<u>Introduction – Brief history and development of nematology in India and abroad</u>

Introduction

Nematology is an important branch of biological science, which deals with a complex, diverse group of round worms known as Nematodes that occur worldwide in essentially all environments. Nematodes are also known as eelworms in Europe, nemas in the United States and round worms by zoologists. Many species are important parasites of plants and animals, whereas others are beneficial to agriculture and the environment. Nematodes that are parasites of man and animals are called helminthes and the study is known as Helminthology. The plant parasitic forms are called nematodes and the study is known as Plant Nematology. The name nematode was derived from Greek words nema (thread) and oides (resembling).

Annual crop losses due to these obligate parasites have been estimated to be about $ 78 billion wordwide and $ 8 billion for U.S. growers. The estimated annual crop loss in Tamil Nadu is around Rs. 200 crores.

The soils in a hectare of all agroecosystem typically contain billions of plant parasitic as well as beneficial nematodes. The damage to plants caused by nematodes is often overlooked because the associated symptoms, including slow growth, stunting and yellowing, can also be attributed to nutritional and water related disorders.

HISTORY OF PLANT NEMATOLOGY

In light of the high population numbers of nematodes. N.A. Cobb (1915) who is considered to be the father of American Nematology, provided a dramatic description of the abundance of nematodes. He stated, “If all the matter in the universe except the nematodes were swept away, our world still would be dimly recognizable we would find is mountaintops, valleys, rivers, lakes and oceans represented by a film of nematodes. The statement “ sowed cockle, reaped no corn” in Shakespeare’2 “Love’s Labour’s List”’ act4, scene 3, as suggested by throne (1961) possibly the first record of plant parasitic nematodes in 1549. The nematode that Throne suspected to be in that reference actually was described by Needham in 1743. Subsequently, discovery of microscope and developments in various disciplines of science led to the discovery of plant parasitic nematodes and the disease caused by them. Some of the important milestones on the history of plant nematology are listed below in chronological order.

1743 – Needham – Discovery of wheat seed gall nematode *Anguina tritici*, the first plant parasitic nematode to come to the attention of the early investigators.

1855 - Berkeley – Determination of root-knot nematode, *Meloidogyne* spp. to cause root galls on cucumber plants in greenhouse in England.

1857 - Kuhn – Reported the stem and bulb nematode, *Ditylenchus dipsaci* infesting the heads of teasel.

1859 - Schacht - Report of sugarbeet cyst nematode, *Heterodera schachtii* from Germany.

1873 - Butschli – Descriptions of the morphology of free –living nematodes.

1884 - DeMan – Taxonomic monograph of soil and fresh water nematodes of the Netherlands.

1889 – Atkinson and Neal – Publication about the root-knot nematodes in the United States.

1892 – Atkinson-Report of root-knot nematode and *Fusarium* complex in vascular wilt of cotton.

1907 - N.A.Cobb – joined the USDA and considered to be the **Father of American Nematology.**

1914 – N.A.Cobb – Contributions to the Science of Nematology.

1918 – N.A. Cobb – Development of methods and apparatus used in Nematology.

1933 – T. Goodey – Book on “Plant parasitic nematodes and the diseases they cause”

1934 – Filipjev – Book on “Nematodes that are importance for Agriculture” translated from Russian to English in 1941 by S.Stekhovan uner the title “A Manual of Agricultural Helminthology”.

1943 – Carter-Description of nematicidal value of D-D which is used in the era of soil fumigation.

1945 – Christie – Description of the nematicidal value of EDB.

1948 – Allen – Taught the World's first formal university course in Nematology at the University of California, Berkeley.

1950 – Oostenbrink – Wrote a Book of on "The Potato Nematode, A dangerous parasite to Potato Monoculture".

1951 – Christie and Perry – Role of ectoparasites as plant pathogens. T.Goodey – Wrote a book on "Soil and fresh water nematodes". Food and Agriculture Organisation of the United Nations organized the first International Nematology course and Symposiumheld at Rothamstead Experiment Station, England.

1955 – European Society of Nematologists founded.

1956 – Nematologica – The first journal published entirely for Nematology papers from The Netherlands.

1961 – Society of Nematologists founded in the United States.

1967 – Organization of Tropical American Nematologists founded.

1969 – Journal of Nematology was first published by the Society of Nematologists, USA.

1973 – Nematologa Mediterranea – published from Italy.

1978 – Revue de Nematologie published from France

1930s – 1990s – Barron, Duddington, Mankau, Linford, Sayre and Zuckerman – they provided an insite on the Biological control of plant – parasitic nematodes. Enhanced understanding of antagonists and related biology enhancing the potential for practical biocontrol.

1940-s – 1990s – Triantaphyllou – Provided advancement in Cytogenetics, modes of reproduction/sexually – and information data base for genetics/molecular research. Enhanced understanding of evolution and taxa interrelationships.

1950s – 1990s – Caveness, Jones, Oostenbrink, Sasser and Seinhorst – International programme such as International *Meloidogyne* project – They expanded educational base of nematologists world wide and provided ecological – taxonomic data base.

1960s- 1990s – Nickle, Poinar and Steiner – Biological control of insects with nematodes.

1960s- 1990s – Brenner, Dougherty and Nicholas – *Caenorhabditis elegans* developmental biology and genetics – model system – provided fundamental information on cell lineage, behaviour, gene function ageing and overall genome for this model biological system.

In addition to the above, now the research advancement are in progress in the following areas in USA from the year 1990.

- Molecular markers for resistance genes, which provide efficiency of breeding for resistance.
- Cloning of resistance genes- Elucidation of the molecular fundamental knowledge on mechanisms of pathogenesis.
- Cloning of resistance genes- Elucidation of the molecular mechanism of resistance.
- Transgenic host resistance to plant parasitic nematodes – Great potential, but limited model system to date.

HISTORY OF NEMATOLOGY IN INDIA

Nematology as a separate branch of Agriculture Science in India has been recognized only about 37 years back. The history and development of Nemtology in India have been listed below in chronological order.

1901 –Barber reported root – knot nematode on tea in Devala Estate, Tamil Nadu, South India.

1906 – Butler reported root – knot nematode on black pepper in Kerala.

1913,1919 – Butler reported Ufra disease on rice in Bengal due to the infestation of *Ditylenchus angustus.*

1926, 1933 – Ayyar reported root – knot nematode infestation on vegetable and other crops in India.

1934, 1936 – Dastur reported white tip disease of rice caused by *Aphelenchoides besseyi* in Central India.

1959 – Prasad, Mathur and Sehgal – reported cereal cyst nematode for the first time from India.

1961 – Nematology laboratory established at Agricultural College and Research Institute, Coimbatore, with the assistance of Rockfeller Foundation and Indian Council of Agricultural Research.

1961 – Nematology unit established at the Central Patato Research Institute, Simla.

1963 – Laboratory for potato cyst nematode research established at Uthagamandalam with the assistance of Indian Council of Agriculture Research

1964 – First International Nematology course held at IARI., NEW Delhi.

1966 – Nair, Dass and Menon reported the burrowing nematode on banana for the first time from Kerala.

1966 – Division of Nematology established at IARI, New Delhi

1968 – First South – East Asian Post – Graduate Nematology course held in India.

1969 – Nematological Society of India founded and first All India Nematology Symposium held at IARI, New Delhi.

!969 – 1970 – Third South – East Asian Nematology course conducted at New Delhi.

1969 – 1970 – Third South – East Asian Nematology course conducted at New Delhi.

!971 – Indian Journal of Nematology published

1971 – Fourth South – East Asian Nematology course at New Delhi.

1972 – First All India Nematology Workshop held at IARI, New Delhi

1973 – Fifth South – East Asian Nematology Course at New Delhi.

1975 – Sixth South – East Asian Nematology Course at New Delhi.

1976 – Summer Institute in Phytonematology held at Allahabad.

1977 – Department of Nematology established at Haryana Agriculture Unviersity, Hisar.

1977 – All India coordinated Research Project (AICRP) on nematode pests of crops and their control started functioning in 14 centres in India with its Project Co-ordinator at IARI, New Delhi.

1979 – M.Sc. (Ag.) Plant Nematology course started at Tamil Nadu Agricultural University, Coimbatore.

1979- All India Nematology Workshop and Symposium held at Orissa University of Agricultural University, Coimbatore

1979 – All India Nematology Workshop and Symposium held at Orissa University of Agriculture and Technology, Bhubaneswar

1979 – Seventh South – East Asian Nematology course at New Delhi.

1981 – Department of Nematology established at Tamil Nadu Agricultural University, Coimbatore.

1981 – All India Nematology Workshop and Symposium held at Tamil Nadu Agricultural University, Coimbatore.

1982 – Department of Nematology established at Rajendra Agriculture University, PUSA, Bihar

1983 – All India Nematology Workshop and Symposium held at Solan, Himachal Pradesh.

1985 – All India Nematology Workshop and Symposium held at Udaipur, Rajasthan.

1986 – National Conference on Nematology held at IARI, New Delhi

1987 – All India Nematology Workshop at Govt. Agriculture College, Pune.

1987 – Group Discussion on Nematological problems of Plantation crops held at Sugarcane Breeding Institute, Coimbatore.

1992 – Silver Jubilee Celebration of Division of Nematology, IARI, New Delhi.

1992 – Summer Institute on " Management of Plant Parasitic nematodes in different crops" organized by ICAR at Haryana Agricultural University, Hisar.

1995 – All India Nematology Workshop and National Symposium on Nematode problems of India held at IARI, New Delhi.

1997 – Summer School on "Problems and Progress in Nematology during the past one decade" was organized by ICAR at IARI, New Delhi.

1998 – Afro – Asian Nematology Conference held during April 1998 at Coimbatore.

1999 – National seminar on " Nematological Research in India: Challenges and preparedness for the new millennium" at C.S. Azad University of Agriculture and Technology, Kanpur

2000 – National Nematology Symposium on " Integrated Nematode Management" held at OUAT, Bhubaneshwar, Orissa.

2001 – National Congress on " Centenary of Nematology in India : Appraisal and Future plans" at IARI, New Delhi.

Position of nematodes in animal kingdom – Importance of nematodes (human being, animals and plants) – Economic loss in crop plants

Importance of Nematodes in Agriculture

- In the United States, the nematodes are known to cause six per cent loss in field crops, ($ 100 million / year), 12 per cent loss in fruits and nuts ($ 225 million / year), 11 per cent loss in vegetables ($ 267 million / year) and 10 per cent loss in ornamental ($ 60 million / year).
- In India, the cereal cyst nematode, *Heterodera avenae* causes the 'molya' disease of wheat and barley in Rajasthan, Punjab, Haryana, Himachal Pradesh and Jammu and Kashmir. The loss due to this nematode is about 32 million rupees in wheat and 25 million rupees for barley in Rajasthan State alone.
- The seed gall nematode, *Anguina tritici* causes the "ear – cockle" disease of wheat in North India. This nematode along with the bacterium, *Clavibacter tritici* causes "tundu or yellow slime" disease. The overall damage is about one per cent, but in severe infestation, the loss may even go up to 80 per cent. The annual loss due to this nematode in North India is about 10,000 tonnes of wheat costing 70 million rupees.
- The potato cyst nematodes, *Globodera rostochiensis* and *G. pallida* are serious problem in the Nilgiris and Kodaikanal Hills in potato. About 3,000 hectares are infested by this nematode. Total failure of the crop has been recorded under severe infestation.
- The root lesion nematode, *Pratylenchus coffeae* is a serious pest of coffee in South India. About 1,000 hectares are infested by this nematode. Annual loss is about 20 million rupees.
- The burrowing nematode, *Radopholus citrophilus* causes "**spreading decline**" of citrus in Florida. *R. similis* causes "**pepper yellows**" in Indonesia and "**banana rhizome rot**" in various parts of the world. This nematode is a serious pest in banana, coconut, arecanut and ginger. It is also responsible for "**slow wilt**" of pepper in Karnataka.

- The citrus nematode, *Tylenchulus semipenetrans* is responsible for "**slow decline**" disease of citrus. It is suggested that the citrus nematode is also one among the factors responsible for "**die – back disease**" of citrus trees in India. The total annual reduction in the citrus crop due to the nematode infestation is estimated at 15 per cent. In severe infestation, the life span of citrus trees are very much reduced. The nematode infestation symptoms are clearly seen in trees with the age group of 5-10 years. The severe infestation in acid lime gardens are observed in Perambalur district of Tamil Nadu.
- The reniform nematode, *Radopholus reniformis* has been reported to cause 14.9, 8.1, 6.0, 13.2 and 8.7 per cent loss in yield of cotton, maize, finger millet, cowpea and black gram respectively.
- The root- knot nematodes, ***Meloidogyne* spp**. produce galls on roots of many vegetable crops, pulses, some fruit crops, tobacco and ornamental crops and lead to severe yield loss. This nematode is mostly polyphagous and attack more than 3000 species of plants.

The avoidable yield losses due to *M. incognita* is as follows

Crop	**% Loss**
Bhendi	28.0
Brinjal	33.0
Tomato	35.0
French bean	43.0
Cowpea	28.0
Peas	20.0

In severe infestation, 60-80 per cent loss in yield was observed in the crops.

Estimated economic annual losses due to nematodes for selected world crops

Crops	Number of estimates per crop	Food and Agriculture Organization production estimates (1000 MT)	Estimated yield losses due to Nematodes (%)
Banana	78	2 097	19.7
Barley	49	171 635	6.3
Cassava	25	129 020	8.4
Citrus	102	56 100	14.2
Cocoa	13	1 660	10.5
Coffee	36	5 210	15.0
Corn	125	449 255	10.2
Cotton (lint)	85	17 794	10.7
Field bean	70	19 508	10.9
Oat	37	43 355	4.2
Peanut	69	20 611	12.0
Potato	141	312 209	12.2
Rice	64	469 959	10.0
Sorghum	53	71 698	6.9
Soybean	91	89 893	10.6
Sugar beet	51	293 478	10.9
Sugarcane	65	935 769	15.3
Sweet potato	67	117 337	10.2
Tea	16	2 218	8.2
Tobacco	92	6 205	14.7
Wheat	89	521 682	7.0

The examples are only a small portion of nematode problem in India. Besides this direct damage, they also associate with bacteria, fungi and viruses to cause complex diseases.

<u>**External morphology of nematode**</u>

MORPHOLOGY AND ANATOMY OF NEMATODES

Nematodes are triploblastic, bilaterally symmetrical, unsegmented, Pseudocoelomate, vermiform and colourless animals. The plant parasitic nematodes are slender elongate, spindle shaped or fusiform, tapering towards both ends and circular in cross section. The length of the nematode may vary from 0.2 mm (*Paratylenchus*) to about 11.0mm (*Paralongidorus maximus*). Their body width vary from 0.01 to 0.05 mm. In few genera, the females on maturity assume pear shape (Meloidogyne), globular shape (Globodera), reniform (*Rotylenchulus reniformis*) or saccate (*Tylenchulus semipenetrans*). The swelling increases the reproductive potential of the organism. Radially symmetric traits (triradiate, tetraradiate and hexaradiate) exist in the anterior region. The regions of intestine, excretory and reproductive systems show tendencies towards asymmetry. The nematodes have one or two tubular gonads which open separately in the female and into the rectum in the male which also have the copulatory spicules.

The free living saprophytic nematodes are generally larger in size. The animal and human parasitic helminthes may have length of fewcentimeters to even a meteer or more. The helminth parasitising whale fish is about 27 feet long. The study on these animal and human parasites are known as Helminthology.

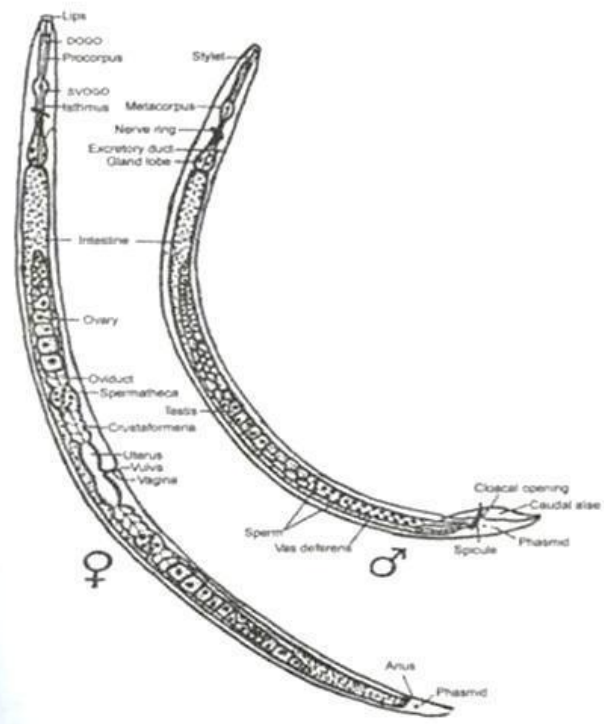


Fig. 1- Body morphology of a typical vermiform plant parasitic nematode DOGO - dorsal oesophageal gland orifice, SVOGO - subventral oesophageal gland orifice

The following are some examples of Helminths

1. Filarial worm - *Wucheria bancrofti*
2. Guinea worm - *Dracunculus medinesis*

3. Round worm - *Ascaris lumbricoides*

4. Tape worm - *Taenia solium*

The nematode body is not divided into definite parts, but certain sub – divisions are given for convenience. The anterior end starts with the head, which consists of mouth and pharynx bearing the cephalic papillae or setae. The portion between the head and the oesophagus is known as the neck. Beginning at the anus and extending to the posterior terminus is the tail.

Longitudinally the body is divided into four regions as dorsal, right lateral, left and ventral. All the natural openings like vulva, excretory pore and anus are located in the ventral region. The nematode body is made up of several distinct body systems. They are the body wall, nervous system, secretory – excretory system, and digestive system and reproductive system. Nematodes do not posses a specialized circulatory or respiratory system. The exchange of gases is thought to occur through the cuticle and circulation proceeds through the movement of fluids within the pseudocolelom and by simple diffusion across membranes.

The following are the characteristics of members of the phylum Nematoda.

1. Inhabit marine, freshwater and terrestrial environments as free – livers and parasites.
2. Bilateraly symmetrical, triploblastic, unsegmented and pseudocoelomates.
3. Vermiform, round in cross – section, covered with a three – layered cuticle.
4. Growth accompanied by molting of juvenile stages, usually four juvenile stages.
5. Oral opening surrounded by 6 lips and 16 sensory structures.
6. Possess unique cephalic sense organs called amphids.
7. Body wall contains only longitudinal muscles connected to longitudinal nerve chords by processes extending from each muscle.
8. Unique excretory system containing gland cells or a set of collecting tubes.
9. Longitudinal nerve cords housed within the thickening of the hypodermis.

Genera of the most common plant parasitic nematodes

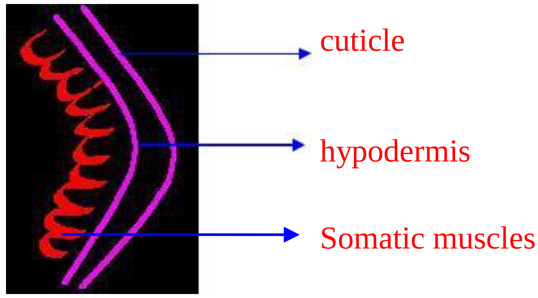
1. Awl nematode	*Dolichodorus spp.*
2. Cyst nematode	*Globodera spp*. and *Heterodera spp*.
3. Dagger nematode	*Xiphinema* spp.
4. Foliar nematode	*Aphelenchoides* spp.
5. Lance nematode	*Hoplolaimus* spp.
6. Lesion nematode	*Pratylenchus* spp.
7. Needle nematode	*Longidorus* spp.
8. Pin nematode	*Paratylenchus* spp.
9. Reniform nematode	*Rotylenchulus* spp.
10. Ring nematode	*Criconemella* spp.
11. Root – knot nematode	*Meloidogyne* spp.
12. Sheath nematode	*Hemicycliophora* spp.
13. Spiral nematode	*Helicotylenchus* spp.
14. Sting nematode	*Belonolaimus*
15. Stubby – root nematode	*Paratrichodorus* spp and *Trichodorus* spp.
16. Stunt nematode	*Tylenchorhynchus* spp.
17. Rice root nematode	*Hirschmanniella* spp.
18. Burrowing nematode	*Radopholus similis*
19. Citrus nematode	*Tylenchulus semipenetrans*

<u>Nematode Morphology</u>

The nematode body is divided into **three** regions. They are the outer body tube or body wall, inner body tube and body cavity or pseudocoelome.

The outer body tube

The outer body tube or body wall includes the cuticle, hypodermis, and somatic muscles. The body wall protect the nematode from the harsh external environment, serves as the exoskeleton and provides the mechanism for movement of the organism through the soil and plant tissue. The body wall also contains much of the nervous and secretory – excretory systems, and it plays a role in the exchange of gases.



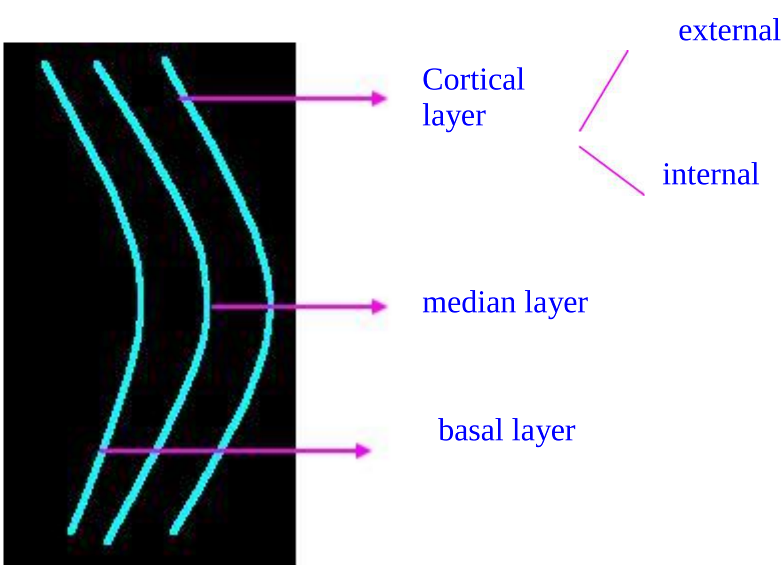
Cuticle or Exoskeleton

The cuticle is a non living, non cellular, triple – layers covering that is secreted by the underlying hypodermis. The cuticle is flexible. It covers the entire body and lines the oesophagus, vulva, anus, cloaca, excretory pore and sensory organs. The feeding stylet and copulatory spicules are formed from cuticle.

The composition and form of the cuticle is highly variable. In general, the cuticle is composed of three primary zones viz., the cortical layer, median layer and basal layer.

The cuticle of many nematodes have markings on the surface. They are varied and complex and have been often used by taxonomists to assist in the identification of various species.

Cuticle

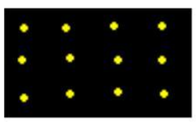


The cuticular markings are categorized into different types. i. Punctuation ii. Transverse marking or striations and iii Longitudinal markings.

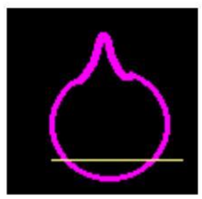
i. Punctuations

These are minute, round dots arranged in a pattern. They act as structures for strengthening the cuticle rather than as pore canals through which cuticular proteins may be transported. In the perineal pattern of *Meloidogyne hapla* these punctuations can be seen.

Punctuations



Cut RKN



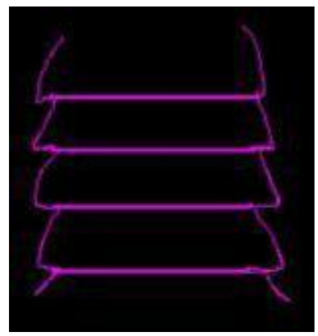
Perineal pattern

ii. Transverse marking or Striations

There are transverse lines present on the surface of the cuticle. These markings exhibit distinct variations among the plant parasitic nematodes and often used by the taxonomists for identification. The transverse markings cause a pattern of ridges and furrows right from head to tail and these markings gives the false appearance as if the nematode is segmented. These markings are well pronounced in some families such as *Criconematidae, Tylenchidae* and

Heteroderidae. In *Criconematids*, the annulations are clearly visible and known as scales and spines. The perineal pattern in the posterior body region of *Meloidogyne* females, as well as rugse wall pattern of *Heterodera* cysts, are considered to be the modifications of transverse markings.

Transverse marking



Criconematids- Annulations

iii. Longitudinal markings

These markings are the lines on the cuticle, which runs longitudinally throughout the length of the nematode body. These markings are divided into **a) lateral lines or incisures**

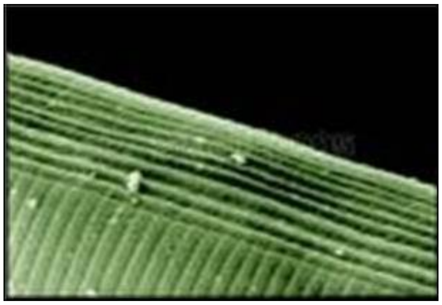
and b) longitudinal ridges.

a) Lateral lines or Incisures

These are lines running longitudinal to the body axis of nematode but they are confined to the lateral field in area just on top of lateral hypodermal chords on either side of the nematode body running throughout the length. The number of lateral lines or incisures is an important taxonomic character as it shows stability within the genus.

b) Longitudinal ridges

Longitudinal ridges are raised lines present on cuticle running longitudinal to nematode body axis but are confined in the area other than lateral field. The number of these ridges is used by taxonomists for species identification.



Longitudinal ridges

Apart from this, alae also present. They are thickening or projections of the cuticle which occur in the lateral or sublateral region. There are 3 types of alae. i. Caudal alae ii. Cervical alae and iii. Longitudinal alae.

i. Caudal alae

These are found in the posterior region and restricted to males as copulatory bursa.

Eg. *Hoplolaimus*

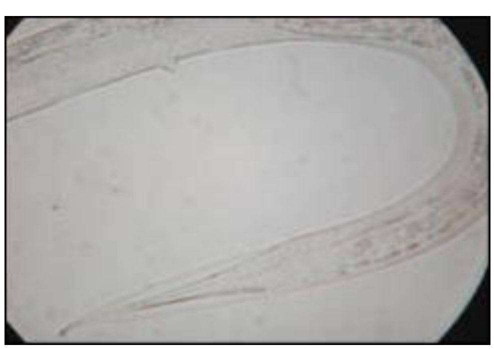
ii. Cervical alae

These are confined to the anterior part of the nematode body. Cervical alae are found in some species of marine nematodes.

Eg. *Toxcara*

iii. Longitudinal alae

The longitudinal alae delimit the later fields and are known as lateral alae. Their form varies in different species. They are transversed by striations or furrows varying in number from 1 to 12. Functionally, they probably assist in locomotion and may permit slight changes in the width of nematodes.



Eg. *Tripyla*

The functions of cuticle

Cuticle gives definite shape and size to the body, acts as an exoskeleton, helps in movement, being semipermeable, it regulates permeability and provides important taxonomic characters for identification of nematodes.

Cuticular layering

The nematode cuticle consists of three layers viz., an outer layer (Cortical layer), a middle layer (median or matrix) and an inner layer (basal or fiber layer). In some nematodes there are only two layers as in the adult females of the family Heteroderidae.

1. **Outer layer**(Cortical layer)

   The cortical layer is amorphous and electron dense layer. In many forms, the cortical layer is divided into an external cortical layer is exposed to the environment. This layer is very thin measuring about 25 to 40 μ and can be subdivided into an outer membrane (3-5 μ thick) and may correspond with a triple layered plasma membrane.

   The external cortical layer has been considered to be a keratin. The disulphide group present in this layer is responsible for resistant properties. In cyst nematodes, this layer become highly resistant due to quinine tanning of the cuticle. For example, in potato cyst nematode, *Globodera rostochiensis* and cyst nematode, *Heterodera* spp., the cuticle of the female on maturity becomes tough and leathery to form cyst which protect hundreds of eggs.

   The internal cortical layer varies considerably in thickness in different nematodes. In preparasitic juvenile forms it may be about 0.15 to 0.25 μ thick. It has a fibrous structure. There is no clear cut demarcation separating the internal cortical layer and median layer. This layer appears to be biochemically active in some nematodes. Enzymes and RNA were detected from this layer.

2. **Median layer**(Middle layer)

   The average thickness of the median layer is 0.1 μ in the juveniles of *Meloidogyne* and *Heterodera*. This layer undergoes marked change in the width in Hemicycliophora arenaria as it grows to become adult. The median layer in this nematodes is about 0.2 μ in width in the second stage juveniles and about 0.7 μ in width in adult female. Chemically this layer consists of proteins resembling collagen. A non- specific esterase, acid mucopolysaccharide and some lipids have been detected in this layer. It does not appear to be as metabolically active as that of cortical layer.

3. **Inner layer** (Basal / fiber layer)

   The basal or fibre layer consists of regularly arranged vertical rods or striations. It is composed of protein with very close linkage between the molecules, resulting in resistant layer which protect the nematode from environment. The thickness of the basal layer varies from 125-500 μ.

Hypodermis

The hypodermis, which can be cellular or partially cellular, secretes the cuticle. It lies beneath the cuticle and contains longitudinal thickening between the somatic muscles that contain the nuclei, mitochondria, lipid droplets, endoplasmic reticulum, longitudinal nerves and the canals of the secretory – excretory system. Most nematodes have four hypodermal chords (one dorsal, one ventral and two lateral chords).

Hypodermal glands

The hypodermal glands vary in different species of nematodes. They act as either osmotic or ionic regulators. The caudal glands of the hypodermis are found in the tail region. The caudal gland (usually 3 to 5 in number) secretes the adhesive substances which help to anchor the nematodes. The hypodermal glands are also associated with the sensory organs like amphids, phasmids and deirids.

Somatic musculature

The somatic muscle cells are arranged in a single layer. The muscle cells are spindle shaped and attached to the hypodermis throughout their length. A non- striated, non-contractile portion of the muscle cell contains the nucleus and other cell organelles.

It is connected to the nervous system by an elongated process of noncontractile portion of the muscle cell. The muscle cells on the ventral side of the nematode body are attached to the ventral nerve and all the cells on the dorsal side are connected to the dorsal nerve.Therefore, stimulation of muscles by the dorsal and ventral nerves causes contractions in the dorso-ventral plane and results in the characteristic sinusoidal movement of the nematode.

Muscle cells

On the basis of arrangement of muscle cells, the following a types are identified.

a) Holomyarian : having two muscle cells in each zone.
b) Meromyarian : 2 or 5 muscle cells in each interchordal zone

c) Polymyarian ; More than 5 ,muscle cells per zone

On the basis of the muscle cell shape, they are grouped as

Platymyrian

A flat type of cell with contractile elements limited in places to the base lying close to the epidermis.

Coelomyarian

'U' shaped cells in which muscle fibre are adjacent and perpendicular to the hypodermis and extend along the sides of the muscle cell of varying distances.

Circomyarian

This type of muscle cells are almost round and the muscle fibres completely surround the cytoplasm

The platymyarian muscle cell is considered primitive which might have modified into coelomyarian type of narrowing and upward elongation of the fibrillar zone. Muscle cells are connected to each oither by means of cytoplasmic bridges and have nerve connections.

Anatomy of nematodes – Digestive, excretory and nervous system and sense organs

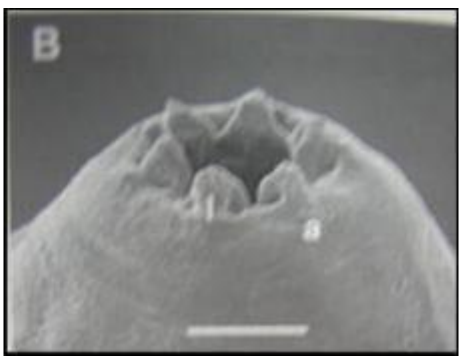
Digestive system

The digestive system of nematodes include the stoma, oesophagus, intestine and posterior gut. The inner body tube is divided into 3 main regions.

1. Stomodeum : which constitute the stoma, oesophagus and cardia
2. Mesenteron : which constitute the intestine
3. Proctodeum : which is the posterior –most region comprising rectum and anal opening.

1. Stomodeum

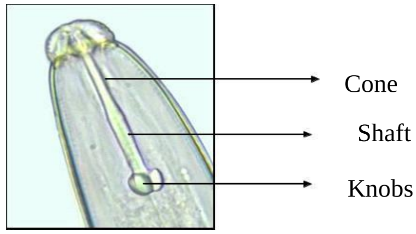
Stoma is the portion of the inner body tube lying between the oral opening and oesophagus. The stomatal opening is small and slit like and is surrounded by six lips.



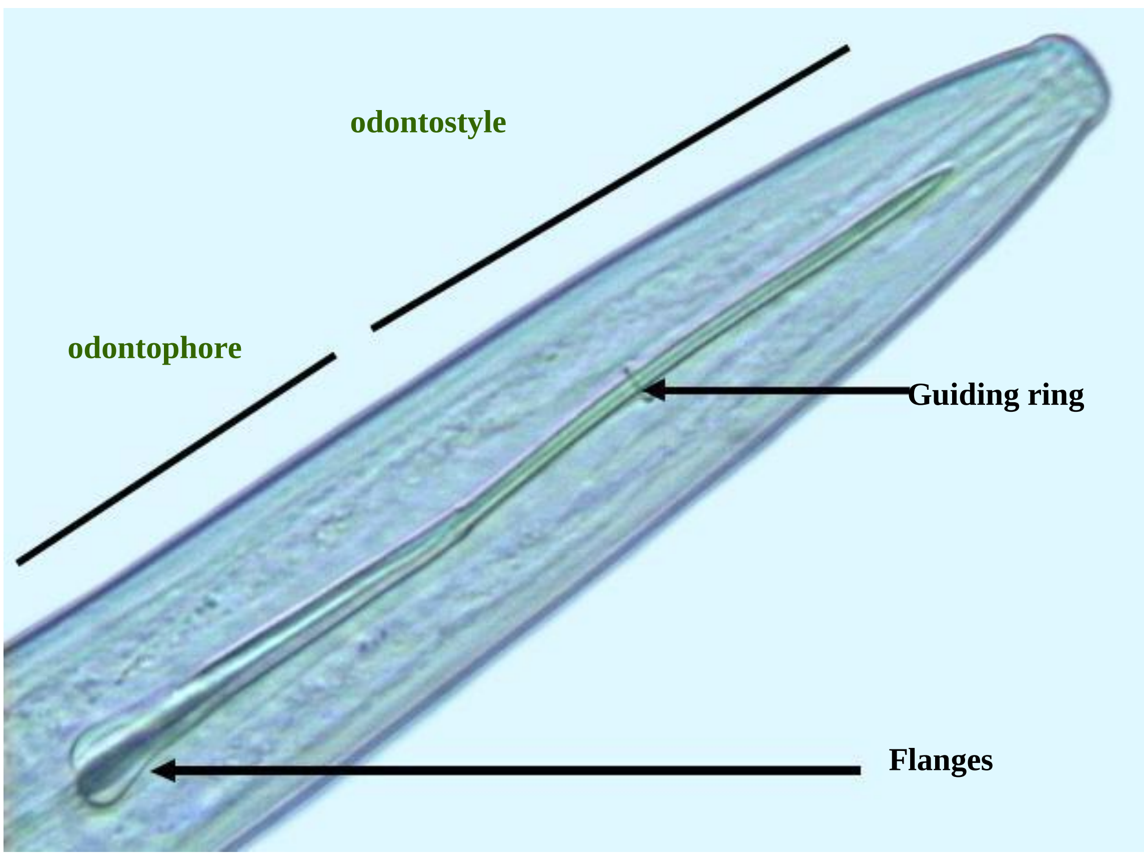
Stomatal opening

Two subdorsal, two subventral and tow lateral. Plant parasitic nematodes are armed with a protrusible stylet which is usually hallow and functions like a hypodermic needlw. In, Secernentea, the stylet is thought to be derived from fusion of the stomatal lining and therefore called as stomatostylet. The stamatostylet consists of a anterior cone, a cylindrical shaft and three rounded basal knobs. In Adenophrea, the stylet is thought to be derived from a tooth and, therefore, it is called as odontostylet. The flanges that serve as points of attachment for the stylet protractor muscles. In some plant parasitic nematodes like Trichodorous and Paratrichodorus the odontostylet is dinstinctly curved ventrally, lacks flanges and it is not hallow. In functions to pierce the cell wall of the root. The nematode secrets a hallow tube out of its stoma that connect it with the plant. This feeding tube serves as the interface between the nematode and the plant.

Stomatostylet- Eg.*Hoplolaimus*



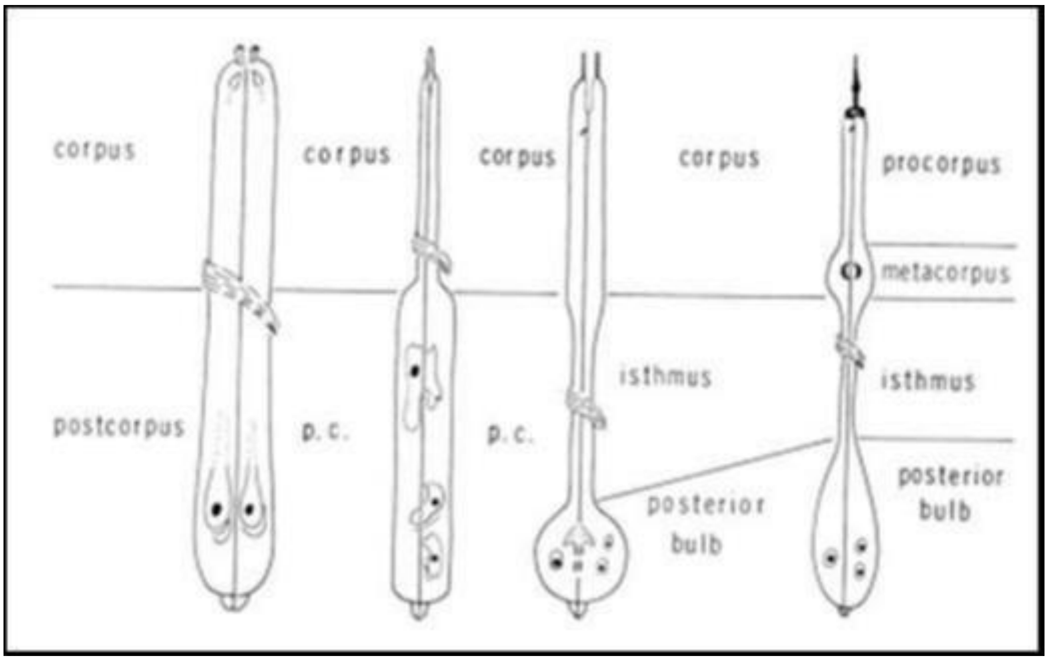
Odontostylet – Eg. *Xiphinema*



Oesophagus or pharynx

The oesophagus is a muscular pumping organ attached to the posterior portion of the stylet and lines with cuticle. In Adenophorea, the oesophagus is divided into a narrow anterior procorpus and a broad posterior corpus. Three to five oesophageal gland cell empty into the lumen (one dorsal and two to four subventral in position in Secernentea the oesophagus is divided into distinct regions, such as narrow procorpus, followed by a broad muscular median bulb or pump, a narrow isthmus and gland lobe. The gland lobe may overlap the intestine in some genera and contain three to six gland cells (One dorsal and tow dub – ventral). The oesophagus has valve (cordia) at the posterior end which prevents the regurgitation of food.

Types of oesophagus



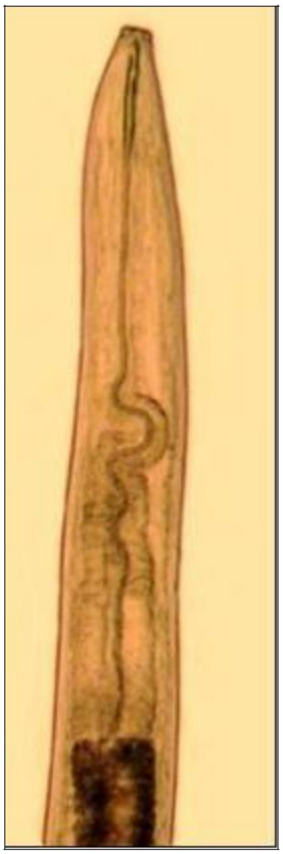
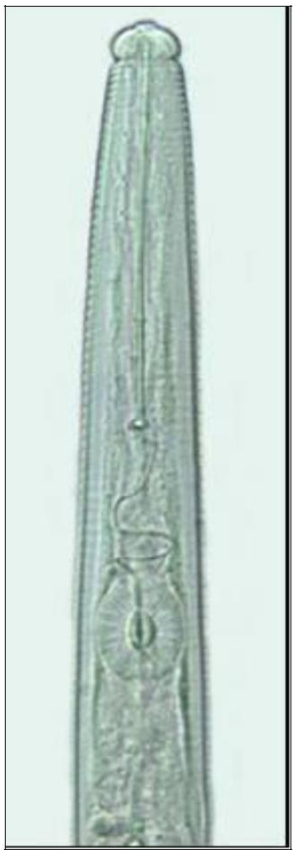
Enoplid Dorylaimid Rhabditid Tylenchid

Mesenteron or intestine

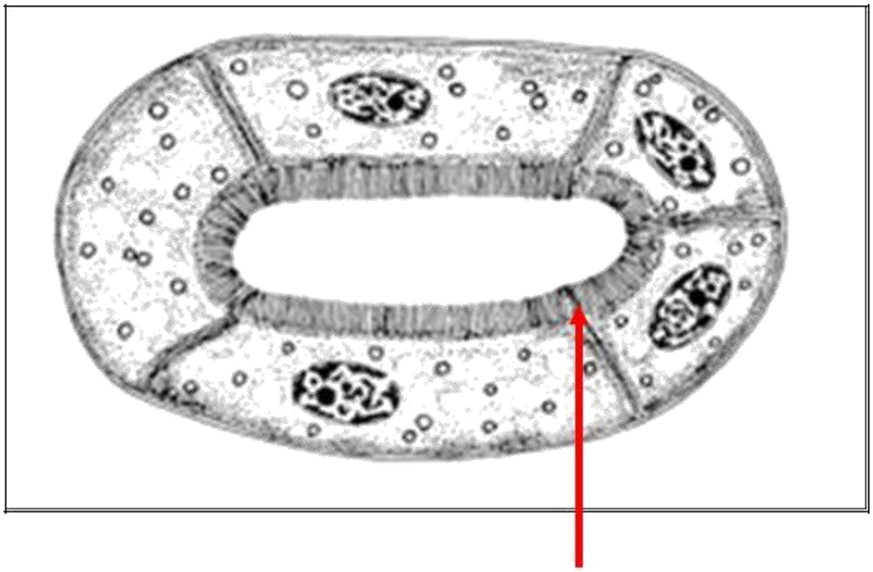
The nematode intestine is a simple, hallow, straight tube consisting of a single layer of epitherlial cells. The intestine is generally divided anterior or ventricular region, the midintestinal region and the posterior or prerectal region. The microvilli are finger like projection of the plasma membrane projecting in to the intestinal regions. They increase the surface area of the intestine and are both secretary and absorbtive in funtion. The whole intestine is separated from the pesducoelom by a basement membrane.

The food moves in the intestine by the ingestion of more food and also by locmotory activity of the nematode.

Dorylaimid **Tylenchid** **Aphelenchid**

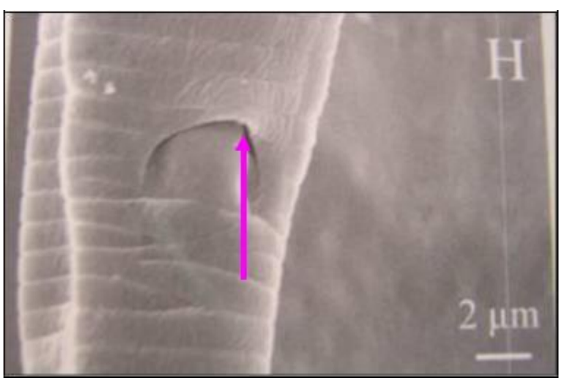

C.S. of intestine



Microvilli seen on the inner lining

Protodeum

Proctodeum comprises rectum and anus. The intestinal tube is connected with a narrow small tube at the posterior end, through a valve known as rectum. It regulates the flow of undigested food material which is to be passed outside the nematode body through a ventrally located aperture known as anus.



Anal opening

In male nematode, the rectum joins with the hind part of the testis forming a common opening known as cloaca. In female, there is a separate opening.

Glands

Oesophageal and rectal glands are present in nematodes. The oesophageal gland enter the stomodeum and rectal gland enter proctodeum.

Oesophageal glands

Three uninucleated oesophageal glands. One gland on dorsal and other tow ventro lateral or sub ventral in position. These gland connect with the lumen of the oesophagus by means of ducts, often by means of a terminal swelling or ampulla.

The oesophageal glands have important role in hatching, host penetration and also establishment of host parasitic relationship.

Rectal glands

Are responsible for the copious production of gelatinuous mucopolysacccharide matrix in which eggs are deposited as a mass. It protects the eggs from adverse environmental conditions.

F**unction of digestive system**

Digestive juices which is secreted from dorsal oesophageal glands are injected into the host plant cell by means of the stylet. During feeding, a distinct zone develop around the feeding site in the host cell . There are two feeding phases.

1. Injection phase or salivation phase and
2. Ingestion phase.

Injection phase or Salivation phase

During this phase, the flow of salivary juices into the host cell occurs due to contraction of lateral muscle of the median bulb.

Ingestion phase

During this phase rhythmical contraction of the posterior part of the oesophagus associated with the median bulb occurs and in some forms, the oesophageo-intestinal valve or cardia is responsible for ingestion of material from the host.

Various glands associated with the digestive system play an important role in secretion. The cells of these glands are associated with protein and mucopolysaccharide synthesis and their products are shed through cuticle lined ducts either into stomodeum or proctodeum.The intestie acts as an excretory organ and defecation is mechanically controlled and it is an intense process.

EXCRETORY SYSTEM

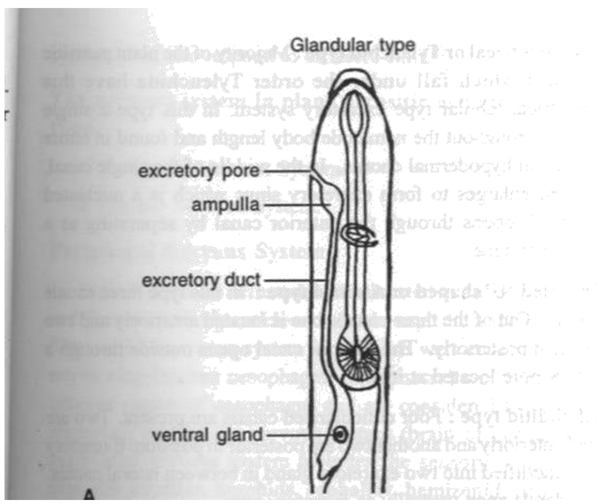
The excretory system is not well developed in nematodes. The excretory pore is located in the anterior midventral line close to the nerve ring. The position of excretory pore may vary in different genera and even in different stages of the same species. In T. semipentrans the excretory. It secrets gelatinous matrix.

The excretory system in nematodes are of two types.

1. Glandular type
2. Tubular type.

Glandular type

The glandular type consists of a single specilalised cell known as renette cell. It has a posteriorly located enlarged gland known as excretory gland or ventral gland. This gland is connected to the excretory pore by a duct that terminates in a pouch like structure known as ampulla. This type is found in members of the class Adenophorea.



Tubular type

The tubular type of excretory system consists of four – cuticularised canals. Two are anterior and another two are posterior canals. There is a pouch like structure in the middle which connects both the lateral canals. It is known as excretory pore. There are four types in tubular system.

1. Asymmetrical or Tylenchid type
2. Inverted 'U' shaped or Ascarid type
3. Rhabditid type
4. Simple'H'shaped or Oxyurid type.

Asymmetrictrical or Tylenchid type : Majority of the plant parasitic nematodes which fail under the order *Tylenchida* have this asymmetrical tubular type excretory system. In this type a single tube runs throughout the nematode body length and found in either of the lateral hypodermal chords. In the middle of the single canal, the lumen enlarges to form excretory sinus which is a nucleated structure. It opens through the anterior canal by separating as a small branch tube.

Inverted 'U' shaped or Ascarid type

In this type three canals are found. Out of the three canals, one is located anteriorly and two are located posteriorly. The anterior canal opens outside through a excretory pore located at its tip.

Rhabditid type

Four cuticularised canals are present. Two are located anteriorly and another two are posterior in position. Excretory sinus is modified into two excretory gland in between lateral canals.These glands open ventrally as excretory pore.

Simple 'H' shaped type

This type has four tubular cuticularised canals. Two canals. Two canals are anterior and slightly shorter than the two canals located posteriorly. These canals are connected by a swollen excretory sinus which opens externally as excretory pore. This type of tubular excretory system is commonly observed in the members of the order Oxyurida. This is a very primitive type of excretory system in nematodes.

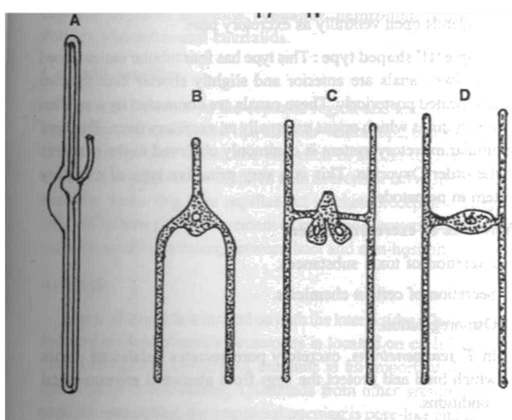


Fig. 7 - Different types of excretory system in nematodes
A - Tylenchid type B - Ascarid type
C - Rhabditid type D - Oxyurid type

Functions of excretory system

1. Excretion of toxic substances. 2. Secretion of certain chemicals. 3. Osmoregulation 4. In *T. semipenetrans* excretory pore secretes gelatinous matrix which bind and protect the eggs from abnormal environmental conditions.

NERVOUS SYSTEM AND SENSE ORGANS

In plant parasitic nematodes, the nervous system is not well developed. Though they posses very primitive type of nervous system, they also respond to different stimuli.

The nervous system in plant parasitic nematodes is of two types

- ❖ Peripheral Nervous System
- ❖ Central Nervous System

1. Peripheral Nervous System

Located in the periphery which mainly includes body cuticle and also the cephalic and caudal regions. The parts of nervous system located are well connected with the nerve ring (circum oesophageal commisure) which encircles the thumus region of esophagus and are considered to be the most important part of the nervous system (brain of nematode). The peripheral nervous system includes the sensory organs such as cephalic paillae; amphids cephalids, hemizonid, hemisonions, deirids, phasmids and caudalids.

Cephalic paillae

Located on the cephalic region and are 16 in number, two each in – two sub – dorsal lips and sub – ventral lips; one each in two lateral lips in outer circle ; and one each in all the six lips in inner circle. These paillae are supplied with neurons or nerve fibres arising from the nerve ring. The papillae act as chemoreceptors. They are believed to take part in movement of nematode governing directions and also in differentiating between host and non – host plants

Amphids

A pair of amphids is located on both the lateral sides. The amphidial opening is pore – like and labial in position. The amphids are also connected with the nerve ring, hence they are sensory in nature.

Cephalids

These are found in cephalic region. A pair of cephalids is found, of which one is anterior and another is posterior in position. The exact functions of cephalids are not known. It is believed that they take part in transmitting massages to the centrally located nerve ring.

Hemizonid and Hemizonion

They are highly refractive, biconvex, semi – circular and may be anteriror or posterior to the excretory pore. Hemizonids is anterior to the excretory pore. Hemizonions are smaller than Hemizoinids and are located posterior to hemizonid. Hemizonoid and hemizonion are believed to be involved in nuerosecretion.

Deirids

These are a pair of small protuberance, one each in lateral side in the middle of the lateral field. These are located in the region of oesophagus at the region of excretory pore. They are also sensory organs.

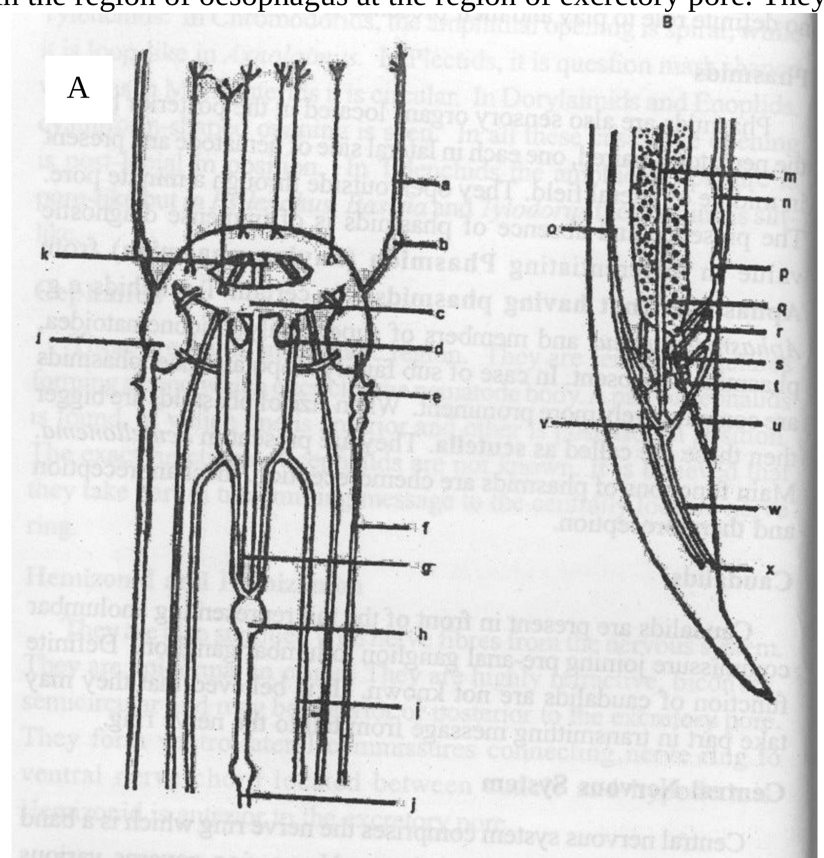


Fig. 8 A - Nervous system in anterior region B - Posterior region
a-amphidial nerve, b-amphidial ganglion, c-nerve ring,
d-ventral ganglion, e-cervical papilla nerve, f-lateral nerve,
g-dorsal nerve, h-retrovesicular ganglion, i-latero ventral nerve,
j-ventral nerve, k-dorsal ganglion, l-amphid, m-lateral nerve,
n-ventral nerve, o-dorsal nerve, p-preanal ganlion, q-intestine,
r-rectal commisure, s-dorso rectal ganglion, t-ventro lateral connective,
u-rectum, v-lumbar ganglion, w-caudal nerve, x-phasmid.

Phasmids

Phasmids are also sensory organs located in the posterior half of the nematode paired one ach in lateral side of nematode and present in middle of lateral field. They open outside through a minute pore. The presence and absence of phasmids is of immense diagnostic value having phasmids. When size of phasmids are bigger then these are called as scutella. They are present in *Scutellonema*. Main functions of phasmids are chemoreception, mechanoreception and thermoreception.

Caudalids

Caudalids are present in front of the tail. It is believed that they may take part in transmitting massages from tail to the nerve ring.

2. Central Nervous System

Central nervous system comprise the nerve ring. Associated with this nerve ring are a small dorsal gangalion. Six or eight longitudinal nerves run posteriorly from these ganglion. Six nerves pass forward from the nerve ring and supply the lips and associated sense organs.

A pair of nerves runs forward from the lateral ganglion to the amphids at the anterior end of the nematode. The dorsal nerve is said to be chiefly motor and lateral nerves mainly sensory in function. The sub – median and the ventral nerves are partly motor and partly sensory. There is a system of three nerves in the pharynx, one in each sector, which are connected with one another by commissures and also with nerve ring. Nematodes are unique in that the muscle cells of the body are innervated by processes which pass from the muscle. It is claimed that the nerve muscle junction is similar to those found in other animals.

Transmission along nerves

Nothing is known about the processes involved in the conduction of an impulse along nerves in nematodes. In Ascaris it is known that the pseudocoelomic fluid contains more sodium as compared with potassium ions. It is thus possible to speculate that the nerve axons in this species function as that of other animals in which the action cureent arises from an influx of external sodium ions.

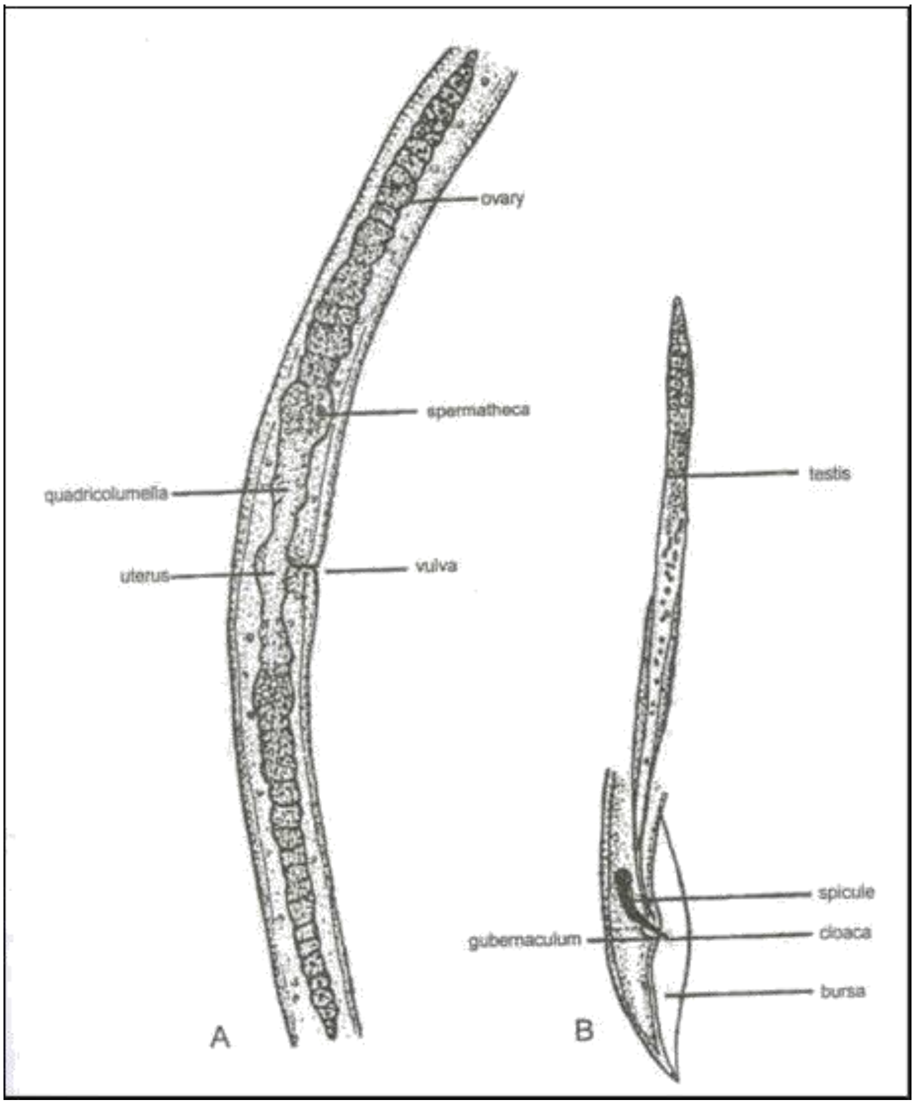
Acetylcholine is apparently involved in nervous transmission in nematodes. Acetylcholine like substances have been detected in Ascaris. The head region of Ascaris was found to contain fifteen times more acetylcholine than that of the remaining body.

Cholineesterase activity is observed to be more in the nerve ring, amphids, phasmids and other sense organs in nematodes.

Anatomy of nematodes (contd…) – Reproductive system

Reproductive System

The nematodes are generally dioecious. Majority of plant parasitic nematodes do not exhibit any differences as far as body shape. Both sexes are vermiform. However, sexual dimorphism is observed in some genera *viz.*, *Meloidogyne*, *Heterodera*, *Globodera*, *Rotylenchulus*, *Tylenchulus* and *Nacobbus*. The females of these genera become enlarged and assume different shapes after attaining maturity.



Female Male

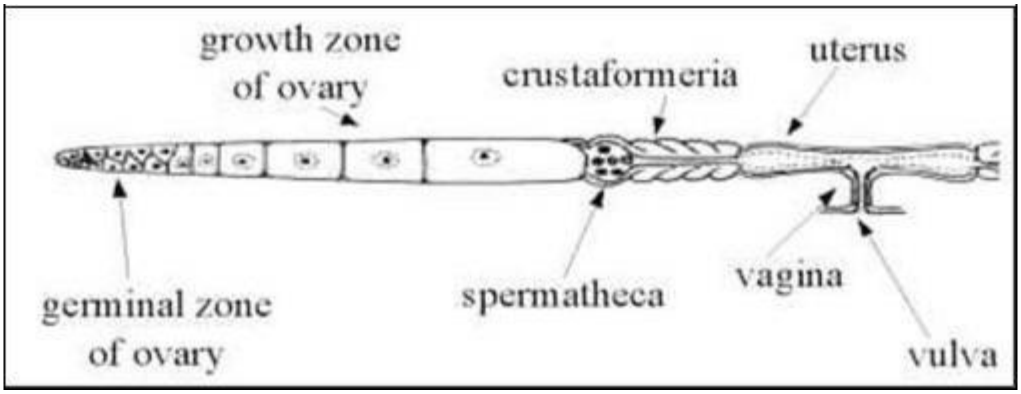
Female Reproductive System

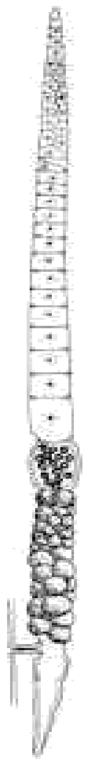
Present in nematodes having single ovary as observed in the genera *Pratylenchus* and *Ditylenchus*. The uterus opens outside to a ventrally located vulval opening through a tube known as vagina, which is a cuticularised structure. In plant parasitic nematodes the number of ovary may be one or two. When there is one ovary that condition is known as monodelphic and when the number is two, the condition is called as didelphic.

In monodelphic condition, the ovary is always, anteriorly directed, i.e Prodelphic. In case of didelphic ovaries, if both the ovaries are anteriorly directed and vulva is terminal in position then the condition is known as didelphic prodelphic as found in the case of *Meloidogyne*, *Heterodera* and *Globodera*. In som nematodes, two ovaries are opposite to one another, such that one is anteriorly directed and the condition, as found in the case of *Tylenchorhynchus*, *Hoplolaimus* and Helicotylenchus etc.

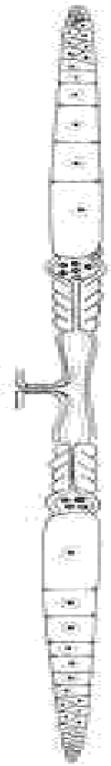
The vulval opening is a trasverse slit and not covered with any flap, but in *Agelenchus* and *Coslenchus* vulva is covered with a membranous flap known as vulval flap. The vaginal tube in *Hoplolaimus* and *Cosaglenchus* are provided with a cuticular sclerotised structure encircling the tube known as epiptygma. Ovary in most of the plant parasitic nematodes is always straight and does not curve back. Such ovaries are called as outstretched ovaries as in the case of *Tylenchorhynchus*, *Radopholus* and *Hirschmanniella* etc. In Dorylaimid nematodes, the tip of the ovary is curved back. It is known as reflexed ovary. If the ovary is single and posteriorly directed, then it is known as monodelphic ophisthodelphic condition and such conditions are rarely seen. (eg.*Xiphinema* spp.)

Further, and ovary is called hologenic if it produced oocytes throughout its length and telogenic if producing oocytes only at its distal end.

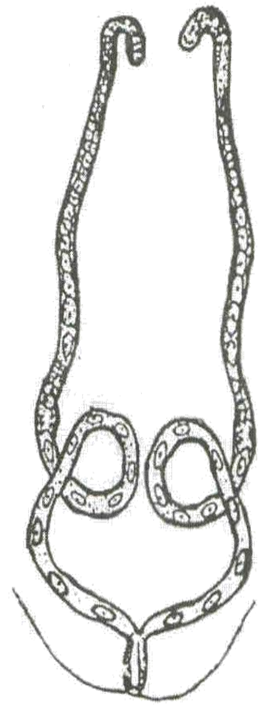




Monodelphic prodeplphic



Didelphic amphidelphic



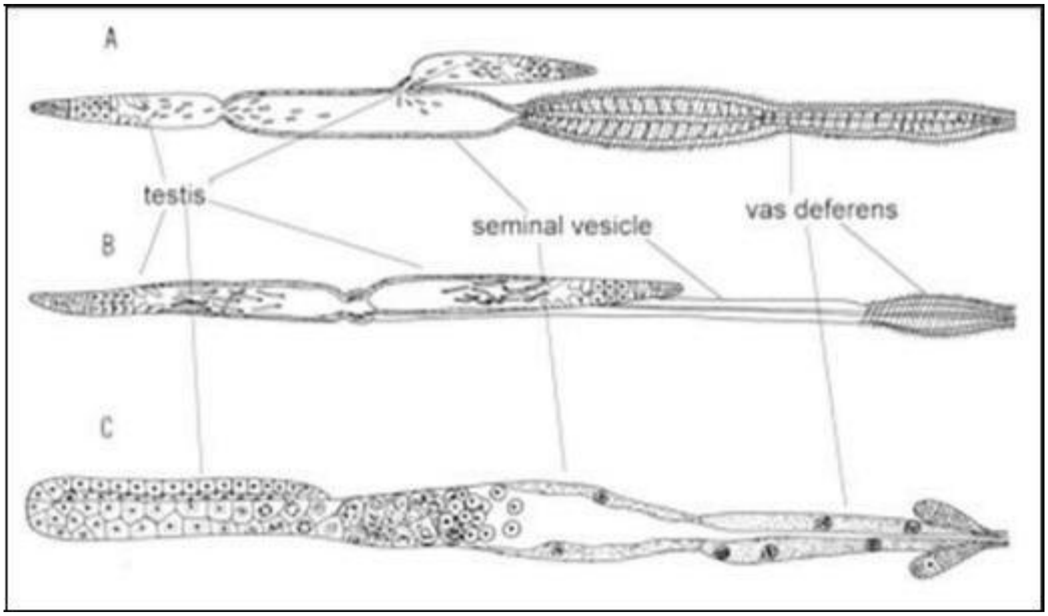
Didelphic prodelphic ovaries

Male Reproductive System

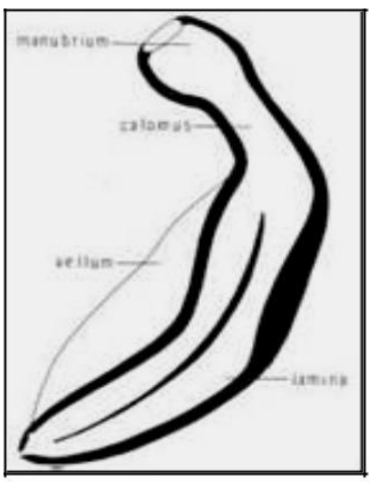
It comprises a cylindrical tube known as **testis** which opens along with the digestive tract in a common opening known as **cloaca.** The testis is differentiated into (i) Seminal vesicle (ii) Vas deferens and (iii) Testis proper.

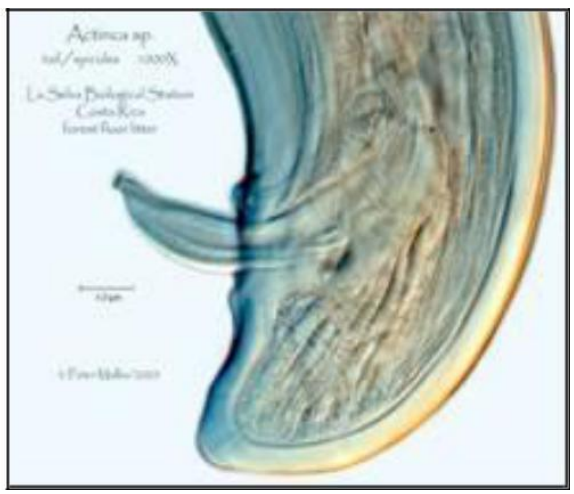
The production of sperms takes place in testis. In nematodes, whenever the number of testis is one, it is known as monarchic conditions and when they are tow in number, the condition is known which moves forward and backward with help of specialized muscles attached with its head region. Spicule is narrower at its tip. A cuticularised structure lying beneath the pair of spicule is known as guberrnaculum which helps and gives support in movement of the spicule. At the tail end, two filamentous cuticular expansions are found and they are known as bursa helps to hold the female during copulation. Plant parasitic nematodes can reproduce sexually where male and female copulate and give rise to off – springs. Sexual reproduction is also called as amphimetic reproduction. Parthenogenetic reproduction is also common phenomenon in *Meloidogyne* and *Tyelchulus semipenetrans*.

Male reproductive system

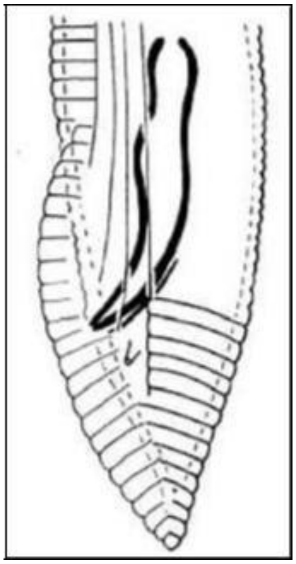


Spicule

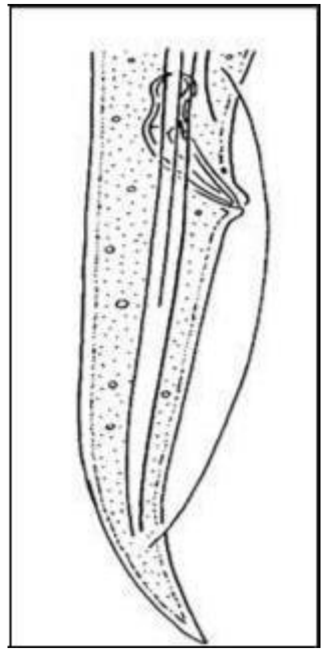




Caudal alae



Peloderan
Eg. *Hoplolaimus*



Leptoderan
Eg. *Hirschmanniella*

Sex reversal

In root- knot nematodes(***Meloidogyne* spp**.) sometimes sex reversal takes place. This happens during stress period, when there is scarcity of food and also due to unfavourable conditions. Under stress conditions the developing females get converted into males.

Inter sexes

In genera like *Meloidogyne* and *Ditylenchulus* inter sexes are found. In such cases one reproductive system act as male gonad and other one as female gonad.

Taxonomy of plant – parasitic nematodes of the Secernentea and Adenophorea

TAXONOMY OF PLANT PARASITIC NEMATODES

Nematodes are placed in the group invertebrate, Kingdon Animalia.

Classification of Phylum Nematoda

Class : **Adenophorea** — **Secernentea**

Subclass: Enoplia — chromadoria

Superorder : Marenoplica
- **Order** : Marenoplicada
- Oncholaimida
- Tripylida

Ternoplica
- Dorylaimida
- Isolaimida
- Mononchida
- Stichosomida

chromadoria
- Araeolaimida
- Chromadorida
- Desmoscolecida
- Desmodorida
- Monhysterida

Class: Secernentea

Subclass: Rhabditia
- **Order :** Rhabditida
- **Family:**
  - Heterorhabditidae
  - Steinernematidae

Spiruria
- Ascaridida
  - Ascarididae
  - Dioctophy -matidae
- Spirurida
  - Dracunculidae
  - Filariidae

Diplogasteria
- Diplogasterida
  - Diplogasteridae
- Tylenchida

Tylenchida

Suborder: Tylenchina
- **Superfamily:** Tylenchoidea
  - Family: Anguinidae
  - Belonolaimidae
  - Dolichodoridae
  - Heteroderidae
  - Hoplolaimidae
  - Pratylenchidae
  - Tylenchidae
- Criconematoidea
  - Criconematidae
  - Tylenchulidae

Aphelenchina
- Aphelenchidae
- Aphelenchoididae

Sphaerulariina
- Fergusobeidae

Diagnostic characters of class Secernentea and Adenophorea

Secernentea (Phasmida)	Adenophoreea (Aphasmida)
Amphidial opening is on the head near the lip region.	Amphids open behind the head i.e. post labial
Lateral canals open into the excretory duct	Lateral canals and excretory duct end in a cell
Oesophagus is divided into procorpous, median bulb, isthmus and basal bulb.	Oesophagus is cylindrical with an enlarges glandular base
Male tail with bursa (Caudal alae)	Male tail lacks bursa but posses genital paillae.
Glands are absent Phasmids are present	Caudal glands are present Phasmids are absent
The mesenterial tissues are less developed	The mesenterial tissues are well developed

The plant parasitic nematodes are included in the orders *Tylenchida* of class *Secernentea* and Dorylaimida of class *Adenophorea*.

Order : *Tylenchida*

Stoma armed with a protrusible spear or stomatodtylet. *Oesophagus* consists of a procorpus, media bulb with selerotized valvular apparatus, nerve ring encloses the narrow isthmus and with a basal bulb. It consists of two superfamilies namely *Tylenchoidea* with *Tylenchida* and *Aphelenchina* as suborders and *Criconematoidea*.

Differences between *Tylenchoidea* and *Criconematoidea*

Character	*Tylenchoidea*	*Criconematoidea*
Labial region	Lips are hexaradiate, Labial frame work present	Labial region is poorly developed, labial plate is present
Stylet	Conus, shaft and knobs are variable in shape and size	'Criconematoid' type stylet long and anchor

		shape knob which lies in base of metacarpus
Stylet	Conus, shaft and knobs are variable in shape and size	'Criconematoid' type stylet long and anchor shape knob which lies in base of metacarpus
Oesophagus	Narrow procarpus, round metacarpus with value, isthmus followed by glandular basal bulb	Pro and metacarpus amalgamated to a single unit, short isthmus, the post carpus reduced, appears as 'set-off' smaller than pro and metacarpus
Deirids	Present (2 pair)	Absent
Female gonad	Single or two ovary; post uterine sac (PUS) is present	Single ovary with posterior vulva; PUS absent
Male gonad	Single testis, caudal alae is present	Single testis; caudal alae rare
Phasmid	Erratically present in tail region	Not known

Difference between *Tylenchina* and *Aphelenchina*

Character	*Tylechina*	*Aphelenchina*
Lip	Varying in shape	Set- off
Annules	Faint to strong annules	Faint annules
Stylet	Well developed; one dorsal and two subventral knobs	Weekly developed; no stylet knobs
Oesophagus	Three parted	Three parted with square shaped median bulb

Gland bulb	Abutting, dorsal, ventral or dorso – ventral overlapping on intestine	Only dorsal over loapping
Gland opening	Behind the stylet knob in procorpous	Opens in the median bulb
Female	One or two; vulval position vary	Single ovary; vulva posterior
Male	Bursa present	Bursa rare
Spicule	Weak to strong sclerotization is seen with gubernaculums	Rose thorne shape spicule present

Order : Dorylaimida

The labial region is set off from body contour. The stoma is armed with a movable mural tooth or a hallow axial spear. *Oesophagus* is divided into a slender, muscular anterior region and an elongated or pyriform glandular posterior region. Females have one or two reflexed ovaries; males have paired equal spicules, gubernaculums rare. The order is divided into three sub orders namely *Dorylaimina*, *Diptherophodrina* and *Nygolaimina.* The former two suborders containing the plant parasitic nematodes.

Suborder

- Dorylaimina
  - Stylet with flangers or guiding ring, long and straight
- Diptherophodrina
  - Teeth like spear, solid, short and ventrally curved.

Family : Longidoride

Genus :*Longidorus:* *amphids* pouch like, slit like opening, spear extension without flanges, guiding ring located near the spear tip.

Genus : *Xiphinema* : amphids funnel shaped wide opening, spear extension with flanges, guiding ring located near the spear base.

Family :Trichodoridae

Genus :'*Trichodorus'* Long curved onchiostylet, female rectum runs parallel to the longitudinal body axis and the anus lies subterminally. Male tail curved, bursa absent, vaginal sclerotization strong, lateral pores present near vulva.

Classification of plant – parasitic nematodes based on feeding habits – Beneficial nematodes

Ecological classification of plant parasitic nematodes

I. Above ground feeders

a. Feeding on flower buds, leaves and bulbs.

i. Seed gall nematode : *Anguina tritici*

ii. Leaf and bud neamtode : *Aphelenchoides*

iii. Stem and bulb nematode **: *Ditylenchus***

b. Feeding on tree trunk

i. Red ring nematode : *Rhadinaphelenchus cocphilus*

ii. Pine wilt nematode : *Bursaphelenchus xylophilus*

II. Below ground feeders

Endoparasite

Sedentary

i. Cyst nematode

Heterodera spp

Globodera spp

ii. Root – knot nematode

Meloidogyne spp

Migratory

i. Lesion nematode

Pratylenchyus spp

ii.Burrowing nematode

Radopholus similes

iii. Rice root nematode

Hischmanniela spp.

Semiendoparasite

i. Citrus nematode

Tylenchulus semipenetrans

ii. Reniform nematode

Rotylenchulus reniformis

Ectoparasite

Sedentary

i. Sheath nematodes

Hemicriconemoides spp.

Hemicycliphora spp. *Cacopaurus* spp.

Migratory

i. Needle nematode : *Longidorus* sp.

ii. Dagger nematode : *Xiphinema* sp.

iii. Stubby nematode : *Trichodorus* sp.

iv. Pin nematode : *Paratylenchus* sp.

According to feeding habits, the nematodes can be divide into

Ectoparasitic nematodes,

Semi endoparasitic nematodes and

Endoparasitic nematodes

a) Ectoparasitic nematodes : These nematode live freely in the soil and move closely or on the root surface, feed intermittently on the epidermis and root hairs near the root tip.

A. Migraotory ectoparasite : (e.g.) *Criconemoides* spp. *Paratylenchus* spp., and *Trichodorus* sp., etc., These nematodes spend their entire life cycle free in the soil . When the roots are disturbed they detach themselves.

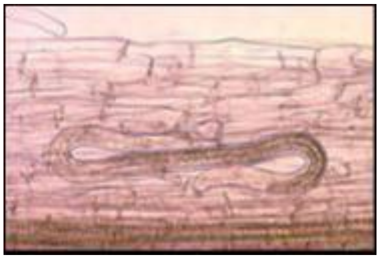
B. Sedentary ectoparasites : (eg.) *Hemicycliophora arenaria* and *Cacopaurus pestis* etc., In this type of parasitism the attachment of nematode to the root system is permanent but for this, it is similar to the previous one.

2. Semi – endoparasitic nematodes : (e.g.) *Rotylenchulus renifomis* and *Tylenchulus semipenetrans*. The anterior part of the nematode, head and neck being permanently fixed in the cortex and the posterior part extents free into the soil.

Eg. *Tylenchulus semipenetrans*

3. Endoparasitic nematodes : The entire nematode is found inside the root and the major portion of nematode body found inside the plant tissue.

a. Migratory endoparasite : (eg.) *Hirschmanniella* spp., *Pratylenchus* spp and *Radopholus similes* etc., These nematodes move in the cortial parenchyma of host root. While migrating they feed on cells, multiply and cause necrotic lesions.



Eg. *Pratylenchus*

b. Sedentary endoparasite : (eg.) *Heterodera* spp and *Meloidogyne* spp. The second stage larvae penetrate the root lets and become sedentary through out the life cycle, inside the root cortex.

Eg. *Meloidogyne*

Symptoms of nematode damage

Nematode Disease symptoms on crop plants

Most of the plant parasitic nematodes affect the root portion of plants except *Anguina spp.*, *Aphelenchus spp.*, *Aphelenchoides spp.*,*Ditylenchus spp*, *Rhadinaphelenchus cocophilus* and *Bursaphelenchus xylophilus.* Nematodes suck the sap of the plants with the help of stylet and causes leaf discolouration, stunted growth, reduced leaf size and fruits and lesions on roots, galls, reduced root system and finally wilting.

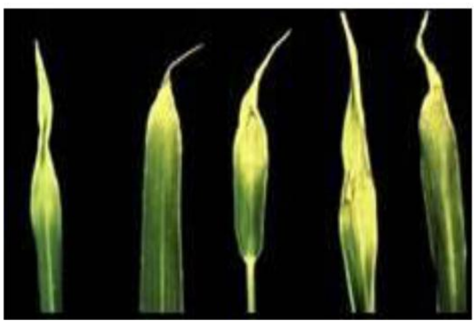
Symptoms of nematode diseases can be classified as

I. Symptoms produced by above ground feeding nematodes

II. Symptoms produced by below ground feeding nematodes

I. Symptoms produced by above ground feeding nematodes

1. Leaf discolouration: The leaf tip become white in rice due to rice white tip nematode *Aphelenchoides besseyi*, yellowing of leaves oin Chrysantyhemum due to Chrysanthemus foliar nematodes, *A. ritzemabosi*.



White tip symptom in rice

Leaf discoloration in Chrysanthemum

2. Dead or devitalized buds: In case of straw berry plants infected with *A. fragariae*, the nematodes affect the growing point and kill the plants and result in blind plant.

3. Seed galls: In wheat, *Anguina tritici* larva enter into the flower primordium and develops into a gall. The nematodes can survive for longer period (even upto 28 years) inside the cockled wheat grain.

4. Twisting of leaves and stem: In onion, the basal leaves become twisted when infested with *D. angustus*.

5. Crinkled or distorted stem and foliage: The wheat seed gall nematode. *A tritici* infests the growing point as a result distortions in stem and leaves take place.

6. **Necrosis and discoloration:**

The red ring disease on coconut caused by *Rahadinaphelenchus cocophilus*. Due to the infestation, red coloured circular area appears in the trunk of the infested palm.

Red colored ring on coconut trunk

7. **Lesions on leaves and stem**: Small yellowish spots are produced on onion stem and leaves due to *D.dipsaci*, and the leaf lesion caused by *A. ritzemabosi* on Chrysanthemum.

II. Symptoms produced by below ground feeding nematodes

The nematodes infest and feed on the root portion and exhibit symptoms on below ground plant parts as well as on the above ground plants parts and they are classified as

a. Above ground symptoms
b. Below ground symptoms

a. Above ground symptoms

1.Stunting: Reduced plant growth, and the plants can not able to withstand adverse conditions. Patches of stunted plants appears in the field. (eg.) in potato due to *Globodera rostochiensis,* in gingelly, due to *Heterodera cajani* and in wheat by *Heterodera avenae.*

2.Discolouration of foliage: Patchy yellow appearance in coffee due to *Pratylenchus coffeae*, *G. rostochiensis* infested potato plants show light green foliage. *Tylenchulus semipenetrans* induce fine mottling on the leaves of orange and lemon trees.

3.Decline and Die-back : In banana , decline and die-back are caused by *Radopholus similis*, spreading decline in citrus due to *Radopholus citrophilus* and slow decline of citrus due to *Tylenchulus semipenetrans*. In **grapevine**, slow decline is caused by ***Meloidogyne*** spp.

4.Wilting: Day wilting due to *Meloidogyne* spp. i.e. In hot weather the root – knot infested plants tend to droop or wilt even in the presence of enough moisture in the soil. Severe damage to the root system due to nematode infestation leads to day wilting of plants.

B. Below ground symptoms

1.Root galls or knots: The characteristic root galls are produced by root – knot nematode, *Meloidogyne* spp. false root galls are produced by Nacobbus batatiformis on sugar beet and tomato. Small galls are produced by *Hemicycliophora arenaria* on lemon roots. *Ditylenchus radicicola* cause root galls on wheat and oats. *Xiphinema* diversicaudatum cause galls on rose roots.

Root galls

2.Root lesion: The penetration and movement of nematodes in the root causes typical root lesions eg. Necrotic lesions induced by *Pratylenchus* spp on crossandra; the burrowing nematode, *Radopholus similis* in banana. Similarly *Pratylenchus coffeae* and *Helicotylenchus multicinctus* cause reddish brown lesion on banana root and corm. The rice root nematode also cause brown lesions on rice root.

Root lesion

3.Reduced root system: Due to nematode feeding the root tip growth is arrested and the root produce branches. This may be of various kinds such as coarse root, stubby root and curly tip.

a.Coarse root: *Paratrichodorus* spp. infestations arrest the growth of lateral roots, and leads to a open root system with only main roots without lateral roots.

b.Stubby roots : The lateral roots produce excessive rootless (eg.*P.christei*)

Stubby roots

c.Curly tip: In the injury caused by *Xiphinema* spp. the nematode retard the elongation of roots and cause curling of roots known as “Fish book’ symptom.

4.Root proliferation: Increase in the root growth or excessive branching due to nematode infestation. The infested plant root produced excessive root hair at the point of nematode infestation.
(eg.) *Trichodorus christei*, *Nacobbus spp.*, *Heterodera spp. Meloidogyne hapla* and *Pratylenchus* spp. etc.

5.Root – rot: The nematodes feeds on the fleshly structure and resulting in rotting of tissues (eg.) Yam nematode *Scutellonema bradys* and in potato *Ditylenchus destructor* cause root rot.

6.Root surface necrosis: The severe injury caused by *T. semipenetrans* on citrus leads to complete decortications of roots and results in root necrosis.

7.Cluster of sprouts on tubers: On the tubers, clusters of short and swollen sprouts are formed due to *D. dipsaci* infestation in many tuber plants.

Interaction of nematodes with other micro-organisms

INTERACTION OF NEMATODES WITH MICRO-ORGANISMS

Plant parasitic nematodes favour the establishment of secondary pathogens viz., fungi, bacteria, virus etc. The nematodes alter the host in such a way that the host tissue becomes suitable for colonization by the secondary pathogens. Even though the nematodes themselves are capable of causing considerable damage to the crops, their association with other organisms aggravate the disease. The nematodes cause mechanical wound which favours the entry of micro organisms. In some cases, the association of nematode and pathogen breaks the disease resistance in resistant cultivators of crop plants.

Nematode – fungus Interaction

Nematode – fungus interaction was first observed by Atkinson (1892) in cotton. *Fusarium* wilt was more severe in the presence of *Meloidogyne* spp. Since then the nematode – fungus interaction had received considerable attention on important crop like banana, cotton, cowpea, brinjal, tobacco and tomato. Some examples of nematode – fungus interaction are given in the following table.

Crop	**Name of the disease**	**Nematode**	**Fungus**	**Role of nematode**
Cotton	Damping off	*Meloidogyne incognita*	*Rhizoctonia solani* *Pythium* sp.	Assists Assists
	Blank shank (vascular wilt)	*M. incognita*	*Pytophtora parasitica var nicotianae*	Assists
Banana	Vascular Wilt	*Radopholus similis*	*F.oxysporum* f.sp. *cubense*	Assists

Tomato	Cortical rot	*Globodera rostochiensis*	*R.solani*	Assists
Potato	Damping off	*Ditylenchus destructor*	*P. infestans*	Assists
Onion	Damping off	*Ditylenchus dipsaci*	*Botrytis allii*	Assists
Wheat	Wheat rot	*Heterodera avenae*	*R.solani*	Assists
Soybean	Damping off	*M. javanica*	*R.solani*	Assists

Nematode – bacterium interactions

Nematode – bacterium interactions are comparatively fewer than the nematode – fungal interactions. Some examples of nematode – bacteria association are presented in the following table.

Crop	Name of the disease	Nematode	Bacterium	Role of nematode
Wheat	Tundu	*A. tritici*	*C.tritici*	Essential
Tobacco	Vascular wilt	*M. incognita*	*Pseudomonas solanacearum*	Assists
Potato	Vascular wilt	*Meloidogyne spp.*	*P. solanacearum*	Assists
Peach	Crown gall	*M. hapla*	*Agrobacterium tumefasciens*	Assists
Raspberry	Crown gall	*M. hapla*	*Agrobacterium tumefasciens*	Assists

Nematode – Virus Interaction

In nematode - virus complex, nematode serves as a vector. Numerous virus – nematode complexes have been identified after the pioneer work by Hewit, Raski and Goheen (1958) who found that *Xiphinema index* was the vector of grapevine fan leaf virus. *Xiphinema* spp., *Longidorus* spp., and *Paralongodorus* spp. tansmit the ring spot viruses which are called "NEPO" derived from Nematode transmitted polyhedral shaped particles. *Trichodorus* spp. and *Paratrichodorus* spp. transmit the rattle viruses and called "NETU" derived from Nematode transmitted tubular shaped particles. All these nematodes have modified bottle shaped *oesophagus* with glands connected by short ducts directly to the lumen of the oesophagus. This actually helps in the transmission of viruses which is different in other genera of neamtodes. Certain examples of the viral diseases and the nematode vectors are given in the following table.

Viruses	**Nematode**
NEPO – virsus	
Arabis mosaic	*Xiphinema diversicaudatum* *X. paraelongatum*
Arabis mosaic, grapevine fan leaf Yellow mosaic	*X. index*
Strawberry latent ring spot	*X. diversicaudatum*
Tobacco ring spot	*X. americanum*
Tobacco ring spot, Peach Yellow bud mosaic	*X. americanum*
Cowpea mosaic	*X. basiri*
Raspberry ring spot – Scottish strain	*Longidorus elongaatus*
Raspberry ring spot – English strain	*L. macrosoma*
Tomato black ring, Beet ring spot	*L.elongatus*
Tomato black ring, Lettuce ring spot	*L.attenuatus*
Arabis mosaic, Raspberry ring spot, Strawberry latent ring spot	*Paralongidorus maximus*

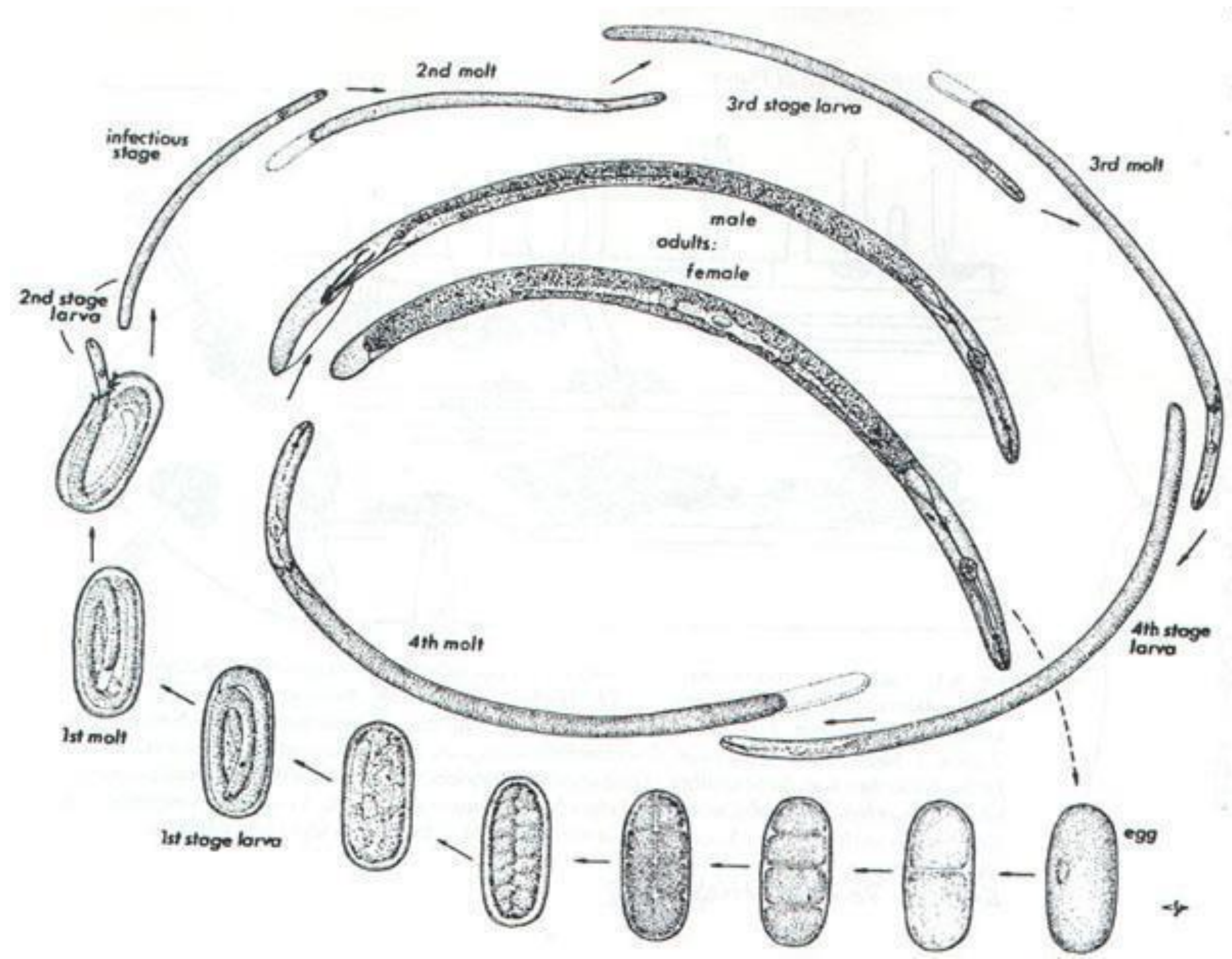
NETU VIRUSES

Tabacco	*Paratrichodorus pachydermus* *P.allius,P.nanus,* *P.porosus,P.teres* *Trichodorus christei* *T.Primitivus, T.cylindricus,* *T. hooperi, T. minor, T. similis*
Pea early browning	*P.anemones,P.pachydermus,* *P.teres,T.viruliferus.*

Nematodes acquire and transmit the virus by feeding, which requires as little as one day. Once acquired, the virus persists for longer period in the nematode body than in vitro. For example, the grapevine fan leaf virus will exist for as many as 60 days in ***X. index***. Two types of mechanisms are observed in virus transmission (i) retention through close biological association between virus and vector as in *Xiphinema*; (ii) retention of virus mechanically as in *Longidours.* Virus is retained in the inner surface of the guiding sheath of *Longidorus,* cuticle lining of the lumen of *oesophagus* in *Trichodorus* and *Paratrichodrous,* cuticle lining of stylet extension and oesophagus in *Xiphinema.* The virus particles are released into plant cell with the help of oesophagus.

Biology and ecology of *Meloidogyne*, *Heterodera*, *Tylenchulus*, *Rotylenchulus* and *Radopholus*

BIOLOGY OF PLANT PARASITIC NEMTODES



The life cycle of nematode has six stages. The egg state, J1 or first stage larva, J2 or second stage larva, J3 or third stage larva, J4 or fourth stage larva and the adult stage. The first four stages are the immature stages and are known as juvenile stages. The female lays eggs in soil or in plant tissues, singly or in groups as egg mass that hatch out into larvae which are almost similar to adults in appearance. The first moult occurs within the egg shell and the second stage juvenile comes out by rupturing the egg shell as J2. In case of *Xiphinema index*, the larvae are reported to emerge from the egg before the first moult. The larval cuticle is shed after each moult.

The Egg

The nematode eggs are oval in shape. The eggs are covered by three membranes, the external protein layer which is the secretion of uterus wall, the middle chitinous layer or the true shell secreted by egg itself and the inner lipid layer. The chitin content in the egg shell vary in different species of nematodes.

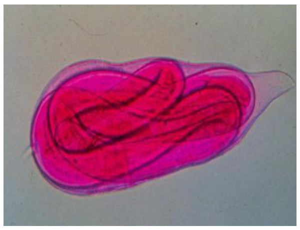
Embryonic Development

The adult female lays the eggs. The egg starts dividing by cleavage of their protoplasams to form cells. The first cleavage occur transverse to the longitudinal axis and gives two equal cells or blastomeres which are the first somatic cell (S1) and the parental germinal cell (P1). The second cleavage results in four cells which are first arranged in a T shape. This shape is achieved by the blastomere S1 dividing longitudinally and the blatomere P1 dividing transversely by P2 and S2. At last these cells get arranged in a rhomboidal shape. The transverse and longitudinal mitotic divisons of daughter cell continue. The S1 blastomere is the primary somatic cell and its two products (A & B) produce most of the nematode's ectodermal cells. The S2 blastomere produce somatic tissue and give rise to ectoderm (E), mesoderm (M) and stomodeum (St) tissues. The gonads of nematode are derived from P1. In the blastula stage the cells are so arranged as to form a fluid filled sphere bound by a single layer of the cells, while in the gastrula stage, the early embryo consists of an open mouthed sac like body with a wall of two layers of cells.

The cells A and B further divide to produce a, b, and P2 divides to give P3 and S3. The dorsal cells produced by A and B continue to divide and finally give rise to most of the hypodermis, excretory cells and nervous system. The daughter cell P2 divides into P4 and S4. These S3 and S4 are ectodermal and produce the hypodermis in the posterior region of the nematode body.

The endodermal tissue produced from the products of cell E1 and P1 divides into P5 and S5. The descendants of S5 give covers to the gonads and their ducts, while the products of P5, G1, G2 and their descendants proliferate into germ cells only.

The primary mesodermal cell M gives rise the nematode's body wall musculature and its pseudocoelomic cells, while the pharynx from St cells. During early embryonic stage these primary cells St, M and E present on the ventral surface of the embryo and are taken within the embryo by process of gastrulation. In further development the dorso ventrally flattened embryo is changed to a cylindrical shape. The embryo starts to become worm shaped and a coiled juvenile is recognized inside the egg membrane. At last the cell constancy is reached and further cell multiplication stops in all organs except the reproductive system. The first moult take place within the egg and J2 ruptures the egg shell and hatch out. Before hatching the J_1 can be seen riggling inside the egg shell.



First moult take place within the egg.

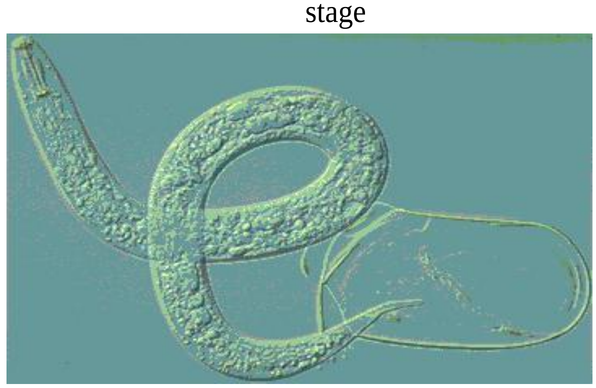
The post embryonic development in plant parasitic nematodes take place within the egg leading to the formation of juvenile which is ready to undergo first moult. In the process of post embryonic development, hatching and moulting are the important stages.

Hatching (Ecdysis)

The term hatching is used for the emergence of the juvenile from the egg. It occurs either in response of a stimulus or stimuli from the host or take place under normal environment. In cyst forming nematodes the release of juvenile from cyst is an emergence and not hatching. Eggs have hatched within the cyst.

The eggs of *Globodera rostochiensis* generally hatch in response to root exudates provided by solanaceous crops Viz., potato and tomato. After embryonic development the first stage juvenile undergoes the first moult within the egg and thus second stage juveniles are found within the egg.

After reaching a particular stage of growth and favourable hatching conditions are present, the juvenile shows vigorous movement, often causing bulging of the egg membrane as seen in case of



2^{nd} stage juvenile cyst nematode has just hatches from an egg

Pratylenchus, Paratylenchus, Nacobbus and *Meloidogyne*. After that the juvenile makes a series of thrusts with the help of stylet on the egg shell @40-90 per minute and finally juvenile emerge out by breaking the egg shell at perforated places.

Moulting (Eclosion)

The hatched juvenile resembles the adult except for body size and gonad development. The juvenile undergoes some changes in form, particularly at the anterior and posterior ends and formation of gonads. Growth in nematodes is associated with moulting which usually occurs four times and there are five stages. After the fourth moult the nematode becomes fully grown adult. During moulting the entire cuticle including the cuticular lining of the stoma, stylet, oesophagus, vulva, cloaca, rectum, amphids, phasmids and excretory pore are shed. In most of the plant parasitic nematodes greatest growth occurs after the last moult and moulting tends to occur in the earlier half of the growth curve.

Stimulus

It is reported that the neurosecretory cells of nematodes are stimulated to produce some secretions which activate glands that produce enzymes or hormones which initiate moulting. In some cases root exudates act as a stimulus for moulting as in the case of *Paratylenchus nanus* and it acts as a stimulus to the fourth stage juvenile moult. In endoparasitic nematode, the stimulus may be more complex and may be closely associated with a increase in size of nematode, because in these nematode moulting does not occur until some growth has completed within the host. The stimulus may depend on the host, temperature, pH and the salt content of the soil. When these factors are optimal, the stimulus acts after a short exposure. Juvenile once stimulated it release the exsheathing fluid into space between the new and old cuticle which then digest the area of the sheath near the excretory pore ultimately releasing the juvenile.

The receptor

In all cases the receptor may be cuticular and hypodermal structure eg. Hemizonid. It seems to be associate with neuro secretory activity which leads to the production of an enzyme which is responsible for moulting. The juvenile becomes sluggish inactive and feed vigorously just before moulting. The old cuticle is discarded by abrasion against soil particles or any rough material. The cuticle may be shed in one piece or the anterior part may be shed separately as a cap.

Growth and development

In plant parasitic nematodes, there are four juvenile stages and an adult stage. The immature stage of the nematode called as juvenile. In case of endoparasitic nematodes, three moults occur with in the host plant. The duration of the different juvenile stages is highly variable. Gonad development starts in the first juvenile stage before hatching but the growth of the organs is slow. The development starts with the formation of genital primordial which consists of two control germinal cells or one large cell which are bordered by two smaller somatic cells. External environment affect the structural development and physiology of the host which may influence the development of the nematode. The plant parasitic nematode fixes its feeding site in different regions of the root. *Meloidogyne* goes even up to stellar region, *Heterodera* and *R. reniformis* mostly confine to pericycle and *T. semipenetrans* penetrates cortex region.

Root – knot nematodes (*Meloidogyne* spp.)

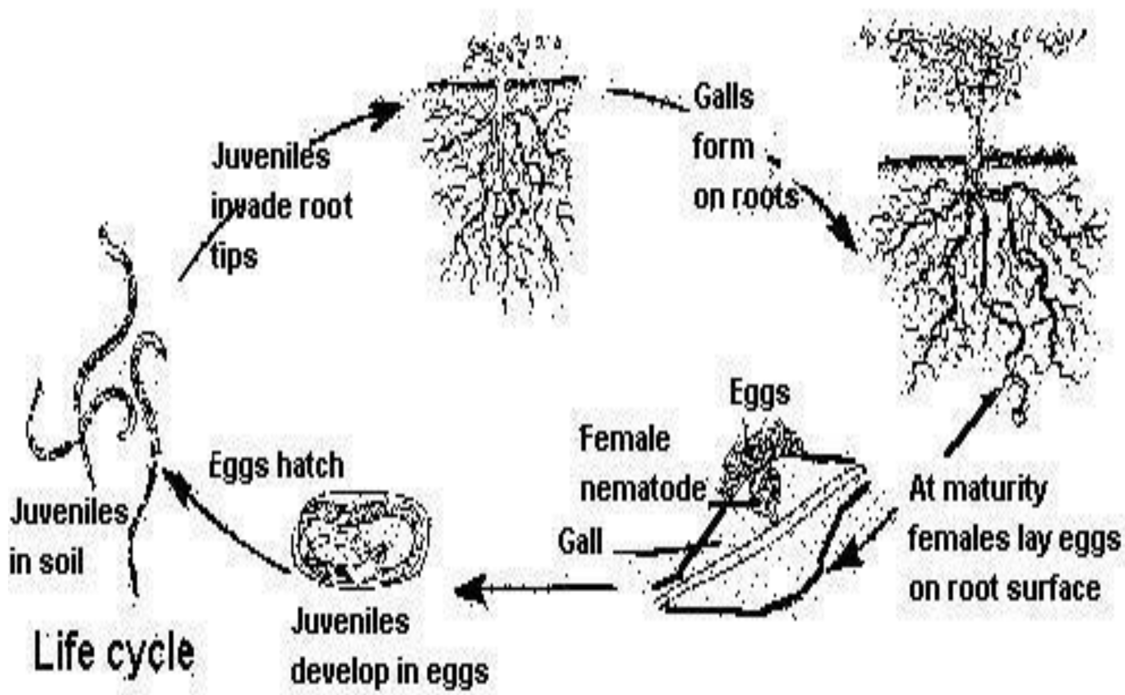
The root – knot nematodes are sedentary endoparasites of underground plant parts. The eggs are retained in a gelantinous matrix, which normally protrudes out of the host tissues. About 200 to 300 oval eggs are found in a single egg mass which makes its size larger than the female body.

The life cycle starts from the egg usually in the one-celled stage deposited by the female. Development of the embryo starts within hour of deposition, resulting in two, four, eight cells, etc., The embryo and the first stage larva move with in the egg but not very active.

After the first moult, the second stage infective juvenile is formed within the egg. Larval hatch occurs under suitable physical condition but not depending on host root exudates or hatching factor. The emerging second stage larvae are found free in the soil. They attack new host root tissue in the region behind the root tip (meristamatic zone). The larvae which develop into females establishes feeding site in the pericycle region and become sedentary. Subsequently three moults occur and the larvae develop into females with spherical body embedded in the host tissue. The neck region is unaltered.

During feeding the larvae pierce the cell wall with secretions cause enlargement of cells in the vascular cylinder and increased cell division in the pericycle. The nematode feeding stimulates the development of a typical nurse cell system called ‘Syncytium’ or ‘Giant cell’. These cells are multinucleate which contain dense cytoplasm and enlarged nuclei with several mitochindrial and golgi bodies and are metabolically active.

The larval which develop into adult males are initially parasitic. After moulting three times they leave the host as a worm like from and come closer to the females for copulation. Parthenogenesis is reported to be common in *Meloidogyne*. For development of a mature female it takes around 30 days which may vary depending upon the species of the host and parasite and environmental factors like temperature and soil type.



The life cycle of the root knot nematode

Cyst nematodes (Globodera spp. and Heterodera spp.)

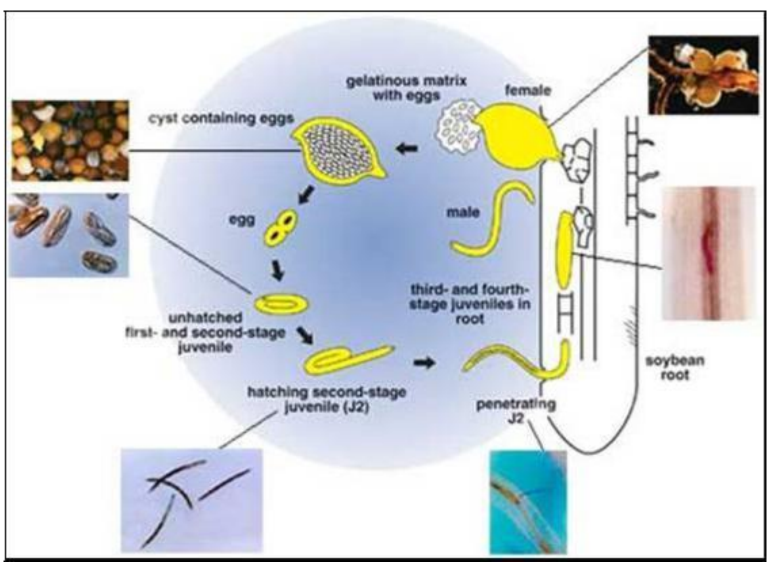
Second stages larvae usually penetrate the root just behind the growing point. These larvae grow rapidly and thee moults occur in the host. In about 5 –6 weeks after penetration, the white cysts are clearly visible which protrude from the root surface. These young cysts are packed with eggs and upon death the body wall hardens due to quinone tanning into a tough resistant brown covering known as cysts. The cysts get separated from the root and fall into soil.

Larval emergence from cysts is often in response to root exudates from a host plant. The best emergence of juveniles occurs as a result of a rise in temperature after a period of low temperature. Maximum emergence of larvae from cysts under Indian condition takes place at a temperature of 20 -22°C. The cysts continue to release eggs over a period of 3 –4 years at the rate of 50 per cent viable eggs per year. There is only one generation of the nematode in a year.

Multiplication of nematode is favoured by soil texture. Migration of second stage juveniles is favoured by light textured soils. The host cells close to the head region of the sedentary female being to modify and finally enlarge to form multinucleate syncytium with a thick outer boundary. The female feeds from this nurse cell system and grows. The swollen adult female protrudes out of the root tissues and later changes into brown cysts.

Although cyst nematodes induce giant cell formation, gall formation is not distinct. Each syncytium is associated with only one nematode in the case of cyst nematodes unlike the root – knot nematodes where one or more nematodes are associated with a syncytium. Nuclei is enlarged in the syncytium caused by the root – knot nematode but in cyst nematode nuclei is relatively small. The syncytia are bound by the vascular elements especially xylem which develops specific wall in growth. There is enlarged nucleoli and irregular nuclei. Abundant mitochondria, golgi bodies, protoplasts and dense endoplasmic reticulum are also found in the syncytia.

Life cycle of cyst nematode- *Heterodera*



Citrus nematode (*Tylenchulus semipenetrans*)

Citrus nematode is a sedentary semi – endoparasite of the Citrus root. Females are most commonly found on thick and stunted rootlets to which a layer of soil particle is clinging. These particles are held in place by a gelatinous mucus secreted by the female. The mucus and adhering soil particles protect the females and eggs deposited by them from their natural enemies. The egg laying young females can be seen in groups clinging to rootlets with their head and neck buried in the root cortex, whereas the posterior body region found outside the root surface.

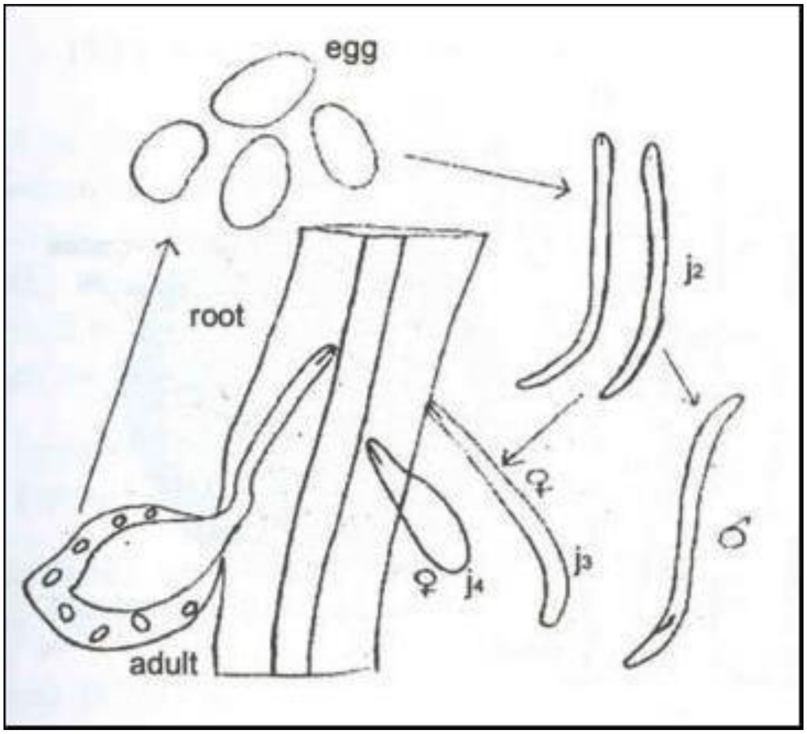
Larva hatches from egg in 12 – 14 days. Mature males develop within a week after 3 moults and one moult having occurred within the egg. The long slender individuals fail to develop unless they feed on a root. The second stage female larva requires about 14 days to locate the host root and feed on epidermal cells until ready for moulting. Fourth stage females and young females are seen in about 21 days after the entry into roots.

At maturity the females secrete the gelations matrix in which eggs are deposited. Egg laying occurs in about 40 days. The complete cycle from egg requires six to eight weeks at 25°C. Reproduction occurs without the help of males.

The feeding zone developed by this nematode is termed as nurse cell, which consists of uninucleate but not enlarged discrete parenchyma cells which are located in the cortex. Syncytium is not formed. This type of nurse cells system is characteristic for this nematode. Feeding of the citrus nematode in cortical cells results in necrosis. The injury does not extend to the stellar region of the root.

The population of the citrus nematode is closely related to the stage of decline of the trees. The nematode infestation is severe in sandy loam soil.

Life cycle of citrus nematode



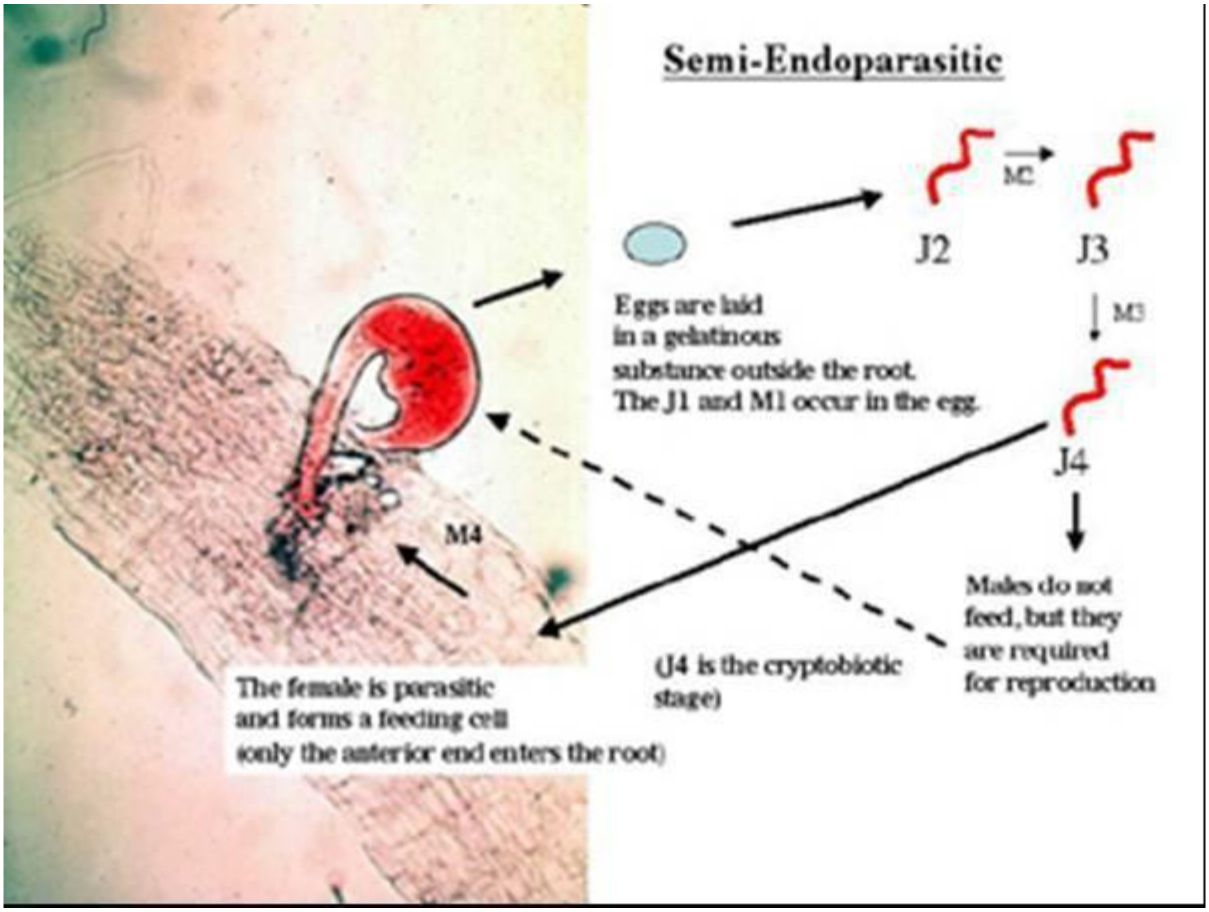
Reniform Nematode (*Rotylenchulus reniformis*)

The adult female is an obligate, sendentary, semi-endoparasite of roots while the males are non – parasitic. The species is bisexual and reproduction is by amphimixis.

The species has an unusual life cycle. Although a newly hatched second stage larva have well developed stylet, they do not feed. They soon pass through three super imposed moults to become young females and adult males. The young females force their way through cells of root cortex until they partially or completely become embedded in this tissues. During the process they feed on cortical cells. Three days after feeding, a slight swelling of the posterior body is seed and eight days later eggs are deposited in a gelatinous matrix outside the root tissue. When these eggs are placed in water they promptly begin to hatch. The life cycle is completed in about 25 days provided the young females have found the host immediately. The nematode as a semi-endoparasite of sedentary nature induces a specialized nurse cell systems for continuous food supply. The system involves wall expansion of several cells at the feeding site, partial wall dissolution, fusion of neighboring cell protoplasts and finally establishment of a multinucleate syncytium. These syncytia are mostly confined to the pericycle. Other pericycle cells are metabolically stimulated but they remain discrete and uninucleate.

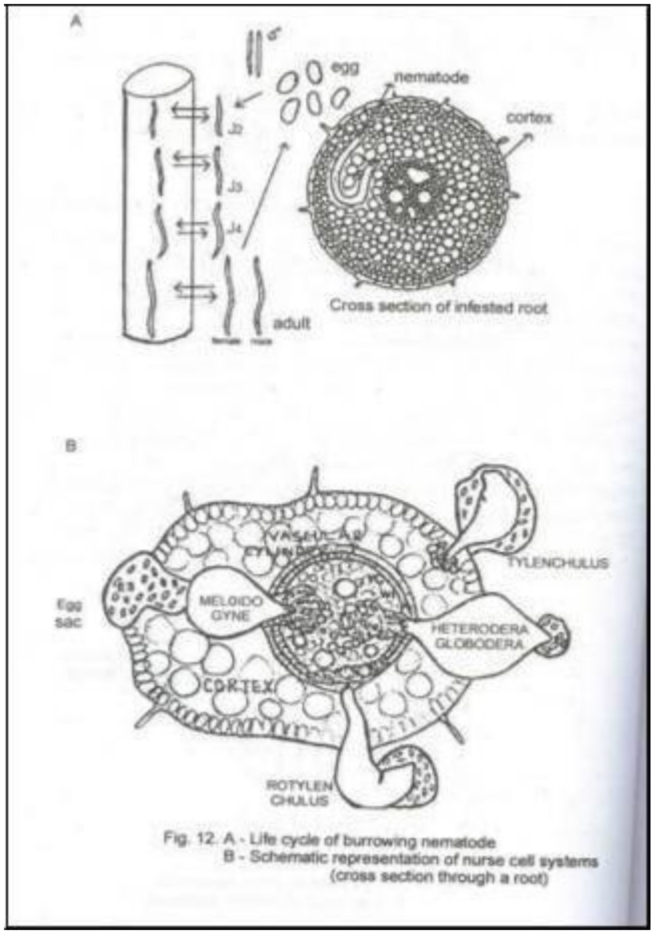
The young infective females destroy the exterior cortical cells o roots and the damage increase when the nematode moves towards the phloem.

Life cycle of Reniform Nematode



Burrowing Nematode (*Radopholus similis*)

Females and all juvenile stages are infective. Males are non-parasitic and morphologically degenerate (without stylet). Penetration occurs mostly near the root tip. The nematode penetrates within 24 hours and the cells around the site of penetration becomes brown. After entering the roots, the nematodes occupy intercellular position in the cortical parenchyma where they feed on the cytoplasm of nearby cells causing cavities which coalesce to form tunnels. Nematodes do not enter the stellar portions of the root. The nematode completes its life cycle within 24 – 30 days at a temperature range of 21 - 32°C. Females lay eggs within infested tissues with an average of 4 –5 eggs for two weeks. Eggs hatch after 8 – 10 days and the juvenile stages are completed in 10 –13 days. A low soil temperature, adequate soil moisture and availability of fresh tender roots help in the build up of population.



Life cycle of burrowing

Principles of nematode management (Legislative, physical, cultural, biological and chemical)

Plant parasitic nematodes can be controlled by several methods. The nematode control aims to improve growth, quality and yield by keeping the nematode population below the economical threshold level. The control measures to be adopted should be profitable and cost effective. It is essential to calculate the cost benefit ratio before adopting control measures.

The nematode control methods are

1Regulatory (Legal) control

2.Cultural control

3.Physical control

4.Biological control

5.Chemical control.

Regulatory control

Regulatory control of pests and diseases is the legal enforcement of measures to prevent them from spreading or having spread, from multiplying sufficiently to become intolerably troublesome. The principle involved in enacting quarantine is exclusion of nematodes from entering into an area which is not infested, in order to avoid spread of the nematode

Quarantine principles are traditionally employed to restrict the movement of infected plant materials and contaminated soil into a state or country. Many countries maintain elaborate organizations to intercept plant shipments containing nematodes and other pests. Diseased and contaminated plant material may be treated to kill the nematodes or their entry may be avoided. Quarantine also prevent the movement of infected plant and soil to move out to other nematodes free areas.

Plant Quarantine in India

The Destructive Insects and Pests Act, 1914 (DIP) was passed by the Government of India which restricts introduction of exotic pests and disease into the country from abroad.

The agricultural pests and disease acts of the various states prevent interstate spread of pests within the country. The rules permits the plant protection advisor to the government of India or any authorizes officer to undertake inspection and treatments.

Strict regulations have been made against *G. rostochiensis,* the potato cyst nematode and *Rhadinaphelenchus cocophilus,* the red ring nematode of coconut. Domestic quarantine regulations have also been imposed to restrict the movement of potato both for seed and table purposes in order to present the spread of potato cyst nematode from Tamil Nadu to other states in India.

Cultural Control

Cultural nematode control methods are agronomical practices employed in order to minimize nematode problem in the crops.

Selection of healthy seed material

In plants, propagated by vegetative means we can eliminate nematodes by selecting the vegetative part from healthy plants. The golden nematode of potato, the burrowing, spiral and lesion nematodes of banana can be eliminated by selecting nematode free plant materials. The wheat seed gall nematode and rice white tip nematode can be controlled by using nematode free seeds.

Adjusting the time of planting

Nematode life cycle depends on the climatic factors. Adjusting the time of planting helps to avoid nematode damage. In some cases crops may be planed in winter when soil temperature is low ad at that time the nematodes cannot be active at low temperature. Early potatoes and sugar beets grow in soil during cold season and escapes cyst nematode damage since the nematodes are not that much active, to cause damage to the crop during cold season.

Fallowing

Leaving the field without cultivation, preferably after ploughing helps to expose the nematodes to sunlight and the nematodes die due to starvation without host plant. This method is not economical.

Deep summer ploughing

During the onset of summer, the infested field is ploughed with disc plough and exposed to hot sun, which in turn enhances the soil temperature and kills the nematodes.

For raising small nursery beds for vegetable crops like tomato and brinjal seed beds can be prepared during summer, covered with polythene sheets which enhances soil temperature by 5 to 10˚C which kills the nematodes in the seed bed. This method is very effective and nematode free seedling can be raised by soil solarization using polythene sheets.

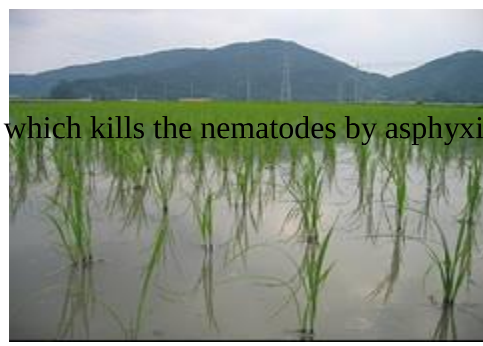
Summer ploughing

Manuring

Raising green manure crops and addition of more amount of farm yard manure, oil cakes of neem and castor, pressmud and poultry manure etc enriches the soil and further encourages the development of predacious nematodes like *mononchus* spp. and also other nematode antagonistic microbs in the soil which checks the parasitic nematodes in the filed.

Flooding

Flooding can be adopted where there is an enormous availability of water. Under submerged conditions, anaerobic condition develops in the soil which kills the nematodes by asphyxiation.



Chemicals lethal to nematodes such as hydrogen sulphide and ammonia are released in flooded condition which kills the nematodes.

Trap cropping

Two crops are grown in the field, out of which one crops is highly susceptible to the nematode. The nematode attacks the susceptible crop. By careful planning, the susceptible crop can be grown first and then removed and burnt. Thus the main crop escapes from the nematode damage. Cowpea is highly susceptible crop can

Cowpea

be grown first and then removed and burnt.Cowpea is highly susceptible to root – knot nematode and the crop can be destroyed before the nematodes mature.

Antagonistic crops

i)Certain crops like mustard, marigold and neem etc have chemicals or alkaloids as root exudates which repell or suppress the plant parasitic nematodes.

ii)In marigold (*Tagetes* spp.) plants the α – terthinyl and bithinyl compounds are present throughout the plant from root to shoot tips. This chemical kills the nematodes.

iii)In mustard allyl isothiocyanate and in pangola grase pryrocaterchol are present which kills the nematodes.

iv)Such enemy plants can be grown along with main crop or included in crop rotation.

Marigold

Removal and destruction of infected plants

Early detection of infested plants and removal helps to educe nematode spread. After harvest the stubbles of infested plants are to be removed. In tobacco, the root system is left in the field after harvest. This will serve as a inoculum or the next season crops. Similarly in *D. angstus* the nematode remains in the left out stubbles in the field after harvest of rice grains. Such stubbles are to be removed and destroyed and land needs to be ploughed to expose the soil.

Use of resistant varieties

Nematode resistant varieties have been reported from time to time in different crops. Use of resistant varieties is a very effective method to avoid nematode damage. Nemared, Nematex, Hisar Lalit and Atkinson are tomato varieties resistant to *M. incogntia* . The potato variety Kufri swarna is resistant to *G. rostochiensis*.

Physical control

It is very easy to kill the nematodes in laboratory by exposing the nematodes to heat, irradiation and osmotic pressure etc., but it is extremely difficult to adopt these methods in field conditions. These physical treatments maybe hazardous to plant or the men working with the treatments and the radiation treatments may have residual effects

Heat treatment of soil

Sterilization of soil by allowing steam is a practice in soil used in green house, seed beds and also for small area cultivation. Insects, weed seeds, nematodes, bacteria and fungi are killed by steam sterilization. In such cases steam is introduced into the lower level of soil by means of perforated iron pipes buried in the soil. The soil surface needs to be covered during steaming operation. Plastic sheets are used for covering. In the laboratory and for pot culture experiments autoclaves are used to sterilize the soil.

Soil solarisation

Hot water treatment of planting material

Hot water treatment is commonly used for controlling nematodes. Prior to planting the seed materials such as banana corms, onion bulbs, tubers seeds and roots of seedlings can be dipped in hot water at 5 0 – 55 ˚C for 10 minutes and then planted.

Irradiation

Irradiation also kills the nematode. Cysts of *G. rostochiensis* exposed to 20,000 Ỵ contained only dead eggs and at 40, 000 Ỵ exposure, the eggs lost their contents. *Ditylenchus* *myceliphagus* in mushroom compost exposed to Ỵ rays between 48,000 to 96,000 Ỵ inactivated the nematodes. UV light also kill the nematodes. But these irradiation is not practically feasible under field conditions.

Osmotic pressure

Feder (1960) reported 100% nematode mortality when sucrose or dextrose were added to nematode infested soil @ 1 to 5% by weight. But these methods are not practical and economical.

Washing process

Plant parasitic nematodes are often spread by soil adhering to potato tubers, bulbs and other planting materials. Careful washing of such planting material helps to avoid the nematodes in spreading in new planting field. Washing apparatus for cleaning potato and sugarbeet tubers are commercially developed and are being used in many countries.

Seed cleaning

Modern mechanical seed cleaning methods have been developed remove the seed galls from normal healthy wheat seeds.

Ultrasonics

Ultrasonic have little effect on *Heterodera* spp. The use of this ultrasonics is not practically feasible.

Biological Control

Biological control aims to manipulate the parasites, predators and pathogens of nematodes in the rhizosphere in order to control the plantparasitic nematodes. Addition of organic amendments such as farm yard manure, oil cakes, green manure and pressmud etc encourages the multiplication of nematode antagonistic microbes which inturn checks the plant parasitic nematodes.

The addition of organic amendments acts in several ways against the plant parasitic nematodes. Organic acid such as formic, acetic propionic and butric acids are released in soil during microbial decomposition of organic amendments. Ammonia and hydrogen sulphide gases are also released in soil during decomposition. These organic acids and gases are toxic to nematodes.

Nematode antagonistic microbes multiply rapidly due to addition of organic matter.

Organic amendements improve soil conditions and helps the plants to grow. The organic matter also provides nutrition for the crps plants.

Predacious nematodes

Predacious nematodes have specialized open stoma armed with teeth to catch and swallow the plant parasitic nematodes. Addition of organic amendments help to encourage the multiplication of predacious nematodes such as *Mononchus* spp. Other genera like *Diplogaster* spp. and *Tripyla* spp. also come under the group of predacious nematodes.

Predacious fungi

Most of the predacious fungi comes under the order **Moniliales** and **Phycomcetes**. There are two types of predacious activities among these fungi. They are nematode trapping fungi and endozoic fungi.

Nematode Trapping Fungi (NTF)

The nematode trapping fungi have adhesive networks and sticky knobs are produced by the mycelium to capture the plant parasitic nematodes. The nematode trappers are grouped as follows.

Sticky branches: The fungal mycelia have short lateral branches and they anastamose to form loops. The nematodes are trapped in this loops.

Sticky networks : The mycelium curl around and anastomoses with similar branches. These loops produce complex three dimensional structures. The adhesive surface of the network helps to hold the nematode eg: ***Arthrobotrys*** spp.

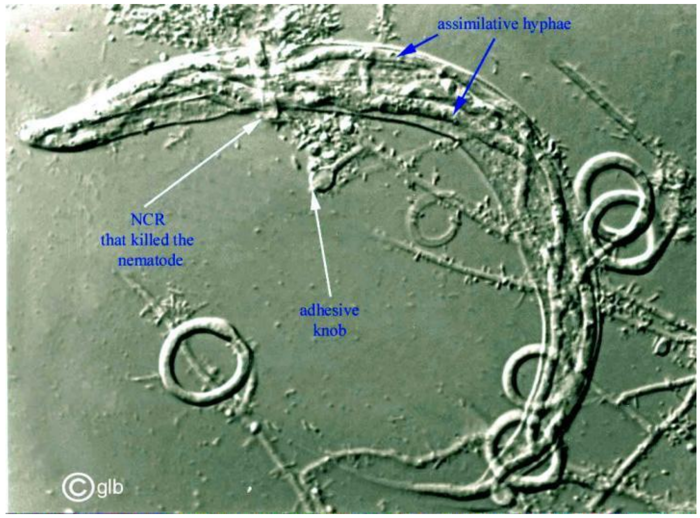
Sticky knobs : Small spherical or subspherical lobes are present on one or two celled lateral hyphae. Only the terminal knob is sticky to hold the nematodes eg: ***Monoacrosporium ellipsospora***

Constricting rings: The short hyphal branch curls back on itself and anastomoses and forming a ring. When the nematode enters the ring and contact the inner walls of the ring cells, the ring cells bulge inward filling the lumen of the ring and kills the nematode eg. ***Monoacrosporium bombicoides*** and ***Dactylaria brochopaga***

Non-constricting rings

The trap is formed similar to the constricting ring. It is a non – adhesive trap. The reing becomes an infective structure and kills the nematode eg. *Daclylaria candida*.

In addition to formation of traps and adhesive secretions, the predacious fungi may also produce toxin which kills the nematodes.



Endozoic fungi

The endozoic fungi usually enter the nematode by a germ tuber that penetrates the cuticle from a sticky spore. The fungal hyphae ramify throughout the nematode body, absorb the contents and multiply. The hyphae then emerge from dead nematode. ***Catenaria vermicola*** often attacks sugarcane nematodes.

Parasitic fungi

Paecilomyces lilacinus / Purpureocillium lilacinum and *Pochonia chlamydosporia* is an effective egg parasite on many nematodes. The parasitic fungus is particularly effective against *Meloidogyne*, *Heterodera*, *Rotylenchulus* and *Tylenchulus*. The fungus attack the eggs as they are deposited in group as a mass. The parasitic fungus was found to be effective against potato cyst nematode, root - knot nematodes in tomato, brinjal, betelvine and banana and *T. semipenetrans* in citrus.

Antagonistic fungi

Trichoderma spp. are one among a group of beneficial fungi that are present in almost all soils and diverse habitats. They have proven commercially viable as a successful biological control agent against plant parasitic nematodes and pathogenic fungi. Many species of ***Trichoderma*** *viz.*, ***T. viride***, ***T. harzianum, T. koningi, T. longibrachiatum*** **and** ***T. hamatum*** were reported effective against several nematodes.

Mechanism of action against phytonematodes

Mycoparasitism

Trichoderma spp. were reported to secrete many lytic enzymes like chitinase which help parasitism of ***Meloidogyne*** and ***Globodera*** eggs.

Antibiosis

T. viride produces antibiotics like **trichodermin, dermadin, trichoviridin** and **sesquiterpene heptatlic acid** which are involved in the suppression of pathogenic fungi and nematodes.

Competition

Competition for space or nutrients is one of the classical mechanism of Trichoderma spp. They have high rhizosphere competency and can easily colonize the roots. This may reduce the feeding sites for nematodes.

Solubilization and sequestration of inorganic plant nutrients

Treatment with T. harzianum increased nitrogen uptake and also solubilized rock phosphate, Zn metal, Mn^{4+}, Fe^{3+} and Cu^{2+}. Enhanced nutrient uptake increases the tolerance of the plants to nematode attack.

Induced Systemic Resistance

Defense enzymes *viz*., peroxidase, polyphenoloxidase, phenylalanine ammonia lyase, catalase and chitinase were induced more in T. viride treated plants which determine the ability of the plant to survive any nematode attack.

Bacteria

Plant growth promoting rhizobacteria for nematode management

Bacteria that colonize the rhizosphere soil under the chemical influence of the root are commonly referred to as rhizobacteria. Specific rhizobacteria that have the ability to improve plant growth are called as plant growth promoting rhizobacteria (PGPR)

Species of rhizobacteria used for nematode management

Bacillus sp.	*Azotobacter* sp.
Azospirillum sp.	*Clostridium* sp.
Pseudomonas sp.	*Burkholderia* sp.
Agrobacterium sp.	*Azospirillum* sp.

Arthrobacterium sp.

Mechanism of action of PGPR

Antibiotic - Mediated Suppression

Antibiotic production is one of the main mechanisms involved in the suppression of plant pathogens which includes both nematodes and pathogens by fluorescent pseudomonads. Antibiotics include phenazines, pyrrolnitrin, pyocyanin and 2,4-diacetyl phloroglucinol.

Siderophore - Mediated Suppression

Pseudomonas fluorescens generally produce yellow green, water soluble, fluorescent siderophores which are linked with their disease suppression ability. This efficient iron uptake mechanism helps these strains to aggressively colonize plant roots thus aiding the physical displacement of deleterious organisms.

Induced Systemic Resistance

Induced Systemic Resistance (ISR) is based on plant defence mechanisms that are activated by inducing agents. ISR once expressed activates multiple potential defence mechanisms *viz*., increased activity of chitinases, peroxidases and other pathogenesis – related proteins, accumulation of phytoalexins and formation of protective biopolymers, e.g. lignin, callose and hydroxyproline – rich glycoproteins.

Pasteuria

Pasteuria penetrans was found to be very effective against the root –knot nematodes in many crops. The *P. penetrans* infested J_2 of root -knot nematodes ca be seen attached with spores throughout the cuticle.

The life cycle of Pasteuria penetrans consists of four stages: spore germination, vegetative growth, fragmentation and sporogenesis. The electrostatic forces on the spores help attach themselves to the nematode cuticle in the soil. Such attached spores germinate by forming a germ tube and penetrate into the nematode cuticle in about 3 days after infection. The bacterial thalli then start spreading and form spherical microcolony or mother colony with dichotomously branched mycelium in about 14 days after infection. Four celled stage of the bacterium, called quartet, is observed in about 18 days after infection. Later quartets fragment into 2 celled stage called doublets which develop into unicellular stage on the 24^{th} day by further fragmentation. Mature spores of the bacterium are formed in about 30 days after infection synchronizing with the life cycle of the host nematode.

Chemical Control

History of chemical control

Kuhn (1881) first tested CS2 to control sugarbeet nematode in Germany and he could not get encouraging results. In South Carolina State, U.S.A. Bessey (1911) treated CS2 or the control of root – knot nematodes but the method proved impractical. Latter on the chemicals like formaldehyde, cyanide and quick line were observed to have nematicidal properties, but all these chemical were found to be highly expensive.

Mathews (1919) observed the effect of chloropicrin (tear gas) against plant parasitic nematodes in England. Carter (1943) an entomologist of Hawai, Pineapple Research Institute, reported the efficacy of 1,3 dichoropropene 1,2 dichloropropane (DD) mixture@ 250 1b/acre, against the plant parasitic nematodes. In 1944, scientists from California and Florida states of USA reported the efficacy of ethylene dibromide (EDB). In the same year the Dow Chemical company, USA introduced the chemical as a soil fumigant for the management of nematodes. The introduction of these two nematicides viz., DD and EDB paved way for the chemical control of nematodes.

Description of some important nematicides

Ethylene dibromide (EDB) : 1.2 Dibromonehane. It is a colourless liquid and the gas in non-inflammable. It is available ad 83% liquid formulation containing 1.2 kg active ingredient per litre and as 35% granules. It is injected or dibbled into the soil for the control of nematodes at 60 to 120 1 or 200 kg ai/ha but it is not very effective against cyst nematodes. Heterodera spp. and soil fungi. Crops like onion, garlic and other bulbs should not be planted after soil treatment with EDB. It is available as Bromofume and Dowfume.

Dibromochloropropane : (DBCP) 1,2 – dipromo – 3 – chloropropane. It is a straw coloured liquid, a litre of it weighing 1.7 kg. It can be used s soil treatment before planting, at the time of planting or as post when the soil temperature is above 20˚C. It is applied as a sprinkle depending upon the crop and stage. Certain crops like tobacco and potato are sensitive due to high bromine content in the chemical. It functions more efficiently than other fumigant at high soil temperature due to its high boiling point (195.6˚C). trade names are Nemagon and fumazone.

DD mixture It is the trade name of the mixture of compounds, chief of them contain thecis and the trans isomers in equal quantities of 1,3 – dichloropropene 30.35%, and a few other chlorinated compounds up to about 5%. Of these, dichloropropene is the most toxic compounent and among its two isomers, the transisomer is twice as toxic as the cis-isomer. It is a black liquid of 100% formulation and a litre of it contains approximately 1kg of technical compounds. It is used in the control of soil insects and nematodes and injected into the soil at a depth of 15 -20 cm at 25 x 30 cm spacing. It is a fungicide a very high diseases. Since it is highly phytotoxic, it is used for preplant soil application at least 2 -3 weeks before planting. It is used for preplant soil application at least 2 -3 weeks before planting. It is used as such at 225 – 280 1/ha, but in clay and peaty soils a higher dosage is required. It taints potato tubers and carrots grown in treated soil. Dichloropropence is available under the trade name Telone andin mixture with dibromoetane under the name Dorlane.

Methylbromide or Bromomethane It boils at 4.5˚C. At ordinary temperatures it is a gas and therefore, confined in containers under pressure as a liquid. The gas is 1.5 times as heavy as air. Its insecticidal properties were described by Le Goupil in 19 -32. Its power of penetration into packed foodstuffs such as flour is remarkable. As it kills insects slowly a longer period of exposure to gas may be required. For control of stored grain pests it is used at 24 – 32 $g.m^3$, exposure period being 48 h. In tent fumigation for the control of termites and powder post beetles, the dosage recommended is 32 0-64 g/ m^3. For fumigating live plants, the dosage is 16 -32. Some plants are likely to be injured. In soil application for the control of nematodes.

Phorate : 0,0 – diethyl S – (ethylthiomethyl) phosphorodithioate. Trade name is Thimet. It is systemic insecticide cum nematicide, available as 10% granule. It has got both contact and fumigant action. It does not persist for a longer period and gets metabolically oxidized yielding for rat: oral 16 – 3.7; dermal 2.5 to 6.2.

Aldicarb : 2 – methyl – 2 (methilthio) propinaldehyde 0 (methylcarbomy) oxime. Trade name is Temik. The sulphur atom in the molecule is oxidized to sulfoxide and then to sulfone. It is a systemic 10% granule. The residues remain in plants for 30 -35 days as a lethal dose. It also acts as repellent, contact nematicide and interferes with reproduction of the nematodes by way of sex reversal.

Carbofuran: C_{12} H_{15} No_3. It is 2,3 – dihydro – 2, 2, dimethyl 7 benzofuranyl methyl carbamate. Trade name Furadon. It is a systemic insecticide cum nematicide. It is formulated as

3% granule and also as 40F. The residual effect last for 30 – 60 days. It has also got phytotonic effect. This systemic chemical has got acropetal action and applied @ 1 -2 kg ai. /ha.

Resistant varieties

The use of resistant varieties provide an effective, economical and friendly means of nematode control.

Crop varieties identified/developed resistant to plant parasitic nematodes

Crop	**Nematode**	**Resistant varieties**
Tomato	Root-knot nematodes (*Meloidogyne javanica / M. incognita*)	PNR-7, NT-3, NT-12, Hisar Lalit
Chilli	Root-knot nematodes ((*Meloidogyne javanica / M. incognita*)	NP-46A, Pusa Jwala, Mohini
Cowpea	Root-knot nematodes (*Meloidogyne javanica / M. incognita*)	GAU-1
Mungbean	Root-knot nematodes (*Meloidogyne javanica / M. incognita*)	ML-30 and ML-62
Cotton	*Meloidogyne incognita*	Bikaneri nerma, Sharda, Paymaster
Grapevine	Root-knot nematodes (*Meloidogyne javanica / Meloidogyne incognita*)	Khalili, Kishmish Beli, Banquabad, Cardinal, Early Muscat, Loose Perlett
Potato	Potato cyst nematode (*Globodera rostochiensis*)	Kufri Swarna, Kufri Giriraj

Integrated nematode management

Definition

INM can be defined as a systems approach to reduce nematode to tolerable levels through a variety of techniques including predators and parasites, genetically resistant hosts, natural environmental modifications and when necessary and appropriate chemical nematicides.

Integrated Nematode Management

The grower combines several measures to prevent the growth of damaging nematode populations. Where there is an advisory service equipped to monitor field populations, these control measures can be utilized with minimum amounts of nematicides. Without advisory services, integrated control of nematode is hardly possible and relatively heavy dosages of chemical nematicides are employed.

Decisions to implement nematode management programmes are based on the perceived value of the potential crop loss and the cost of the management procedure. Theoretically this involves determining an economic threshold. Management procedures should usually be implemented when the marginal revenue derived from the management input is equal to or excess the marginal cost.

The design development and implementation of INM systems for plant protection requires extensive interaction of nematologists with scientists in complementary disciplines.INM includes following components.

a. Exclusion

Crop losses caused by plant parasitic nematodes can be avoided through preventing the introduction of specific nematodes or nematode problems in areas where the species do not exist. The focal point of exclusion is the target nematode species. Exclusion procedures should be used as first order defenses to prevent dissemination and establishment.

Exclusion procedures include sanitation, certified plant material, nematode free soil or planting media, population reduction or eradication procedures and regulatory activities. Quarantines are used to prevent or slow the spread of plant parasitic nematodes. Certified plant material and nematode free planting media or equipment are

used for nematode exclusion. All available exclusion procedures should be considered in the system evaluation and design of the INM programme.

b. Population Reduction

Crop losses caused by plant parasitic nematodes can be alleviated by procedures designed to decrease population densities of the target species to an acceptable level. Whenever possible population reduction strategies should stabilize nematode population densities below the damage threshold. The focal point of population reduction is the target species. It is assumed that the species of concern is present and eradication is not feasible.

Established nematode populations are usually managed through population reduction by cultural, physical, biological and chemical procedures. Cultural procedures include the use of fallowing, flooding, cover crops, crop rotation, planting date, rougeing, trap crops or weed management for population reduction. Heat is the physical factor most widely used in nematode population reduction. Nematode biocontrol resoures include prokaryons (viruses, rickettsias and bacteria), nematophagus fungi and predacious, parasitic or environmental modifying invertebrates(nematodes,protozoa, mites etc) and antagonistic plants.

Nematicides can directly or indirectly reduce populations associated with nematode infested materials and can be used for soil application, root tips, foliar applications or seed treatments.

c. Tolerance

Crop losses caused by plant parasitic nematodes can be reduced by manipulating the host in relation to its environment. The objective of tolerance is to elevate the damage threshold. The focal point is the host crop.

Procedures that protect or increase plant tolerance have excellent potential for INM. These include cultural manipulation, chemical application, mycorrhizal colonization and resistant cultivars.

If no method is suitable for the management of nematodes, the principle of tolerance can be attempted.

Nematode parasites of cereals and millets

NEMATODE PESTS OF FIELD CROPS

RICE

Plant parasitic nematodes cause serious damage to rice crop. Thirty two species belonging to 13 genera were observed in association with the crop. Among them few are considered to be important. They are the rice white – tip nematode (*Aphelenchoides besseyi*), rice stem nematode (*Ditylenchus angustus*), rice root nematode (*Hirschmanniella oryzae*), root – knot nematode (*Meloidogyne graminicola*) and the cyst nematode (*Heterodera oryzicola*)

The white tip nematode (*Aphelenchoides besseyi*)

The yield loss due to the white – tip nematode is estimated to be as such as 17.4 to 54 .1 per cent. The nematode is distributed in India, Bangladesh, Sri Lanka, Japan, Indonesia, Taiwan, USSR, Italy Cuba and Madagascar.

Symptoms

- Infested seeds emerge late in seed beds and produce small seedlings.
- The upper 2 to 5 cm leaf tip turn white or pale yellow in the tillering stage and then turn brown.
- Flag leaves are characteristically shortened and twisted at their apical portions.
- Panicles are shorter and spikelets are reduced which inturn produce deformed kernels.
- The infested spikelet show numerous nematodes while examining under a microscope. The nematode delays the maturity of panicles and secondary panicles arise from lower nodes.

Life cycle

The nematode is carried beneath the hull of the kernel in quiescent, immature pre –adult stage. In this quiescent stage the nematode can remain dormant for 2 years. When such infested seeds are sown, the nematode revive and move to the growing points of the leaf and stem and feed ectoparasitically. The eggs are deposited in the leaf axis or in panicles and many generations occur in one season. Reproduction follows plant growth and the nematodes move upward along with the development of leaf. Movement of nematodes are mostly due to the presence of thin film of moisture due to rain or dew or high humidity. Many nematodes enter into the panicles and some nematodes found inside the hull. Normally 5 to 6 nematodes are found in each seed. The life cycle takes 8 days at 23°C and 10 days at 21°C.

Host range

The nematode also infests Setaria italic, S. viridis, Panicum sanguinale and Cyperus iria. Apart from this strawberry, tuberose, chrysanthemum, Boehmeria nivea, Ficus elastic and Pennisetum typhoides are also reported to be the hosts for the nematode.

Spread and Survival

The spread is mainly by infested seeds. The nematode is also carried along with irrigation water to nearby fields. Second stage juveniles remain in quiescent stage outside or inside the husk and can survive for 3 years in this stage but die in 4 months on grain left in the field and they cannot survive in the soil. Rice seedlings growing from shed grain may allow the nematodes to survive from one season to the next.

Management

1. Use of certified seeds can eliminate the nematode.
2. Hot water treatment of seeds at 55°C for 15 minutes prior to sowing or seed disinfestations by sun drying for 12 hours between 9 am and 3 pm for 2 days.
3. Burning of stubbles after harvest for preventing perpetuation of the nematode in field through dormant nematodes.

Nematode parasites of vegetables and fruit crops

NEMATODE PESTS OF VEGETABLE CROPS

POTATO

Potato is one of the most important vegetable crop grown in India. It thrives best in cool climate. Therefore it is a summer crop in the hills and a winter crop in plains.

Cyst nematodes (*G. rostochiensis* and *G. pallida)*

In India the cyst nematode menace on potato was first reported by Dr. Jones during 1961 from Nilgiri Hills.

The vegetable crops like bhendi, brinjal, tomato,carrot, radish, chillies, cauliflower, cabbage, bitter goured and garden beans are often infected by this nematode.

The second stage larvae penetrate the young roots behind the root cap and migrate to cortex region and fix a feeding site. At the feeding site 4 -5 giant cells are formed which provide nourishment to the developing larvae. The giant cells are bigger in size and multicnucleate with dense cytoplasm. AT the feeding site proliferation of cells occurs due to hypertrophy and hyperplasia. Due to pressure in the cortical tissue, galls are formed on the roots. The gall formation leads to the destruction of xylem vessels which in turn affects conduction of water and the nutrients to the above ground parts. The adult female lays 200 – 300 eggs in gelsyinoud matrix which usually protrudes outside the roots. The life cycle is normally completed in 25 - 30 days depending upon the host and other ecological factors.

Reniform nematode (*Rotylenchulus reniformis*)

Reniform nematode is a semi – endoparasite and causes damage to beans, cabbage,carrot, cauliflower cucmber, brinjal pea, cowpea. Radish, behndi and lettuce. The preadult females are parasitic. The nematode initiate infection by destroying the epiderma cells and cause necrosis. Distintergration of phloem cells occur in the stellar region of plants. Juveniles of female survive for six months in desiccate soil and for several month in moist soil. The fourth stage larvae are better adapted to adverse condition. The adult females are reniform in shape with their head and neck inside the roots whereas the posteror reniform shaped body seen outside the root. The female lays 150 – 200 eggs in gelations matrix.

Stem and bulb nematode (*Ditylenchus* spp.)

The stem nematode commonly attack beansm, peas,c arrot, potato, onion and garlic. D. dipsaci commonly feeds on stems, leaves and bulbs and very rarely found in soil.

Stunt nematode (*Tylenchorhynchus* spp.)

The most common species of stunt nematode is T. brassicae which cause damage to cabbage and cauliflower in Utter Pradesh. The seedlings growth is very much reduced due the nematode. The nematode is mostly an ectoparasite and rarely observed in the stellar region. The multiplication of the nematode takes place in a wide range of temperature. (15 - 35˚C).

Management

The nursery needs to be raisedin nematode free soil. Nematode infested seedling should not be used for planting. Soil solarisation in nursery beds using polythene sheets during summer reduces the soil infestion of nematodes.

Rotation of crops like , brinjal , bhendi and chilli with non hosts crops like mustard, sesame, maize, wheat and rice.

Use of organic amendments: Incorporation of decomposed farm yard manure, poultry manure and green leaf manures reduce the nematode infestation by promoting the predacious nematodes and other antagonistic fungi which checks the parasitic nematodes. During decomposition of organic matter, several organic acids, ammonia and other nematode toxic compounds are released in soil.

Chemical treatment: Nursery beds can be treated with carbofuran 3G @ 3gai/m2. In main field, carbofuran or phorate can be applied spot treatment @ 1.5 kg ai/ha on 15 days after transplanting.

Host plant resistance: The use of resistant varieties provide an effective, economical and friendly means of nematode control. Hissar – Lalit and NDTR are resistant tomatoes against *Meloidogyne* spp. Pusa Jwala is a resistant chilli variety against *M. incognita.*

<u>Nematode parasites of spices and plantain crops, flower crops and medicinal and aromatic plants</u>

NEMATODE PESTS OF SPIES AND PLANTATION CROPS

BLACK PEPPER

Black pepper (*Piper nigrum*) is indigenous to the tropical forests of western ghats of South India. The crop is grown in Kerala, Karnatak, Tamil Nadu, Andra Pradesh and Assam.

The root knot nematode, *Meloidogyne incognita* and the burrowing nematode, *Radopholus similis* are important pests of this crop. The root knot nematodes infested vines show yellowing of lower leaves and the leaves loose natural luster. The yellowing of leaves gradually progress upwards. The affected vine leaves become flaccid and wither. The infested plant root show root galls of varying sizes.

The burrowing nematode also cause serious damage to the vine. Var der Vecht (1950) first reported slow wilt in this crop due to R. similes infestation in Indonesia. The nematode in association with *Fusarium* and *Rhizoctonia* cause serious damage to the crop.

Management

Treat the plants in the nursery with carbofuran 3G 1.5 kg a.i./ha. In the main field the vines can be treated once in 6 months with carbofuran @ 1.5 – 2.0 kg ai./ha. Application of neem cake @0.5 to 1 kg / vine also reduce the nematode damage.

Turmeric

Turmeric (*Curcuma longa*) is grown in the states of Andhra Pradesh, Maharastra, Tamil Nadu, Orissa, Kerala andBihar. It is a herbaceous perennial with a thick underground rhizome giving rise to primary and secondary rhizomes called fingers.

The root – knot nematode, *Meloidogyne* spp. is widely prevalent in all the turmeric grown areas. The nematodes spread through the rhizomes. In case of severe infestation stunting and yellowing of plant appear in patches. The infested plant root show severe root galls and there will be poor development of fingers.

Management

Application of crbofuran 3G or phorate 10G @ 1 – 1.5 kg ai/ha. Neem cake application @ 1t/ ha also reduces the nematode incidence.

Betelvine

Betelvine is cultivated in Orissa, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Maharastra, Madhya Pradesh, Assam, Uttar Pradesh and Bihar. About 40 species of plant parasitic nematodes are associated with the crop in India. Among them, the most important and frequently observed nematodes are *Meloidogyne incognita*, *Rotylenchulus reniformis* and *Helicotylenchus incisus*. The root – knot nematode cause typical root galls in the betelvine root.

The reniform nematode, *R. reniformis* is a semi – endoparasite and cause lesion on the root. This nematode also enhance the wilt disease in association with *Phytopthora* spp. The adult female can be seen in the infested root. The reniform shaped females protrude their posterior body outside where as the head and neck are embedded inside the root tissue.

The spiral nematode, *Helicotylenchus incisus* is an ectoparasite and feed on the growing root tip. They cause lesions on the root.

Management

- Application of farm yard manure @ 30t/ha. Application of neem cake @ 3 t /ha in three split doses at 45 days interval along with manures.
- Spot application of the parasitic fungus, *Paecilomyces lilacinus* inoculated neem cake @ 500 kg / ai/ha at the rhizosphere of the vine at quarterly interval was found to be very effective in controlling the root - knot and reniform nematodes.

NEMATODE PESTS OF COMMERCIAL FLOWER CROPS

Crossandra (*Crossandra undulaefolia*) is one of the important commercially grown flower crop in Tamil Nadu. In recent years there is a marked decline in the cultivation of this crop in Madurai, Dindugal, Coimbatore, Salem, Thiruvannamalai and Tiruchirapalli districts. The common problem with the crop is death of plants in patches during the second and third year. This is due to the nematode – fungal complex disease in the crop.

Investigations revealed the association of root – knot nematode, *Meloidogyne* spp. And the root lesion nematode, *Pratylenchus delattrei* with crop along with fungal pathogen, *Fusarium solani*.

Root – Knot nematode

Both *M. incognita* and *M. javanica* are reported to cause damage and yield loss to the crop. The affected plants exhibit stunted growth, yellowing of leaves and also have chlorotic symptoms. The nematode in association with *R. solani* cause serious damage to the crop. The infested plants show root galls.

Root – lesion nematode

The root – lesion nematode, *P. delattrei* cause serious damage to the crop and prevalent in all the localities where the crop is continuously cultivated. This is a migratory endoparasite and cause damage to the cortical parenchyma cells in the root. The infested root show brown to back colour lesion varying in length and intensity.

The affected plant leaves exhibit mottled appearance and pink colouration which ultimately turn yellow and wither.

Nematode fungal complex disease

The association of the nematode and wilt disease pathogen *Rhizoctonia* and *Fusarium* leads to mortality of plants. The disease incidence will be more if both the nematode and the pathogen are found together in the crop field.

Management of the nematode fungal complex disease

- Planting nematode free healthy seedlings in the main field

- Treating the nursery bed with phorate 10G @ 5g/m^2
- Application of neem cake @ 100g/m^2 in the nursery
- The nursery beds needs to be drenched with 0.1% carbendazim solution one week after nematicide application
- In the main field spot application of phorate 10G@ 1g/plant on 30 days after transplanting and one week after nematicide application; spot drenching with varendazim at 0.1% is done to manage the nematode fungal complex disease in the crop.

Tuberose

Tuberose (*Polianthes tuberose*) are valued commercial flower crop for their prettiness, elegance and sweat pleasant grangrance. It has got a great economic potential for cut flower trade and essential oil industry. It is cultivated o=in the tropical and subtropical countries of the world. The flowers are used for artistic garlands, floral ornaments, bouquets and buttonholes . The flowers emit a delightful fragrance and are the source of tuberose oil. In India, it is cultivated in West Bengal, Karnataka, Tamil Nadu and Maharastra.

Many plant parasitic nematodes are reported from the rhizosphere of tuberose. Among them the root – knot nematode, *Meloidogyne incognita* and *M. javanica* are commonly associated with the crop and cause serious damage. The infested plants show yellowing and drying up of leaves. Stunting of plants also occur in patches. In case of severe infestation the spike emergence is suppressed resulting in loss of flower yield. Emergence of side shoots from bulbs were also seen in some plants. The infested plant root have characteristic root galls of varying size.

Management

Summer ploughing and exposing the field to sunlight during the month of May for a period of one month prior to planting the bulbs, minimize the initial nematode load in the soil. Spot application of phorate 10G or carbofuran 3G @ kg a.i./ha. Addition of farm yard manure @ 30t/ha enhance the multiplication of predacious nematodes and antagonistic fungi which in turn checks the plant parasitic nematodes in the crop.

JASMINE

Jasmine (*Jasminum sambac*) is an important commercial flower crop grown mainly in countries like India, China and Malaysia. The natural oil of jasmine is used in high grade perfumes. The crop is grown in an area of 1025 ha in Tamil Nadu.

Many plant parasitic nematodes are reported from the rhizosphere of the crop. Among them few are very important. The root knot nematode, *Meloidogyne incognita* the lesion nematode, *Pratylenchus delattrei* and the spiral nematode, Helicotylenchus spp. are often associated with the crop.

The root knot nematode infested jasmine plant root show characteristic galls. The second stage juvenile of the nematode penetrate the growing root tip and invade the cortical parenchyma cells. The nematode fix feeding site in root cortex and develop to become adult. The adult female lays 200 – 300 eggs. The life cycle is completed in 25 – 30 days.

The lesion nematodes are migratory endoparasite invading the roots and destroy the cortical cells. This leads to dark lesions on the root surface and subsequently rotting of roots occur and then the nematode migrate to invade fresh healthy roots. The infested plants show stunted growth and yellowing of leaves. The jasmine plants of more than 2 years age are commonly infested by these nematodes.

Nematode fungal complex disease

Soil borne fungal pathogen (*Fusarium* spp.) easily enter the root through the injuries caused by the nematodes. Thus the nematode act a pre-disposing factor for the severe wilt disease in jasmine crop.

Summer ploughing and exposing the filed to sunlight during the month of May for a period of one month prior to planting the bulbs, minimize the initial nematode and soil borne fungal pathogen in soil. Spot application of phorate 10G 5g/plant or carbofuran 3G @ 15g/plant. Addition of farm yard manure @ 5 kg / plant to enhance the multiplication of predacious nematodes and nematophagous fungi which in turn checks the plant parasitic nematodes in the crop. Spot after nematicide application. The granule and carbendazim treatment have to be given once in every six month in order to arrest the nematode and pathogen multiplication.