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PHYTONEMATODES PROBLEM, THEIR OCCURRENCE, DISTRIBUTION, DAMAGE AND MANAGEMENT IN FORAGE AND FODDER CROPS: A REVIEW

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SUMMARY

Forage crops can be defined as those plants which are directly or indirectly consumed by animals while fodders are those plant species which are generally fed to the animals as fresh and storage products *viz.,* hay and silage. The cultivation of forage and fodder crops subjected to various biotic and abiotic constraints. Among the biotic constraints, various insect pests and diseases including plant parasitic nematodes are major limiting factor for cultivation of forage and fodder crops. Several nematodes are responsible for causing serious damage to these crops. However, *Meloidogyne* spp. has become most important pest and is a serious problem in major forage producing countries of the world. Management of the potential economic damage caused by these tiny organisms to forage crops is generally accomplished by a combination of various factors i.e. host resistance, cultural practices, bio-control agents and to a lesser extent chemical control. The selection of a highly resistant variety is the first line of defense in combating nematodes. Cultural practices can be very effective in preventing the initial spread of the nematodes into new production fields and help in minimizing the damage in established forage crops. Keeping this in mind, the present article is focused on nematodes problems of forage and fodder crops along with their management.

Key words : Cultural practices, forage and fodder crops, *Meloidogyne* spp., plant parasitic nematodes, Management

Forage and fodder cultivation emphasizes the importance of crops in livestock production and land management. Forage occupies over half of the arable land area of the world (Lamp *et al.,* 2007). Generally, grasses are rich in crude fibres, crude protein and some minerals. Legume forages are particularly rich in proteins and minerals while root crops are high in starch and sugar and low in fibre content, making them easy to digest. The fibre content of most fodder crops consists of cellulose, a complex carbohydrate polysaccharide that is indigestible for humans, but is a good source of energy for animals and particularly ruminants (Barnes and Baylor, 1995). They can also play an important role in maintaining ground cover, preventing erosion, accumulating nitrogen in the soil and improving land condition. Forage crops and pastures provide the bedrock to sustainable agriculture (Allen *et al.*, 2011). Fodder crops may be classified as either temporary which is grown and harvested in every season/year or permanent crops which are cultivated/growing wild for five years or more. Permanent fodder crops may include some parts of forest land if it is used for grazing. Temporary fodder crops are mainly divided into three major groups of fodder (i) grasses which include cereals that are harvested green (ii) legumes, including pulses that are harvested green and (iii) root crops that are cultivated for fodder. All three types are fed to animals, either as green feed, as hay, *i.e.* crops harvested dry or dried after harvesting, or as silage products. Silage, or ensilage, refers to green fodder preserved without drying by fermentation that retards spoiling. A few forage crops are annuals, such as sorghum, oats, annual rye grass, silage maize, and forage peas. Major legume forage crops which are grown in India are annual or perennial species and it includes crops like berseem (*Trifolium alexandrinum*), alfalfa (*Medicago sativa*), cowpea (*Vigna unguiculata*), forage pea (*Pisum sativum* L.) and forage vetch (*Vicia sativa* L.) etc.

Forage and pasture species are also subjected to great risk of insect-pests and diseases including plant parasitic nematodes (PPNs) in the same way as are other crops. Nematodes are translucent, microscopic roundworms which inhabit all agricultural soils and their abundance ranges from about 1000 per quintal of soil in heavily tilled soil with low organic matter to about 50,000 per quintal of fertile soil with good organic matter. Not all nematodes present in soil are PPNs, few of them may be "free-living" species that feed on bacteria or fungi and are known as bacterivores and fungivores, respectively. Many species of these plant parasitic nematodes are well recognized as damaging pathogens of high valued field, vegetable, medicinal, aromatic and fruit crops. Due to the less value of forage crops, the impacts of these tiny organisms on forage crops have not been focused so intentionally and are not as well recognized. The research performed to date, however, indicates that plant-feeding nematodes can have important influences on forage production and deserve more research attention. PPNs are present in every part of the world which are known to hamper the pasture establishment, decrease forage production and seed yield with impure quality (Jain, 1992). Besides causing direct yield loss, PPNs have also been reported to suppress nodule formation in leguminous forage crops. In some cases, the losses may further increase because of ubiquitous interaction of PPNs with other soil borne pathogens like fungi, bacteria and virus especially in warmer regions. These are often of greater economic importance than the losses caused by nematode alone.

Occurrence and distribution of PPNS

Survey of mountainous pastures of southern Spain has been done for occurrence and distribution of PPNs which resulted into occurrence of sixty-three species distributed over 25 genera of nematodes (Table 1). *Pratylenchus microdorus* and *P. thornei* were widely distributed and most prevalent species in 69 and 41 per cent of sampling sites, respectively. Other species like *Amplimerlinius globigerus*, *Helicotylenchus digonicus, H. dihystera, H. tunisiensis, Merlinius brevidens, M. microdorus, Rotylenchus unisexus* and *Scutylenchus quadrifer* were observed in more than 10 per cent of the fields. In general, we can say grasses are better hosts of *P. neglectus* and *P. thornei* than the pasture legumes tested (Talavera and Navas, 2002).

Patra *et al*. (2019) conducted a survey of forage crops for the distribution of PPNs in different places of Bhubaneswar (Odisha), India. About 140 soil samples were collected across 5 different locations from the forage crops (hybrid napier, maize, cowpea, lemongrass, bajra, rice bean and guinea grass). Results of survey showed the abundance of *Rotylenchulus reniformis*, *Tylenchorhynchus mashoodi*, *Pratylenchus zea*, *Xiphinema insigne*, *Caloosia heterocephala*, *Helicotylenchus dihystera*, *Hoplolaimus indicus*, *Aphelenchus avenae*, *Criconemalla ornata*, *Rhabditids, Mononchids, Mylonchulus* and *Dorylaimid* exhibiting varying population densities (Table 2). Among the isolated PPNs, *Xiphinema insigne* had highest frequency of occurrence 110.00 per cent with absolute frequency of 78.57 per cent followed by *Hoplolaimus indicus* (75.7%). Highest prominence value was found with *Rotylenchulus reniformis* species (80.6) followed by *Xiphinema insigne* (60.6) and lowest prominence value (2.5) was recorded in *Criconemalla ornata*. Among free living nematodes, *Rhabditids* were having the highest frequency of occurrence (136.0 %) with absolute frequency (97.1%) followed by *Dorylaimids*.

Nematode prevalence, relative abundance, mean intensity and maximum densities were calculated according to Boag (1993);

- **Prevalence :** Number of samples having a particular nematode species divided by the number of samples examined, expressed as a percentage.
- **Relative abundance :** Total number of individuals of a particular species per 100 cm^3 of soil in all the samples divided by the number of samples including those with zero counts for that species.
- **Mean intensity :** Number of individuals of a particular nematode species per 100 cm^3 of soil in a number of positive samples divided by the number of positive samples.
- **Maximum density:** Maximum number of individuals of a particular nematode species per 100 cm^3 of soil recovered from a sample.

Absolute Frequency = (Number of samples containing a species/Number of collected samples) × 100

Relative Frequency = (Frequency of species/ Sum of frequencies of all species) × 100

Absolute Density = Number of individuals per unit of soil

Relative Density = (Number of individuals of a species in a samples/total of all individuals in a sample) × 100

Prominence Value (PV) = Absolute density √Absolute frequency

TABLE 1

Occurrence and incidence of PPNs in 51 sites from mountain grassland in southern Spain

Nematode species	Prevalence (%)	Relative abundance	Mean intensity	Maximum densities
Paratylenchus microdorus Andrássy, 1959	69	70.0	102.0	738.0
Pratylenchus thornei Sher & Allen, 1953	41	9.0	21.0	122.0
Helicotylenchus digonicus Perry, 1959	39	39.0	99.0	524.0
Xiphinema spp. *(americanum* group)	35	<0.5	1.0	3.0
Criconemoides informis (Micoletzky, 1922) Taylor, 1936	31	5.0	8.0	85.0
Ditylenchus spp.	29	<0.5	1.0	6.0
Heterodera spp. (juveniles)	25	<0.5	1.0	4.0
Paratylenchus nanus Cobb, 1923	24	27.0	116.0	564.0
Paratylenchus ciccaronei Raski, 1975	22	17.0	77.0	492.0
Helicotylenchus dihystera (Cobb, 1893) Sher, 1961	18	11.0	62.0	226.0
Pratylenchus pinguicaudatus Corbett, 1969	18	2.0	12.0	44.0
Rotylenchus unisexus Sher, 1965	16	12.0	75.0	322.0
Anguina sp.	5:09	<0.5	<0.5	<0.5
Hoplolaimus sp.	3:09	6.0	154.0	246.0
Rotylenchus sp.	3:09	1.0	31.0	51.0
Rotylenchus pumilus (Perry, 1959) Sher, 1961	3:09	1.0	22.0	40.0
Xiphinema conurum Siddiqi, 1964	2:00	<0.5	2.0	2.0
Pratylenchus vulnus Allen & Jensen, 1951	2:00	<0.5	1.0	1.0
Longidorus apuloides Roca, 1996	2:00	<0.5	<0.5	<0.5

Source : Talavera and Navas, 2002.

TABLE 2

Prominence, frequency of occurrence and population density of nematodes associated with forage crops in Bhubaneswar, Odisha

Nematode species	Total no. of samples collected	No. of samples containing the species	Absolute Frequency (%)	Relative Frequency (%)	Absolute density (%)	Relative density	Prominence value
Aphelenchus avenae	140	20	14.29	2.04	18	2.20	6.80
Caloosia heterocephala	140	104	74.29	10.61	64.23	7.85	55.36
Criconemella ornata	140	36	25.71	3.67	4.88	0.60	2.47
Helicotylenchus dihystera	140	86	61.43	8.78	63.95	7.82	50.12
Hoplolaimus indicus	140	106	75.71	10.82	38.15	4.67	33.20
Pratylenchus zea	140	46	32.86	4.69	91.47	11.19	52.43
Rotylenchulus reniformis	140	48	34.29	4.9	137.75	16.84	80.66
Tylenchorhynchus mashhoodi	140	20	14.29	2.04	133	16.26	50.27
Xiphinema insigne	140	110	78.57	11.22	68.36	8.36	60.59
Dorylaimid	140	132	94.29	13.47	28.30	3.46	27.48
Mononchid	140	94	67.14	9.59	45.82	5.60	37.55
Mylonchulus	140	42	30.00	4.29	35.80	4.38	19.61
Rhabditid	140	136	97.14	13.88	88.05	10.77	86.78
				100.00		100.00	

Source : Patra *et al*., 2019.

PPNS Damage to forage crops

PPNs reduced pasture production by around 15 per cent annually, mainly through their effect on white clover in New Zealand pastures. Application of chemical nematicide increased clover yields in pasture by an average 40 per cent and also increased N-fixation levels by over 50 per cent. The impact of clover nematodes in reducing nitrogen inputs and forage quality was estimated to exceed $1 billion annually in lost production potential (Watson and Mercer, 2000). Greatest yield reduction was observed in *Agropyron cristatum, A. desertorum, A. riparium* and *A. trichophorum* due to *Pratylenchus neglectus* at 800

TABLE 3
Host range of different plant parasitic nematodes

Nematode associated	Host range	References
Meloidogyne chitwoodi	Wheatgrasses (*Agropyron cristatum, A. cristatum X. desertorum, A. desertorus, A. riparium, A. trachycaulum, A. trichophorum, Elymus lanceolatus, Elytrigia repens, Pascopyrum smithii,* and *Thinopyrum intermedium*), Jointed goatgrass (*Aegilops cylindrica*), *Dactylis glomerata, Echinochloa crusgalli, Poa annua* etc.	O'Bannon *et al.,* 1984)
Meloidogyne hapla	*Cynodon dactylon,* Penncress and Seaside, *Dactylis glomerata* etc.	Riggs *et al.*, 1962, Radewald *et al.,* 1970
Heterodera avenae	*Avena sativa* (oats), *A. nuda and A. fatua, Echinochloa* spp., *Festuca* spp., *Hordeum vulgare, Phalaris* spp., *Poa annua, Setaria* spp., *Sorghum bicolor*, etc.	McGawley and Overstreet, 1998, Williams and Siddiqi, 1972
Paratrichorodus minor	*Cynodon dactylon*, *Dactylis glomerata* etc.	Cook and Yeates, 1993
Pratylenchus penetrans	*Agropyron cristatum, A. intermedium, A. trachycaulum, Dactylis glomerata, Echinochloa frumentacea*, *Festuca arundinacea* etc.	Bernard *et al.*, 1998
Xiphinema americanum	*Agropyron cristatum*, *A. cristatum, A. desertorum*, *Pascopyrum smithii*, *Thinopyrum intermedium,Elytrigia repens* and *Pseudoroegneria spicata*, *Dactylis glomerata* etc.	Griffin *et al.,* 1996
Longidorus elongatus	*Hordeum vulgare, Lolium perenne* etc.	Norton *et al.,* 1984, Griffiths and Robertson, 1984

nematodes per 100 cm^3 soil, but damage observed at 200 nematodes per 100 cm^3 (Griffin and Jensen, 1997).

Due to non-specificity of above ground symptoms of PPNs in forage crops, damage is ignored once by the farmers. It is difficult to distinguish from other stresses such as uneven water availability, salts or even nutrient deficiencies. Below ground symptoms are specific for nematode damage but sometimes these also found not obvious and damage is typically manifest as reduced overall root growth.

General symptoms produced by PPNS on forage crops

Damage of PPNs to forage crops resulted into a huge biomass reduction and symptoms produced may be different based on type of nematodes. Some forage crops debilitate the root function due to nematode attack at several levels (Watson and Mercer, 2000). Attack and feeding by ectoparasitic nematodes results into loss of feeding root, disruption of nutrient transportation system and root elongation mechanism. Nematode penetration into roots and their intra and intercellular movement within root tissues by various endo-parasitic nematodes (root-knot nematode, cyst nematode, citrus nematode etc.) causes root trauma, tissue degradation and entry port for secondary root pathogens like fungi, bacteria, viruses etc. Feeding by nematodes disrupts the transportation of water and nutrients required at upper portion of plants for photosynthesis activity. Stubby and deformed roots create hindrance with normal physiological process of plants. Disruption of rhizobium nodulation for N fixation and establishment of beneficial mycorrhizal fungi in roots that assist with P uptake. Some nematodes like *Meloidogyne*, *Xiphenema* etc. form visible galls or knot on root portion of plants and gives patchy chlorotic appearance to grassland due to poor growth of plants. Symptoms produced by nematodes depends upon various factors like soil and edaphic conditions (soil type, soil pH, soil texture etc.), environmental conditions (temperature, moisture etc.) and biotic factors like presence of antagonistic microorganisms in soil (Mercer *et al.,* 2008).

Effects of nematodes on forage legumes: The impact of nematodes has been observed more on legume forage crops (alfalfa, berseem, clovers etc.) than grasses.

1. **Stem nematode (*Ditylenchus dipsaci*):** It is the most destructive nematode pest of alfalfa and berseem mainly dominating areas of high rainfall or in irrigated fields within semi-arid regions. This nematode can survive for long periods in an anhydrobiotic (dry) state in dried infested plant material or dry soil. It feeds primarily as an endo-parasitic in crowns, stems and occasionally in leaves causing stems to become shortened, swollen and discoloured (Pederson and Quesenberry, 1998).

2. **Root-knot nematodes (*Meloidogyne* spp.):** There are various species of genus *Meloidogyne* which attack various forage crops including legume crops. Important pest species of *Meloidogyne* are *M. incognita, M. javanica*, *M. hapla*, *M. arenaria* and *M. chitwoodi* that often parasitize the legume crops like alfalfa and clover (Santo and Pinkerton, 1985). More than one juvenile per cm^3 of *M. hapla* can build up to high population densities in alfalfa fields and results into seedling mortality and significantly reduction in crop biomass. Heavy population density of *M. hapla* also increases susceptibility of alfalfa to *Phytophthora* root rot (Gray *et al.*, 1990).

3. **Root lesion nematodes (*Pratylenchus* spp.):** Most of legume crop are susceptible to *Pratylenchus penetrans, P. thornei* and *P. neglectus* which cause considerable loss (Griffin, 1994). It reduces cold hardiness and increase susceptibility to *Fusarium* in alfalfa (Mauza and Webster, 1982).

Nematode management approaches

The first step of nematode management process is detection of type and population density of nematodes by taking samples from the infested location. After diagnosis, an effective plan should be designed and implemented efficiently. Intensive and costly nematode management practices are designed for high valued crops but not suitable for forage production due to their less economic importance. So, there is great need of resistance genotypes against plant parasitic nematodes. High dose of nitrogen content in soil also increase some type of PPNs density in field. For example, population density of *P. penetrans* increased with excess use of manures and nitrogenous fertilizers in tall fescue (Forge *et al.,* 2005).

1. Cultural practices for namatode management

(a) Crop rotation: Crops rotating in a sequential cropping system is widely regarded as a good agricultural practice in traditional and modern agriculture. This method is not only useful as pests or diseases management but also enhance soil fertility status. The main principle of crop rotation is to reduce population of PPNs below a level that allow subsequent forage crops to complete early growth before making a heavy damage by nematodes. This can be achieved by alternating host forage crop with poor hosts, non-hosts or resistant forage crops (Swamy *et al.,* 1995). Nematode control can be difficult and expensive task for a farmer. Crop rotation with non-host forage crop is a major means of managing PPNs without any economic burden to farmers. In forage crops, limited options are available because most of the common grasses are also typically increase sting and stubby-root nematode populations (Grabau, 2020).

TABLE 4

Host status of major forage crops against important nematode pests

Group	Forage crop	Good host	Poor host	Non host
Legume	Berseem	*Tylenchorhynchus vulgaris, Pratylenchus zeae*	*Meloidogyne incognita*	*Heterodera cajani, H. sorghii, H. avenae, Rotylenchulus reniformis*
	Lucerne	*M. incognita, M. javanica, P. zeae*	-	*H. cajani, H. sorghii, H. avenae, R. reniformis*
	Cowpea	*M. incognita, M. javanica, H. cajani, R. reniformis*	-	*H. sorghii, H. avenae*
	Cluster bean	*M. incognita, M. javanica, H. cajani, R. reniformis*	-	*H. sorghii, H. avenae*
Grasses	Oat	*H. avenae, P. zeae, T. vulgaris*	*H. sorghii, M. incognita*	*H. cajani*
	Sorghum	*H. sorghii, P. zeae, T. vulgaris, H. sorghii, R. reniformis*	*M. incognita, M. javanica,*	*H. cajani, H. avenae*
	Maize	*M. incognita, M. javanica, P. zeae, T. vulgaris*	*R. reniformis, H. sorghii, H. avenae*	*H. cajani*
	Bajra	*M. incognita, M. javanica, R. reniformis, H. sorghii, P. zeae, T. vulgaris*	-	*H. cajani, H. avenae*

(b) Addition of organic amendments: Application of organic amendments have been widely used for management of PPNs in forage and field crops. The basic principle of adding organic matter for rapid declines in nematode population levels is toxic compounds which are released during decomposition of materials (Stirling, 2011a). This may also help in increase of nematode antagonists. Improved plant nutrition level and growth status lay lead to enhance tolerance capacity against PPNs. The nematicidal response mainly depends on a variety of factors such as material used, processing/composting of material, application rate, test arena, crop rotation, agronomic practices, soil type, climate and other environmental factors.

2. Biological controlagents

The term "bio-control agents" is used to cover diverse organisms that include natural enemies such as parasites and predators, but also organisms that produce antibiotics, extracellular enzymes or induce systemic resistance in plants (Stirling, 2011b). For some fungal and bacterial antagonists of nematodes, the ability to colonize the rhizosphere of plants is essential to their success as biological control organisms (Kloepper *et al.,* 1992; Bourne *et al*., 1994). Many of the fungi that parasitize nematodes are common soil inhabitants such as *Purpureocillium lilacinum* (syn. *Paecilomyces lilacinus*), *Pochonia chlamydosporia* (syn. *Verticillium chlamydosporium*) and trapping fungi. Bacteria in the genus *Pasteuria* are also regularly found parasitizing nematodes in soil. Carnivorous nematodes and micro-arthropods such as collembolans and mites are abundant in soil and can consume large numbers of nematodes. *Pasteuria penetrans*, the obligate endospore forming bacterial hyperparasite with high host specificity, effectively control the *Meloidogyne* and *Heterodera* species. Application of *Trichoderma harziamum* or VAM fungi *i.e. G. fasciculatus* along with organic amendment gave effective control in cowpea and berseem against nematode diseases (Bourne *et al*., 1994).

3. Resistant cultivars

Host plant resistance represents the inherent ability of crop plants to restrict, retard or overcome the pest/pathogen infestation and thereby to improve the yield or quality of forage products. The cowpea was one of the crops in which natural inherent trait of resistance against root-knot nematodes was recognized (Webber and Orton, 1902).

Genetic variation of some legume forage plants (alfalfa, red & white clover, cowpea, clusterbean etc.) has been demonstrated against various PPNs by many workers in India and abroad. As a result, large number of germplasms exhibiting varying degree of resistance has been identified. So, likewise resistance developed in forage varieties has been proved great economic value for farmers.

4. Botanicals

The plant world is comprised of a rich storehouse of secondary metabolites which have a significant role in potential bioactivity. The bio-potential of neem has provides effective bio-pesticides against a list of agriculturally important pests from last many years. It is reportedly found effective against more than 12 species of nematodes. In forage crops, a good number of natural and commercial formulations of neem have been tested. The aqueous solution of leaf at 10 and 20 per cent, seed kernel at 1 and 2 per cent and oil suspension at 2 per cent were found effective for the management of various PPNs (Faruqui *et al.,* 2002).

5. Chemical control

Forage and fodder crops are consumable

TABLE 5
Some resistance source against PPNs in legume forage crops

Crops	Nematode species	Germplasms	References
Cowpea	*M. incognita*	Iron, Clay, Chinese red, Viktor K 798	Dasgupta and Ganguly, 1986
	R. reniformis	V-16	
Alfalfa	*M. incognita*	Sonora, Moapa	Bingefors, 1971
	D. dipsaci	Frontier, Nemastan	
Cluster bean	*M. incognita*	ILO 1539-1, ILO 77-4-1	Hasan and Jain, 1988
Clover	*D. dipsaci*	Resident, Dorset, Milka, Mira etc.	

Source : Trivedi, 1998.

product by animals and the persistence of chemicals exists in variable quantity in plant. This may result into residue/toxicity problem in both animals as well as human being directly and indirectly. So, the priority should be given to use of other alternative options instead of chemical nematicides. Upon severity of infestation by PPNs, soil fumigants alone or in combination with non-fumigant nematicides can provide effective and reliable control in forage crops. With the time, development of new effective and environmentally safe non-fumigant nematicides has reduced the dependency on fumigant nematicides (Taylor, 2003).

CONCLUSIONS

Plant-feeding nematodes are insidious but ubiquitous forage pests and a particular in legume forage crops throughout world. Hence, these tiny organisms become a major problem for forage cultivating farmers. Progress to ameliorate the nematode problem has progressed on several fronts, in particular in plant improvement such as development of resistance varieties. Growing a nematode suppressive crop will not eliminate plant parasitic nematodes from the soil. However, it may reduce nematode numbers enough to allow cultivating nematode resistant/ tolerant forage crop variety along with the management practices like crop rotation, addition of organic amendments, bio-control agents etc. in a nematode infested field. Upon severity of plant parasitic nematodes in soil, the farmers are advised for application of effective botanical pesticides or chemical nematicides.

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