

## Plant-Parasitic Nematodes and Their Management: A Review

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### Abstract

Nowhere will the need to sustainably increase agricultural productivity in line with increasing demand be more pertinent than in resource poor areas of the world, especially Africa, where populations are most rapidly expanding. Although a 35% population increase is projected by 2050. Significant improvements are consequently necessary in terms of resource use efficiency. In moving crop yields towards an efficiency frontier, optimal pest and disease management will be essential, especially as the proportional production of some commodities steadily shifts. With this in mind, it is essential that the full spectrums of crop production limitations are considered appropriately, including the often overlooked nematode constraints about half of all nematode species are marine nematodes, 25% are free-living, soil inhabiting nematodes, 15% are animal and human parasites and 10% are plant parasites. Today, even with modern technology, 5-10% of crop production is lost due to nematodes in developed countries. So, the aim of this work was to review some agricultural nematodes genera, species they contain and their management methods. In this review work the species, feeding habit, morphology, host and symptoms they show on the effected plant and management of eleven nematode genera was reviewed. The review result indicated that all of the reviewed nematodes were different in terms of the above mentioned character; some have wide host range like *Aphelenchoide* while some have generally narrow host range and specialized like *Heterodera*. Some are ectoparasite and some are endoparasite and some are both in different part of the plant in their feeding habit like *Aphelenchoide* it is endoparasite in leaves, but also feeds ectoparasitically on leaf and flower buds in some plants. Most of them have large number of species. They can be managed by using different methods like; Sanitation of fields and equipment like Pots potting soil, bio-control agents *Paecilomyces lilacinus*, Periodic rotation, fumigation and using of clean planting materials.

**Keywords:** Nematodes; *Aphelenchoide*; *Heterodera*; bio-control; Periodic rotation and rotation

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### Introduction

A major global challenge in the coming years will be to ensure food security and to feed the increasing human population. Nowhere will the need to sustainably increase agricultural productivity in line with increasing demand be more pertinent than in resource poor areas of the world, especially Africa, where populations are most rapidly expanding. Although a 35% population increase is projected by

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2050 [41], an increase in food demand in the order of 75% is anticipated, due to economic development and changes in food preferences [19]. Significant improvements are consequently necessary in terms of resource use efficiency. In moving crop yields towards an efficiency frontier, optimal pest and disease management will be essential, especially as the proportional production of some commodities steadily shifts. With this in mind, it is essential that the full spectrums of crop production limitations are considered appropriately, including the often overlooked nematode constraints.

Nematodes are the most abundant group of multicellular animals on earth in terms of numbers of individuals. Although over 4,100 species of plant-parasitic nematodes have been identified [10], new species are continually being described while others, previously viewed as benign or non-damaging, are becoming pests as cropping patterns change [23]. However, the plant parasitic nematodes of economic importance can be grouped into relatively restricted specialized groups that either cause direct damage to their host or act as virus vectors. In a square meter of moderately fertile soil to 30 cm depth, there are about 50 million nematodes. About half of all nematode species are marine nematodes, 25% are free-living, soil inhabiting nematodes, 15% are animal and human parasites and 10% are plant parasites. Today, even with modern technology, 5-10% of crop production is lost due to nematodes in developed countries. So, the aim of this work was to review some agricultural nematodes genera, species they contain and their management methods.

### Literature Review

#### Impact of Plant Parasitic Nematodes

Although over 4,100 species of plant-parasitic nematodes have been identified [10], new species are continually being described while others, previously viewed as benign or non-damaging, are becoming pests as cropping patterns change [23]. However, the plant parasitic nematodes of economic importance can be grouped into relatively restricted specialized groups that either cause direct damage to their host or act as virus vectors. Most affect crops through feeding on or in plant roots, whilst minorities are aerial feeders. In addition to direct feeding and migration damage, nematode feeding facilitates subsequent infestation by secondary pathogens, such as fungi and bacteria [30].

Although plant parasitic nematodes are among the most widespread pests, and are frequently one of the most insidious and costly [39], data on their economic impact remain less than comprehensive, especially for crops produced in resource poor areas. In the tropical and sub-tropical climates, crop production losses attributable to nematodes were estimated at 14.6% compared with 8.8% in developed countries. Perhaps more importantly, only ~0.2% of the crop value lost to nematodes is used to fund nematological research to address these losses [33]. One difficulty with assessing nematode impact is that damage resulting from nematode infection is often less obvious than that caused by many other pests or diseases. Losses that result from nematode attack may not necessarily be as a consequence of direct cell death, necrosis or 'diseased' tissue but may derive from other more insidious aspects, such as interference with the root system, reducing their efficiency in terms of access and uptake of nutrients and water; to the unaware, nematode-affected plants present typical drought and nutrient stress symptoms, which are easily and often misdiagnosed. On *Musa* spp. (bananas and plantains) nematode damage affects root efficiency on the one hand, but additionally leads to root necrosis and death, undermining plant anchorage; heavily infected bunch-bearing plants can topple due to poor root anchorage leading to total loss of the unripe fruit [15]. The degree of damage a nematode causes can also be dependent upon host and age.

In addition, prevailing soil, environmental and climatic conditions all influence the threshold population density, above which measurable damage occurs. For example, *Tylenchorhynchus martini* causes damage on sugarcane at populations between 600 and 6,400/plant, whilst on onions just 5 individuals per seedling of *Pratylenchus penetrans* will result in serious damage ([www.encyclopedialive.com](http://www.encyclopedialive.com)).

#### Distribution of Plant Parasitic Nematodes

On a global scale the distribution of nematode species varies greatly. Some are cosmopolitan, such as certain *Meloidogyne* spp. while others are particularly restricted geographically e.g. *Nacobbus* spp. or are highly host specific, such as *Heterodera carotae* which attacks

only carrots. Some crops may have very few nematode pests while others have a particularly wide range of genera and species associated with them, such as sugar cane and rice, leading to difficulties for nematode control strategies. Distribution maps and host range data are available and updated regularly as a useful source for determining nematode damage potential (<http://www.cabi.org/dmpd>). Although plant parasitic nematodes are among the most widespread pests, and are frequently one of the most insidious and costly [39], data on their economic impact remain less than comprehensive, especially for crops produced in resource poor areas.

### Genera, species and management methods of some agricultural nematodes

**Aphelenchoide:** Is a genus of plant pathogenic foliar nematodes.

**List of species:** *A. besseyi*, *A. bicaudatus*, *A. centralis*, *A. clarus*, *A. confusus*, *A. vigor*, *A. dactylocercus*, *A. obtusus*, *A. parietinus*, *A. pusillus* and *A. sacchari*.

**Adaptation:** Aphelenchoide is more commonly associated with temperate climates, even though it can be found in both tropical and temperate localities. It is best suited to thrive and reproduce when in highly humid environments, where it tends to be more active in infesting hosts than in dryer environments [18]. The optimal temperature for reproduction is 17°C-23°C [16].

**Morphology:** Nematode in this genus is 0.5-1.2 mm long and slender and also has a large meta-corpus, dorsal overlap of the esophageal glands over the intestine. They have a slender stylet with small, distinct knobs. Dorsal esophageal gland opens into lumen of esophagus in metacarpus, just anterior to the pump chamber. Sub-ventral esophageal glands open into lumen of esophagus in metacarpus, posterior to the pump chamber. Spermatheca with sperm in outstretched female gonad, the tail is mucronate (has terminal spikes) in some species and Males have no bursa and have rose-thorn-shaped spicules.

**Host and symptom:** The genus has a wide host-range; plant-feeders usually associated with leaves and buds but many species are fungal feeders. It is an important disease in chrysanthemum and other ornamentals. A common symptom is seen when the nematode is feeding in the foliar tissue. Angular lesions are formed, which are chlorotic at first then turn necrotic as the feeding persists [17].

**Feeding habit:** Endoparasite in leaves, but also feeds ecto-parasitically on leaf and flower buds in some plants. Many species of *Aphelenchoides* feed on fungi. Fungal-feeding species are common in soil and generally appear to have shorter stylets (< 8 µm) than plant-feeding species.

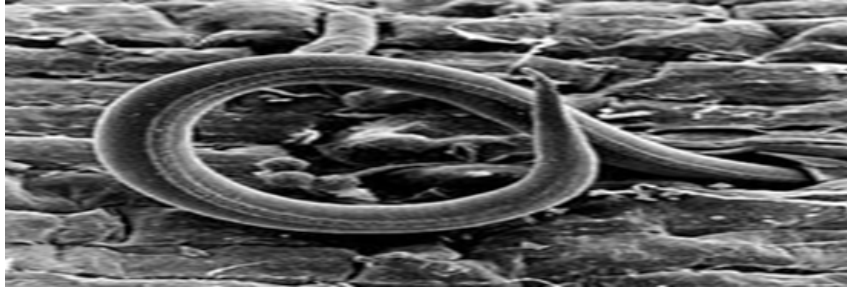
**Management:** Sanitation of fields and equipments like Pots potting soil, and tools should be cleaned by baking or steaming at 180-200 degrees Fahrenheit for 30 minutes [37]. Avoid period of wetness, using appropriate irrigation scheme (Drip irrigation), hot water treatment (115°F for 5 minutes) for dormant plant materials such as bulbs, runners of cutting and finally by using host plant resistance.

**Meloidogyne:** Root-knot nematodes. It is one of the three most economically damaging genera of plant-parasitic nematodes on horticultural and field crops.

**List of species:** The genus includes more than 90 species [22], with some species having several races. Four Meloidogyne species (*M. javanica*, *M. arenaria*, *M. incognita*, and *M. hapla*) are major pests worldwide, with another seven being important on a local basis [11].

**Adaptation:** Root-knot nematodes are distributed worldwide. Especially in warm climates. During dry conditions, a dried eggshell can also decrease water loss rate by changing its permeability [5]. Additional research on eggshell permeability was done by [14], and he observed that, the lipid layer of the eggshell played a major role for lowering the water loss during desiccation. Different activities such as growth and development, mobility, infection capability and hatching are affected by its surrounding temperature [13]. Meloidogyne arenaria require at least 12.2°C with short photoperiod for their egg mass production.

## Morphology



**Figure 1:** Morphology of *Meloidogyne*.

**Host and symptom:** About 2000 plants worldwide are susceptible to infection by root-knot nematodes and they cause approximately 5% of global crop loss [33]. Root-knot nematode larvae infect plant roots, causing the development of root-knot galls that drain the plant's photosynthate and nutrients. Infection of young plants may be lethal, while infection of mature plants causes decreased yield. *Meloidogyne* occurs in 23 of 43 crops listed as having plant-parasitic nematodes of major importance, ranging from field crops, through pasture and grasses, to horticultural, ornamental and vegetable crops [35].

**Feeding habit:** Migratory endoparasite *Meloidogyne* - Root Knot

**Management:** Root-knot nematodes can be controlled with biocontrol agents *Paecilomyces lilacinus*, *Pasteuria penetrans* [6] and Juglone. [8]. Also by managing our fields.

*Heterodera* is a genus of nematodes in the family Heteroderidae. Members of the genus are obligate parasites and different species attack different crops, often causing great economic damage. The genus is unique among nematode genera because of the ability of the female to transform into a tough, brown, cyst which protects the eggs which have been formed within her body. The name *heterodera* "refers to the different 'skins' of female and cyst [36].

**List of species:** by 2009, more than 40 species of the genus *Heterodera* had been molecularly characterized by sequencing the ITS-rRNA genes and by PCR-RFLP profiles. These tools are so far the best available for identifying cyst-forming nematode [38]. *Heterodera amygdali*, *Heterodera arenaria*, *Heterodera aucklandica*, *Heterodera avenae*, *Heterodera bergeniae*, *Heterodera bifenestra*, *Heterodera cacti*, *Heterodera cajani*, *Heterodera canadensis*, *Heterodera cardiolata*, *Heterodera carotae*, *Heterodera ciceri*, *Heterodera cruciferae*, *Heterodera delvii*, *Heterodera elachista*, *Heterodera filipjevi*, *Heterodera gambiensis*, *Heterodera glycines*, Soybean cyst nematode, *Heterodera goettingiana*, *Heterodera hordecalis*, *Heterodera humuli*, *Heterodera latipons*, *Heterodera longicaudata*, *Heterodera medicaginis*, Alfalfa cyst nematode, *Heterodera oryzae*, *Heterodera oryzicola*, *Heterodera rosii*, *Heterodera sacchari*, *Heterodera schachtii*, *Heterodera tabacum*, *Heterodera trifolii*, *Heterodera ustynovi* and *Heterodera zae*, corn cyst nematode.

**Adaptation:** J2 of soybean cyst nematode *Heterodera glycines* hatched in water at optimum conditions but at the end of the plant growing season when environment is becoming complex, most of the J2 remains in the cyst and hatching is solely dependent on hatching factors, irrespective to the origin of hatching factors; i.e. natural or artificial. Other cyst nematodes, such as *H. carotae*, *H. goettingiana* *H. sacchari* contain the same characteristics. Even, RKN, *M. chitwoodi* and *M. triticoryzae* also the same features for hatching of J2. Entomopathogenic nematode *Heterorhabditis megidis* also retains cuticle sheath that provides them lowering their drying in unfavorable environment.

**Morphology:** Female swollen; males vermiform. Female body forms a cyst. Anterior neck-like region; swollen body shape-lemon, round, or pyriform shape (about 0.5-0.6 mm diameter). Weak cephalic framework. Metacarpus enlarged and fills neck region. Diovarial;

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prodelphic; ovaries coiled or reflexed. Vulva sub terminal; anus terminal. Pre-parasitic stage: vermiform J2, 300-500 µm long. Heavily sclerotized head framework; head offset. Stylet prominent with anteriorly-directed knobs. Ventrally-lateral overlap of esophageal glands over intestine. Genital primordia visible. Pointed tail. Post-parasitic stages: swollen. Stylet weak, sometimes not visible in 3<sup>rd</sup> and 4<sup>th</sup> stage. Developing gonads visible.

**Host and symptom:** Generally narrow host range and specialized. Little mechanical injury due to the parasitism, body of female on outside of the root and no cell division stimulated. Branch rootlets may be stimulated near the point of infection. General debilitation and reduction in efficiency of the root system. Chlorosis, stunted growth, wilted plants.

**Feeding habit:** Migratory endoparasite, Heterodera - Cyst. Juveniles enter root to region of developing vascular tissues by direct penetration of cells. Juveniles may feed from individual cells as they cut through cell walls while migrating to permanent feeding site region.

**Management:** Management strategies vary with species and biology. Management of this genus is usually difficult due to prolonged viability. Possibilities include:-.Prevention/Exclusion: attempt to prevent spread, for example quarantine of potato growing areas of Long Island, New York. Clean equipment before entry into field, but cysts can also be spread by wind and birds. Crop rotation: sugar beets grown once every 4 years in recommended rotation sequence in southern California. Clean seed sources: Cysts are readily introduced in infested planting stock or seed.

Longidorus is a genus of needle nematode. Some of its species are plant pests [31]. They may also transmit important plant viruses [42].

**List of species:** As of 2015, there are more than 150 described species. From these species *Longidorus breviannulatus*, *L. attenuatus*, *L. caespiticola*, *L. nudus* and *L. striola* among them.

**Adaptation:** Worldwide, usually moist environments. Although widely distributed they are sometimes rather difficult to find.

**Morphology:** This is needle nematodes, like dagger nematodes, are very large, ranging in length from 2 to 8 mm. In needle nematodes, odontostyle is long; the total length of odontostyle and odontophore is about 150 µm. The odontostyle is connected to the lining of cheilostome by a cuticular membrane that becomes variously folded, with refractory qualities - the "guiding ring." In *Longidorus*, the guiding ring is located within two lip-widths of the anterior portion of the nematode. Opening of amphid is pore-like in *Longidorus* and slit-like in *Paralongidorus*. Females of *Longidorus* have two ovaries that are opposed and reflexed.

**Host and symptom:** at least seven species of *Longidorus* are reported from grape vineyards throughout the world. They include *L. attenuatus* Hooper, *L. diadecturus* Eveleigh and Allen, *L. elongatus*. Thorne and Swanger, *L. iranicus* Sturhan and Barooti, *L. macrosoma* Hooper, *L. protae Lambertii* and *Bleve-Zacheo*, and *L. sylphus* Thorne. Relatively little critical biological and ecological data have been developed for this genus on grapes. Severe stunting of loblolly pine seedlings.

**Feeding habit:** migratory ecto-parasite – Needle. This genera share a migratory ecto-parasitic habit. They do not enter into host root tissue but feed externally by inserting their mouth stylets into root cells from the root surface.

**Management:** Periodic rotation from pine production to grow cover crops consisting of small grains important management practices this species [12].

*Pratylenchus* is a genus of nematodes known commonly as lesion nematodes [7]. They are parasitic on plants and are responsible for root lesion disease on many taxa of host plants in temperate regions around the world.

**List of species:** *Pratylenchus exilis*, *P. fallax*, *P. flakkensis*, *P. gibbicaudatus*, *P. goodeyi*, *P. hexincisus*, *P. impar*, *P. jordanensis*, *P. kumaoensis*, *P. loofi*, *P. loosi*, *P. microstylus*, *P. morettoii*, *P. mulchandi*, *P. neglectus*, *P. penetrans*, *P. pinguicaudatus*, *P. pratensis*, *P. pseudopratensis*, *P. ranjani*, *P. scribneri*, *P. similis*, *P. subpenetrans*, *P. subranjani*, *P. tenuis*, *P. teres*, *P. thornei*, *P. vulnus*, *P. zaeae*.

**Adaptation:** *Pratylenchus* abundance is affected by soil moisture, mineral components, temperature; aeration, organic matter, and pH [25]. They are more common in sandy soils and land with weed. *Pratylenchus* can endure a wide range of environmental conditions. Moist temperate soils are ideal conditions for breeding and migrating underground, but they can persist in warm and dryer environments. In very dry conditions they are quiescent until moisture increases and plants resume growth. Most lesion nematodes remain inactive when soil temperatures are below 59°F (15°C) and are not fully active until temperatures rise above 68°F (20°C).

**Morphology:** lesion nematodes are small nematodes with adults, being usually less than 1 mm long. The head region is low and flattened, with 2-4 head annuli. It has distinct head skeleton, continuous with the body contour. The stylet is 20 µm or less, and moderately developed with distinct basal knobs. The esophagus has a well-developed median bulb, and the posterior gland lobes overlap the intestine ventrally. The female has posterior vulva (V= 70-80%) with a single anterior gonad and a short post vulval sac; it is tall, cylindrical to conoid, and with two to three anal body widths long. The male tail is conical with a distinct bursa that reaches the tail tip.

**Host and symptom:** root lesion nematodes infect a great variety of hosts. *Pratylenchus penetrans* alone has over 350 host plants. They include agricultural crops such as soybeans [4], potatoes, corn, bananas, and wheat. The genus is found most often in corn [29]. Signs of disease are similar in most plants and generally include necrotic lesions of the roots [3]. The lesions can also be entrances for pathogenic bacteria and fungi, which produce secondary infections [2]. Above ground the plant becomes stunted, chlorotic, and wilted, and it often dies. A crop field may be patchy as plants wither and die. Root lesion nematodes can cause significant yield losses [3].

**Feeding habit:** migratory endo parasite *Pratylenchus*– Lesion. Feeding and migration by lesion nematode can result in visible lesions forming on roots. Lesion nematodes feed and reproduce in the root and move around, unlike the cyst or root-knot nematodes, which may stay in one place. They usually only feed on the cortex of the root [20]. Species are distinguished primarily by the morphology of the stylets [24].

**Management:** One common management option for crop-pest lesion nematodes is soil fumigation and nematicides. This is not effective for all species, and can be expensive for growers. Water immersion is another option. Infected plants are immersed in a hot water bath for about 30 minutes, which rids them of nematodes but does not harm the plant. This method has been successful for *P. coffeae*. Crop rotation can help control the nematode load in the soil because different plants are susceptible to different *Pratylenchus* species. Selecting resistant plant varieties and cultivars can reduce nematode problems. This is currently the only option for control of *P. vulnus*.

*Pratylenchus* is a genus of nematodes (round worms). Many of the species in this genus are plant pathogens.

**List of species:** *Paratylenchus aquaticus*, *P. latescens*, *P. projectus*, *P. vandenbrandei*, *P. variatus*, *P. curvatus*, *P. elachistus*, *P. hamatus*, *P. macrophallus*, *P. microdorus*, *P. projectus* and *P. tenuicaudatus*.

**Adaptation:** the nematode is found in all temperate regions around the world, because of the wide host range. For normal nematode activity a moisture film is needed for movement of the nematode. Soil moisture, relative humidity, and related environmental factors directly affect nematode survival.

**Morphology: Females:** Usually less than 0.5 mm long, vermiform, not swollen, except that gravid female may swell anterior to the vulva. Labial framework weakly sclerotized (except in *P. israelensis* and *P. sheri* where it is stronger). There is a strong stylet (from 12 to 40 µm, usually about 36 µm) which allows the nematode to feed several cell layers below the root surface. Females have a single outstretched ovary and the vulva is in the posterior region of the body. Spermatheca appears as a modification of cells, or pouch-like sac, at the anterior end of the uterus.

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**Males:** Have reduced feeding structures, with stylet reduced or absent, and degenerate esophagus. They probably do not feed. However, they may be common in the population.

**Juveniles:** Juvenile stages resemble the female, but with a smaller stylet. The stylet is usually absent in the J4 stage. The J4 is a dauer (survival) stage, and development will not proceed beyond this stage unless a host plant is present.

**Host and symptom:** root lesion nematode has a wide host range, including hosts like apple, cherry, conifers, roses, tomato, potato, corn, onion and sugarbeets, and ornamentals such as Narcissus. More than 164 hosts for *P. penetrans* have been recorded [40]. In the host range there are some hosts that are susceptible, wheat, oat, field pea, faba bean, and chickpea, and some that are moderately susceptible, barley and canola [9]. Some general symptoms that are produced on infected plants include poor growth and chlorotic foliage.

**Feeding habit:** migratory ecto-parasite, *Paratylenchus*-Pin. This genera share a migratory ecto-parasitic habit. They do not enter into host root tissue but feed externally by inserting their mouth stylets into root cells from the root surface.

**Management:** fumigation with 1, 2-dibromoethane can be an effective tool to reduce the number of *Paratylenchus* spp. in the soil, but the process typically kills most of the beneficial soil fauna as well. This can have additional negative repercussions on the soil health. Fumigation would also kill the plants you are trying to cultivate, so the soil would need to be fumigated before the planting date. Crop rotation with small grains is also another management tool for *Paratylenchus hamatus* since they typically parasitize on fruit and vegetable crops. For post-planting control some non-fumigant nematicides can be used, but the effectiveness is not always consistent.

*Radopholus* nematode known commonly as the burrowing nematode [34]. It is a parasite of plants, and it is a pest of many agricultural crops.

**List of species:** *Radopholus citrophilus* and *R. similis*.

**Adaptation:** the nematode was first described from necrotic tissue in a species of *Musa*, the banana genus, in 1891. It is one of the most important root pathogens of banana crops [26]. It causes yield losses of up to 30 to 60% in many countries. It is known in temperate regions worldwide [26].

**Morphology:** adults and juveniles are vermiform in shape. Adults are sexually dimorphic. The male has a poorly developed stylet, a knob-like head, and a sharp, curved spicule enclosed in a sac. The male is 500 to 600  $\mu\text{m}$  in length, while the female is about 550 to 880  $\mu\text{m}$  long. The female has a well-developed stylet. Both male and female have long, tapered tails with rounded or indented ends [4]

**Host and symptom:** over 350 known hosts. Burrowing nematode may be the most important nematode pest on fruit crops (especially citrus and banana) in the tropics. Most of the banana and plantain cultivars are attacked by *R. similis*. Other primary hosts include: citrus, coconut, ginger, palm, avocado, coffee, *Hibiscus* sp., prayer plant, black pepper, sugarcane, tea, vegetables, ornamentals, trees, grasses and weeds. They argued that not enough populations had been studied, and that routine separation was very difficult. The citrus race attacks both citrus and banana.

**Feeding habit:** migratory endo-parasite in all life stages

**Management:** the nematode load in the soil can be reduced with fumigation and crop rotation. Cover crops that are not susceptible to the nematode, such as *Crotalaria* or *Tagetes*, can be sown. Disease-free sprouts raised from clean tissue cultures can be used.

*Trichodorus* is a genus of terrestrial root feeding (stubby-root) nematodes in the Trichodoridae family (trichorids), being one of five genera. They are economically important plant parasites and virus vectors.

**List of species:** *Trichodorus obtusus* and *T. proximus*

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**Adaptation:** widespread in sandy or sandy loam soils. Highest densities occur at 20-30 cm, rarely deeper, and the nematode shows a high tolerance to low pH soils.

**Morphology:** body configuration usually rounded at both ends. Cuticle tends to swell in water and fixative when nematodes are killed. Curved onchio style with dorsal groove.

**Host and symptom:** nematodes in the Trichodoridae have wide host ranges. Root tip damage causes root elongation to cease hence “stubby root” symptoms.

**Feeding habit:** migratory ecto-parasite, Trichodorus - Stubby Root. Feeding by stubby-root nematode causes the root tip to stop growing and appear stubby.

**Management:** use of nematicides on subsequent crops. Similarly organophosphate and carbamate nematicides such as aldicarb and fenamiphos were very effective for management.

*Xiphinema* is a very large, diverse and complex group. It may be divided into the americanum and non-americanum lineages. The americanum lineage consists of around 55 nominal species and cryptic species, many of which are morphologically indistinguishable, and the non-americanum groups of more than 200 more-or-less distinguishable species.

**List of species:** [21] recognized 172 valid species of *Xiphinema* by that time and more have been added since. They developed a polytomous key which was split into eight groups on the basis of development of the anterior female genital branch, uterine differentiation and tail shape. From these species *Xiphinema abrantinum*, *X. aceri*, *X. aequum*, *X. americanum*, *X. artemisiae*, *X. bakeri*, *X. barensis*, *X. basilgoodeyi* and *Xiphinema belmontense* are among them.

**Adaptation:** *Xiphinema* is found widely throughout most of the world and it is found in all of the continents, except for Antarctica. This species of nematode is also found to be sensitive to soil pH, and they are found most frequently in soils with a pH of 6.0 or higher [21].

**Morphology:** *Xiphinema* are large nematodes, with an adult length between 1.5mm – 5.0mm. They have a long protrusible odontostyle, with 3 basal flanges at the posterior end of the stylet and a relatively posterior guiding ring when compared to the genus *Longidorus*. The odontostyle is lined with cuticle and alongside the esophagus serves as a good surface for viruses such as arabis mosaic virus to form a monolayer, which can be vectored to healthy plants. *Xiphinema* have a two-part esophagus, which does not contain a metacarpus. A modification in the posterior end of the esophagus forms a muscular posterior bulb, which can generate a pumping action similar to that of a metacarpus in other plant parasitic nematodes.

The number of males varies from abundant to sparse depending on the species. Males have paired spicules but the gubernaculum and bursa are absent. Males of different species can be characterized using the varying number and arrangement of papillae. Females have 1 or 2 ovaries.

**Host and symptom:** many species of *Xiphinema* have wide host ranges. Five species belonging to the *Xiphinema americanum*-group have been detected on tomato, grape, oak, sea grape, pines, hackberry, Brazilian pepper and citrus in Florida and Morocco. Other hosts include Sudan grass (sorghum), cotton, pearl millet, turf grasses, legumes, sugarcane, chili pepper, banana, sugar beet, corn, weeds, cassava and many more. The *Xiphinema* genus is distributed worldwide. Two economically important *Xiphinema* species; *X.index* and *X.americanum*. Species of *Xiphinema* are primarily problematic in biennial and permanent crop situations. Except for damage to emerging seedlings, they are seldom of major importance in annual crops as they rarely attain high population levels when soil is frequently tilled. However, in the case of species that are vectors of plant viruses, the damage caused by the viruses may be independent of the abundance of nematodes. The damage dagger nematodes cause to root systems is similar to that of other plant ecto-parasitic nematodes. The feeding at the meristematic root-tips destroys root cells and reduces root volume. Terminal galling of roots of woody plants is common. The above-ground effects of damaged roots are stunted growth of crops and patchy fields.

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**Feeding habit:** ecto-parasites; feed along root, including root tips. Species of *Xiphinema* feed at root tips and along the length of young roots. Feeding along roots produces symptoms similar to those caused by other cortical feeding nematodes (disintegration of the cortex); those that feed at root tips produce very different symptoms, including root-tip galling and stunting.

**Management:** Control of *Xiphinema* spp. on many annual crops may not be of major importance since species of this nematode seldom attain high population levels when soil is frequently tilled.

*Anguina* (Seed-gall nematode, Seed and leaf gall nematode, Seed gall nematode, Shoot gall nematode) is a genus of plant pathogenic nematodes.

**List of species:** *Anguina agrostis*, *A. pacificae*, *A. tritici*, *Anguina agropyri*, *Anguina agropyronifloris*, *Anguina agrostis*, *A. cecidoplaste*, *A. funesta*, *A. graminis*, *A. microlaenae*, *A. pacificae*, *A. spermophaga*, *A. amsinckiae*, *A. australis*, *A. balsamophila*, *A. caricis*, *A. lolii*, *A. agrostis*, *A. millefolii*, *A. phalaridis*, *A. Agrostis*, *A. poophila*, *A. agrostis*, *A. tumefaciens*.

**Adaptation:** if we take *Anguina tritici* it has special adaptation aptitude against desiccation. Commonly, life cycle of a PPN is divided into different distinct stages such as egg, four juvenile stages (J1, J2, J3 and J4) and adults and different major PPN also exhibits different adaptation mechanism at their different life stages. Eggs of RKN are laid in mucoid protein mass that provides safety to eggs water loss and predators. Furthermore, extreme temperature makes this glycoprotein shriveled and hard that promotes mechanical pressure and hinders the hatching of J2 larva that is prone to drought environment. Additionally, gelatinous matrix defends the eggs from the attack of some soil microorganism as was observed in *M. javanica*. During dry conditions, a dried eggshell can also decrease water loss rate by changing its permeability. Under drying condition, species of *Anguina* showed coiling and clumping like features in their life cycle that helps to avoid water loss by reducing their surface. On the other hand, J2 of 2 gall producing nematode *Anguina tritici* and *A. pacificae* become anhydrobiotic but remain uncoiled and survived many years. So, coiling is not obligatory for survival during desiccation.

**Morphology:** the lip region is slightly offset (3-4  $\mu\text{m}$  high) and the nematode has a very short stylet (10  $\mu\text{m}$ ). *A. agrostis* has a three-part esophagus. The procorpus is cylindrical with a swelling near its midsection. The metacarpus is ovoid in shape and the isthmus is long and narrow. The post corpus has three glands and is highly developed, but does not overlap the intestine. On average, infective juveniles (J2) measure 530  $\mu\text{m}$  and dauer juveniles measure 760  $\mu\text{m}$ ; the increase in size is due to feeding and the formation of lipid droplets or storage bodies. Females range from 1.5-2.7 mm in length, are curved ventrally, and are swollen. The vulva is located near the posterior end and one ovary is present. Males are smaller (1.1-1.7 mm in length), are not as swollen, and have a small bursae that extends sub-terminally. One testis is present.

**Host and symptom:** *A. agrostis* infects bent grasses within the genus *Agrostis* as well as annual and perennial rye grasses (*Lolium* spp.). In seed gall forms, developing seed is converted to a nematode feeding site. Galls do not germinate as seeds.

**Feeding habit:** endo-parasites; all species produce galls on plant leaves or seeds, especially on grasses.

**Management:** field sanitation, use of clean seed, following appropriate postharvest operation and dry cleaning

*Ditylenchus* is a genus of plant pathogenic nematodes.

**List of species:** *Ditylenchus anchilisposomus*, *D. caudatus*, *D. clarus*, *D. destructor*, *D. dipsaci*, *D. microdens*, *D. obesus*, *D. valveus*, *Dolichodera*.

#### Adaptation

Under drying condition, species of *Ditylenchus* showed coiling and clumping like features in their life cycle that helps to avoid water loss by reducing their surface [10]. *Ditylenchus myceliophagus* also lessen their water loss becoming coiled. Furthermore, at the last

stage of the crop growing season, *D. dipsaci*, stops their development at J4 stage due to shortage of food and make large aggregations and start coiling. This attribute known as 'eelworm wool' that helps them to remain alive for many years at desiccated condition by the sacrifice of peripheral J4s of this aggregation. Rice grain nematodes, *Aphelenchoides besseyi* also stops their multiplication at ripening stage of rice and adults become coiled and clumped which helps them surviving for 2-3 years with dry.

**Morphology:** short stylet. Plant-feeding species generally have slightly longer stylet (10-14 $\mu$ m) than fungal-feeding species. Median with or without valve; isthmus not separated from glandular bulb by a constriction. Post corpus short; esophagus short and butting intestine esophagus, or long - when long, may overlap the intestine. Female: Single ovary directed forward, short or long, sometimes reaching esophageal region and/or flexed; oocytes in one/two rows; columned uterus with four rows of four cells; post-uterine sac (PUS) present or absent. Mature female may be slightly swollen.

**Host and symptom:** it attacks rice, potato, mushrooms and some other cereal and vegetable crops. All stages are infective, penetration at shoot apical meristem. Pectinase production is speculated in degradation of the middle lamella that results in cell separation and cavity formation during infection. Swelling, galling, stunting, distortion, and necrosis result from serious infection. Small numbers of nematodes are capable of causing serious damage. No necrosis and little damage are seen in resistant varieties with incompatible reactions. 4<sup>th</sup> stage juvenile survival stage (up to 23 years). Produce "Nema Wool" an anhydrobiotic survival structure. Cause galling and distortion to leaves, brown rings in bulbs.

**Feeding habit:** non-derived, migratory ecto-parasites and endo-parasites of stems, bulbs, and tubers. Obligate parasite of higher and lower plants and/or fungi, found in soil or above ground.

**Management:** use of resistant varieties, sanitation practice like burning of stubbles after harvest, deep.

### Summary and Future Direction

Although over 4,100 species of plant-parasitic nematodes have been identified, new species are continually being described while others, previously viewed as benign or non-damaging, are becoming pests as cropping patterns change. However, the plant parasitic nematodes of economic importance can be grouped into relatively restricted specialized groups that either cause direct damage to their host or act as virus vectors. Most affect crops through feeding on or in plant roots, whilst minorities are aerial feeders. In addition to direct feeding and migration damage, nematode feeding facilitates subsequent infestation by secondary pathogens, such as fungi and bacteria. Significant improvements are consequently necessary in terms of resource use efficiency. In moving crop yields towards an efficiency frontier, optimal pest and disease management will be essential, especially as the proportional production of some commodities steadily shifts. With this in mind, it is essential that the full spectrums of crop production limitations are considered appropriately, including the often overlooked nematode constraints about half of all nematode species are marine nematodes, 25% are free-living, soil inhabiting nematodes, 15% are animal and human parasites and 10% are plant parasites. Today, even with modern technology, 5-10% of crop production is lost due to nematodes in developed countries. So, the aim of this work was to review some agricultural nematodes genera, species they contain and their management methods.

In this review work the species, feeding habit, morphology, host and symptoms they show on the effected plant and management of eleven nematode genera was reviewed. The review result indicated that all of the reviewed nematodes were different in terms of the above mentioned character; some have wide host range like *Aphelenchoide* while some have generally narrow host range and specialized like *Heterodera*. Some are ecto-parasite and some are endo-parasite and some are both in different part of the plant in their feeding habit like *Aphelenchoide* it is endoparasite in leaves, but also feeds ecto-parasitically on leaf and flower buds in some plants. Most of them have large number of species. They can be managed by using different methods like; Sanitation of fields and equipment like Pots potting soil, bio-control agents *Paecilomyces lilacinus*, Periodic rotation, fumigation and using of clean planting materials. Further research has to be done to evaluate the efficacy of some promising botanicals for the management of some nematode like root rot nematode under field condition of different agro-ecologies and improve their application technology. Other area of further research

may include the use of such promising botanical extracts in integrated pest management strategy and evaluation of their effects on other soil-borne plant diseases and characterization of nematodes using modern techniques like molecular characterization has to be done for formulating of effective management practices.

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