Trichoderma harzianum*, a known egg parasite of root-knot nematode, in neem cake amended soil was highly effective against *M. incognita* and resulted into better plant status in tomato. The improvement was found to be due to enhanced root colonization by the fungus and availability of better soil nutrition due to neem cake (Kumar and Khanna, 2006). *Pupurescillium lilacinus* and *T. viridae* with mustard cake and furadon gave maximum reduction in nematode population in soil and roots and improved plant growth parameters in tomato (Tripathi and Singh, 2006). Integration of VAM and neem cake improved plant growth parameters and yield and reduced *M. incognita* population on eggplant (Borah and Phukan, 2004). Similarly, combined use of AMF and oil-cakes derived from neem, mustard and castor resulted in reduced galling and nematode multiplication and thereby enhancing the plant growth and yield of tomato (Bharadwaj and Sharma, 2006).

Fruit crops: Considering the fact that fruit consumption is essential for human health and nutrition, fruit crops play a significant role in a country's economy as commercial crops. Production of fruit crops is found to be continually threatened due to its considerable susceptibility to PPN. Globally, 9-28% yield loss has been reported to be caused by nematode infestation in fruit crops (Khan, 2008). Important nematodes associated with fruit crops include *Meloidogyne* spp., *Pratylenchus* spp., *Radopholus similis, Rotylenchulus reniformis* and *Tylenchulus semipenetrans.* Application of neem, sesame, soybean or cotton seed cake to the soil considerably reduced *Tylenchulus semipenetrans* populations and enhanced root and shoot growth of potted *Citrus reticulata* seedlings (Mohammad *et al*., 1980). Application of neem cake+*Paecilomyces lilacinus* gave maximum shoot length and shoot weight along with maximum reduction in soil nematode population while castor cake+*P. lilacinus* gave maximum root length and root weight along with least nematode population in the roots (Reddy *et al*., 1991). Soil application of powdered neem seed or neem cake at 100 g plant^{-1} at planting and subsequently at three months interval reduced the populations *Pratylenchus goodeyi* and *Meloidogyne* spp. on banana plants. Eight months after planting treated banana plants had 4-95 times fewer parasitic nematodes than the untreated control (Musabyimana and Saxena, 1999). Neem cake (1.5 t ha^{-1}) or Press mud (15 t h^{-1}) caused significant reduction in *M. incognita* and *Helicotylenchus multicinctus* population in banana plants coupled with enhanced fruit yield (Jonathan *et al*., 2000). Integration of neem cake (500 g plant^{-1}) with carbofuran (40 g plant^{-1}) and *T. viride* (10 g plant^{-1}) was found to be most effective in reducing population of *Radopholus similis*, improving the plant growth and increasing the fruit yield (76.3 t h^{-1}) in banana (Harish and Gowda, 2001). Amendment of neem cake at 2.5 t h^{-1} caused maximum reduction of *M. incognita* population in papaya along with enhanced yield (51.8 kg tree^{-1}) (Srivastava, 2002). Sundraraju and Kiruthika (2009) that found that combined application of *P. lilacinus* and neem cake caused significant enhancement in plant growth parameters of banana and subsequently reduced the population of *M. incognita*.

Yang *et al*. (2015) investigated the nematicidal effect of *Camellia* seed cake on *Meloidogyne javanica* infesting banana and found that in dish experiments, *Camellia* seed cake extracts under low concentration (2 g L^{-1}) exhibited a strong nematicidal effect. After treatment for 72 h, the eggs of *M. javanica* were slowly disintegrated and the intestine of the juveniles gradually became invisible. Saponins and 8 types of volatile compounds especially 4-methylphenol showed to possess effective nematicidal activity. The pot experiments exhibited that the application of *Camellia* seed cake suppressed *M. javanica* and enhanced the growth of banana plant.

Miscellaneous crops: Several other crops of economic importance are found to be susceptible to nematode attack and suffer from significant losses both in term of yield and quality. A few reports are available on the use of oil-cakes in the nematode management on these crops.

Application of neem cake was found to be beneficial in suppressing nematodes associated with the fodder crop berseem (*Trifolium alexandrinum*) by Hasan and Jain (1984). Both, fresh fodder yield and nematode populations were affected in the subsequent crop bajra (*Pennisetum typhoides*) by the residual effects of the oil-cake. Azmi *et al.* (2000) observed that neem cake at 15 q h^{-1} suppressed the population of *Meloidogyne* spp., *Tylenchorhynchus* spp. and *Pratylenchus* spp. by 40, 40 and 10%, respectively on berseem. Application of neem oil cake was found to be effective in reducing *M. incognita* population in betelvine (Jagdale *et al*., 1985; Acharya and Padhi, 1988; Sitaramaiah *et al*., 1993). Sivakumar and Marimuthu (1986) also reported reduction in populations of *M. incognita*, *R. reniformis*, *Hirtschmaniella mucronata*, *Hoplolaimus indicus* and *Dorylaimus* spp. on betelvine by the application of neem cake (44.4%). Jonathan *et al.* (1991) reported that neem cake (2 t ha^{-1}) and press mud (25 t ha^{-1}) were most effective in reducing the population of *M. incognita*, *Pratylenchus coffeae* and *Helicotylenchus dihystera* on sugarcane. Vaishnava *et al.* (1993) recommended the application of neem cake for the management of root-knot nematode (*M. arenaria*) in groundnut. Root-knot nematodes are found to be effectively controlled by the application of neem cake (5.2%), karanj cake (4.8%) and groundnut cake (7.39%) (Desai *et al*., 1979), by neem cake (2 kg m^{-2}) (Gowda *et al*., 1985) and by neem cake (20 g plant^{-1}) (Ravindra *et al*., 2003) on tobacco plants coupled with significant increase in leaf yield. Neem cake is also found to be effective in suppressing the root-knot nematode (*M. incognita*) population on *Ocimum basilicum* by Haseeb *et al.* (1988), on subabul (*Leucaena leucocephala*) by Azmi (1990), on Japanese mint (*Mentha arvensis*) by Pandey (2000) and on tea by Bora and Neog (2006).

Challenges in the application of oil-cakes for the management of plant parasitic nematodes: Modern day agriculture involving the use of organic amendments as oil-cakes faces a number of challenges that includes basically high application rate, labor requirement, financial problems and environmental perturbations.

The amount of oil-cakes usually needed per unit area is large. This presents the problems of obtaining, transportation and application especially in large scale farming. However, in developing countries, these wastes are produced in large amounts and the efforts are needed by the government organizations, research centers etc. to mobilize them in the forms that can be used by the farmers more easily. Secondly, the use of oil-cakes requires a lot of energy and labor. This is actually not a serious problem in developing countries because there is abundance of labor that can be utilized for this purpose.

It is common misconception that increasing the level of oil-cakes by soil amendments is always a good practice. Excessive amount of amendment creates enhanced micronutrients concentration in the soil which ultimately causes pollution of surface and ground water with phosphorus and nitrates. Besides, research and formulation of oil-cakes in organic farming is also hampered in developing countries due to scarce funding from government, NGOs etc.

Nevertheless, organic farming in many developing countries may be improved by adequate funding and elimination of production subsidies that have adverse economic, social and environmental effects.

CONCLUSION

Oil-cakes have been found to provide most suitable and easily available substrate for vigorous growth of beneficial microorganisms and in turn benefitting the plants in various ways. Among oil-cakes, most effective and widely used one is neem cake followed by various others like castor, mustard, groundnut etc. It has been noted that microorganisms assist in rapid decomposition of oil-cakes and in turn, they help to diminish nematode population. Research on oil-cake amendments in last few decades have followed the same investigation pathways, but with a greater concern towards knowing the actual mechanisms involved in nematicidal action and effect of integrating bio-control agents and nematicides along with oil-cakes. In conclusion, for the sustainable management of phytonematodes on economically important crops, no single strategy can be applied solely, but there is a need to integrate various chemical and biological methods, in which oil-cakes play an important role.

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