BIO 309: LECTURE NOTE ON SOME ASPECTS OF NEMATOLOGY

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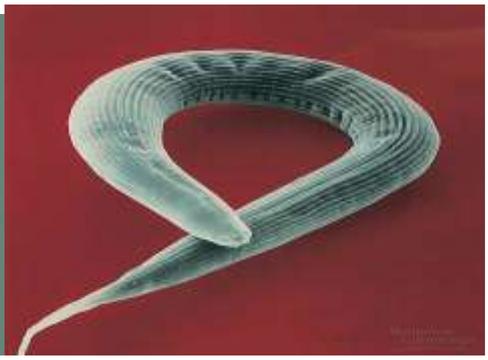
1. DEFINITION OF NEMATODES

The nematodes or roundworms constitute the phylum Nematoda. They are a diverse animal phylum inhabiting a very broad range of environments. Nematode species can be difficult to distinguish, and although over 25,000 have been described, of which more than half are parasitic, the total number of nematode species has been estimated to be about 1 million. Nematodes have tubular digestive systems with openings at both ends.

Nematodes have successfully adapted to nearly every ecosystem from marine (salt water) to fresh water, to soils, and from the polar regions to the tropics, as well as the highest to the lowest of elevations. Many are free living and abound in soils and sediments in terrestrial, freshwater and marine habitats. As parasites they occur in every multicellular group. And occupy diverse tissue sites. Nematodes may be found in every major organ of the vertebrate body.

They are ubiquitous in freshwater, marine, and terrestrial environments, where they often outnumber other animals in both individual and species counts, and are found in locations as diverse as mountains, deserts and oceanic trenches. They are found in every part of the earth's lithosphere. They represent 90% of all animals on the ocean floor. Nematodes have even been found at great depth (0.9–3.6 km) below the surface of the Earth in gold mines in South Africa. The many parasitic forms include pathogens in most plants and animals (including humans).

Nematodes are distinguished by their smooth cuticular body covering which may or may not be broken by annulations. They have a very simple body plan. They are pseudocoelomates, and possess a fluid filled body cavity which functions as a hydrostatic skeleton. The organ systems are simple consisting of one or two cell types. The digestive system consists of a pharynx of varied structure that leads through and intestine to a culticularly lined rectum at the posterior end.

2. TAXONOMY

All living organisms, plants and animals, are organized into a hierarchy of groups called taxa. This structure is based primarily on the degrees of similarity among members of the same group and also shows the contrasts among members of different taxa.

The highest level of classification considered here is the Phylum and the lowest is the Species. Nematodes belong to the Animal Kingdom and their taxonomic hierarchy is expressed as follows:

- **KINGDOM**
- **PHYLUM**
- **CLASS**
- **ORDER**
- **SUPERFAMILY**
- **FAMILY**
- **SUBFAMILY**
- **GENUS**
- **SPECIES**

Classification of Phylum Nematode (Round Worms) of Medical Importance

Phylum: Nematoda (round worms)

Traditionally the Phylum nematode is broadly divided into two, depending on whether caudal sense organs, the phasmids are present or not Symth (1994). These are:

(a) Class: **Aphasmidea** and
(b) Class: **Phasmidea**

Phasmids, a sensory structure in nematodes are unicellular sensila in the lateral tail region of certain species of nematodes. Phasmid neurons were recently shown to function in modulation of chemorepulsion behaviour.

Class1: Aphasmidea (Adenophorea)

- Phasmids are absent or few in number.
- Excretory system is without lateral canals and terminal duct is not lined with cuticle.
- Pharynx (oesophagus) is a long fine tube forming a stichosome or trophosome.
- Eggs are usually unsegmented with a plug at either poles or hatching in utero.
- First-stage larva often with stylet and usually infective to final host

Order: Trichurata

The body consists of a slender anterior portion (sometimes thread-like) and a thicker posterior portion (like a whip with a handle), hence they are called whip worms; they have no lips or buccal capsule; both sexes have s single gonad and males have one or no spicule.

Two families are of medical and importance:

- Family1: Trichuridae. Example *Trichuris trichuria*
- Family 2: Trichinellidae. Example Trichinella spiralis

Class 2: Phasmidea

- Phasmids are present in this class.
- No caudal glands.
- Excretory system is well developed with one or two lateral canals, sometimes with glandular cells.
- Amphids are poorly developed with simple pores.

There are six main Orders in this class: Rhabditata; Strongylata; Ascaridata; Oxyurata; Camalanata and Filariata.

Order 1: Rhabditata

Only one family is of medical importance:

Family: Strongyloididae. Example *Stronyloides stercoralis*

Order 2: Strongydata

Family: Ancylostomatidae contains human parasites. Examples: *Necator Americana* and *Ancylostoma duodenale*.

Order 3: Ascaridata

There are two medical important families in this Order:

Family 1: Ascaridae. Example *Ascaris lumbricoides*

Family 2: Toxocaridae. Example *Toxocara canis*

Order 4: Oxyurata

Only one family contains medically important species.

Family: Oxyuridae. Example: *Enterobius vermicularis*

Order 5: Camalanata

One medical important family is:

Family: Dracunalidae.Example *Drancunculus medinensis*

Order 6: Filaiata

Family: Filarioidae (Filarial worms)

Of the more than 500 filarial parasites in this family known to infect mammals, birds, reptiles and amphibians, only eight are common parasites of man:

(a) *Wuchereria banorofti*
(b) Brugia malayi
(c) Onchocerca volvulus
(d) Loa loa
(e) Mansonella perstans
(f) Mansonella streptocerca
(g) Mansonella ozzadi
(h) Brugia timori

These human filarial parasites may be classified into three main group by the habitat of the adult worms:

- Cutaneous group: *O.volvulus, L.loa, M. strepotocerca*
- Body cavity group: *M.perstans, M.ozzardi*
- Lymphatic group: *B.Malayi, B. timori, W. bancrofti*

Table 8: Intestinal round worms of man

Important species	Diseases caused	Goegraphical distribution

1. *Enterobius vermicularis*	Enterobiasis, oxyuriasis or pin worm infection	World wide, especially in children
2. *Trichuris trichuria*	Whip worm infection or trichuriasis.	World wide with greater incidence in warm countries.
3.*Ascaris lumbricoides*	Ascariasis or round worm infection	World wide, especially in areas with poor sanitation, warm moist climate and poor economic and social development.
4.Hookworms [a] *Ancylostoma duodenale* [b] *Necator americana*	Hookworm disease, hookworm anemia, ancylostomiasis	[a] *A. duodenale* [Old World hookworm] is more prevalent in Europe, China, Japan, India and Africa, especially in northern part of Africa. [b] *N. American* [new World hookworm] is more prevalent in tropical Africa, southern Asia, South America and southern USA.
5. *Strongyloides stercoralis*	Strongyloidiasis	Worl wide, especially in the tropica and subtropical regions

Table 9 Tissue round worms of man

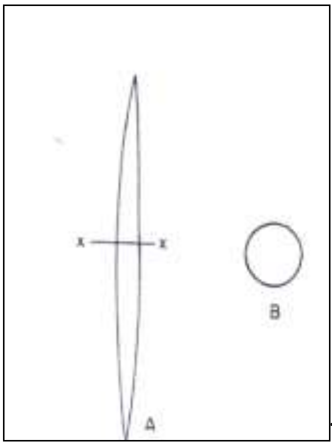
Species		Diseases caused	Distribution	Definitive hosts	Intermediate hosts [principal]	Location in man	
						Adult	Microfilariae MF [larvae]
1.*Trihinella spiralis*		Trichinosis or trichiasis	More prevalent, Central Europe, USA, Central America. Recent incidence in Africa and India.	Man, and wild and domestic carnivores.	Rat, pig, and other carnivoes.	Small intestine	Striated muscle
Filariasis	2.*W. bancrofti*	Bancroftian filariasis, filariasis bancroftian	Tropical and subtropical [world wide]	Man	Mosquitoes [*Anopheles, Aedes, Culex, Mansonia*]	Lymphatics	Blood
	3.*Brugia malayi*	Malayan Filariasis	Southern Asia, East Indies	Man	Mosquitoes [*Mansonia species*]	lymphatics	Blood
	4.*B.tumori*						
	5*Onchocerca Volvulus*	Onchocercia-sis	Tropical Africa, Central America, Arabian.	Man	Black flies: *Simulium damnosum, S. naevi* and other species	Subcuta-neous tissue	Skin
	7.*Loa loa*	Loiasis	Africa	Man,	Tabanid	Skin	Blood

				baboon	flies: *Chrysops dimidiate, C. silacea*	tissue	
	8.*Mansonella Streptocerca*	M. streptocerca infection	Africa	Man, chimpanzee	Unknown	Connect-ive tissue of skin	Skin
	9.*Mansonella Perstans*	M.perstans infection	Africa, South America	Man, gorilla, chimpanzee	Biting midges: Culicoides austeni, C. grahami	Mesentery perirenal and retroperitone-al tissues	Blood
	10.*M. Ozzardi*	Ozzard's filariasis	South and Central America	Man, baboon	Biting midges: Culicoides furens	Mesentry, body cavities	Blood
11.*Dracunculus medinensis*		dracontiasis guinea worm infection	Africa, Arabian, Pakistina, India, Afghanistan, New Guinea	Man	Copepod: Cyclops	Subcutane-ous tissue	In the viviparous female in subcutane-ous tissue
12. Larvae of: [a] *Toxocara canis* [b] *Toxocara cati*		Visceral larval migrans	World wide, especially in cat and dog owners	Man	Dogs and cats	-	Blood, central nerveous system, liver, lungs
13. Larvae of: [a]*Ancylostoma Braziliense* [b] *Ancyclostoma Caninum* [c] Horse or cattle bot Flies [d] *Strongyliodes Stercoralis*		Cutaneous larval migrans	World wide	Man	Dogs, cats and horses	-	Skin

3. CHARACTERISTICS OF NEMATODES

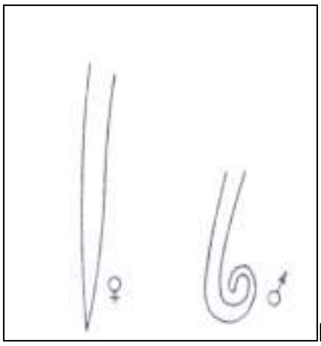
Nematodes can be distinguished from other animals by the following features:

(a) The Nematoda, or roundworms, are a major eukaryotic group and display a startling variety of life histories. Body is elongated, cylindrical, rounded in transverse section (hence the name roundworm), and usually pointed at both ends.



The external feature of nematode: A= whole body pointed at both ends and B = transverse section of body

(b) Most nematodes have the same simple body plan. Their bodies are bilaterally symmetrical (one half is a mirror image of the other), and while most are microscopic, they can grow to as long as 8 meters



Posterior end of nematode body: A= female with straight posterior end and B= male with curled tail

(c) Many have a "tube-within-a-tube" body plan comprised of a long, cylindrical body that encloses a hose-like canal (called an alimentary canal). Food enters the alimentary canal on one end, and waste is expelled through the anus on the tail end

(d) While nematodes have digestive, reproductive, nervous and excretory systems, they do not have a distinct circulatory or respiratory system. Adults are made up of roughly 1,000 somatic cells, and hundreds of those cells are typically associated with the reproductive system.

(e) Many are free living and abound in soils and sediments in terrestrial, freshwater and marine habitats. As parasites they occur in every multicellular group. and occupy diverse tissue sites.

(f) Nematodes are distinguished by their smooth cuticular body covering which may or may not be broken by annulations.

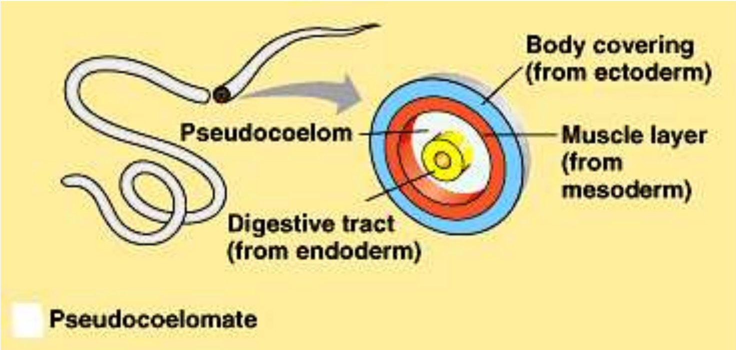
(g) They have a very simple body plan. They are pseudocoelomates, and possess a fluid filled body cavity which functions as a hydrostatic skeleton. The organ systems are simple consisting of one or two cell types.

(h) The digestive system consists of a pharynx of varied structure that leads through and intestine to a culticularly lined rectum at the posterior end.

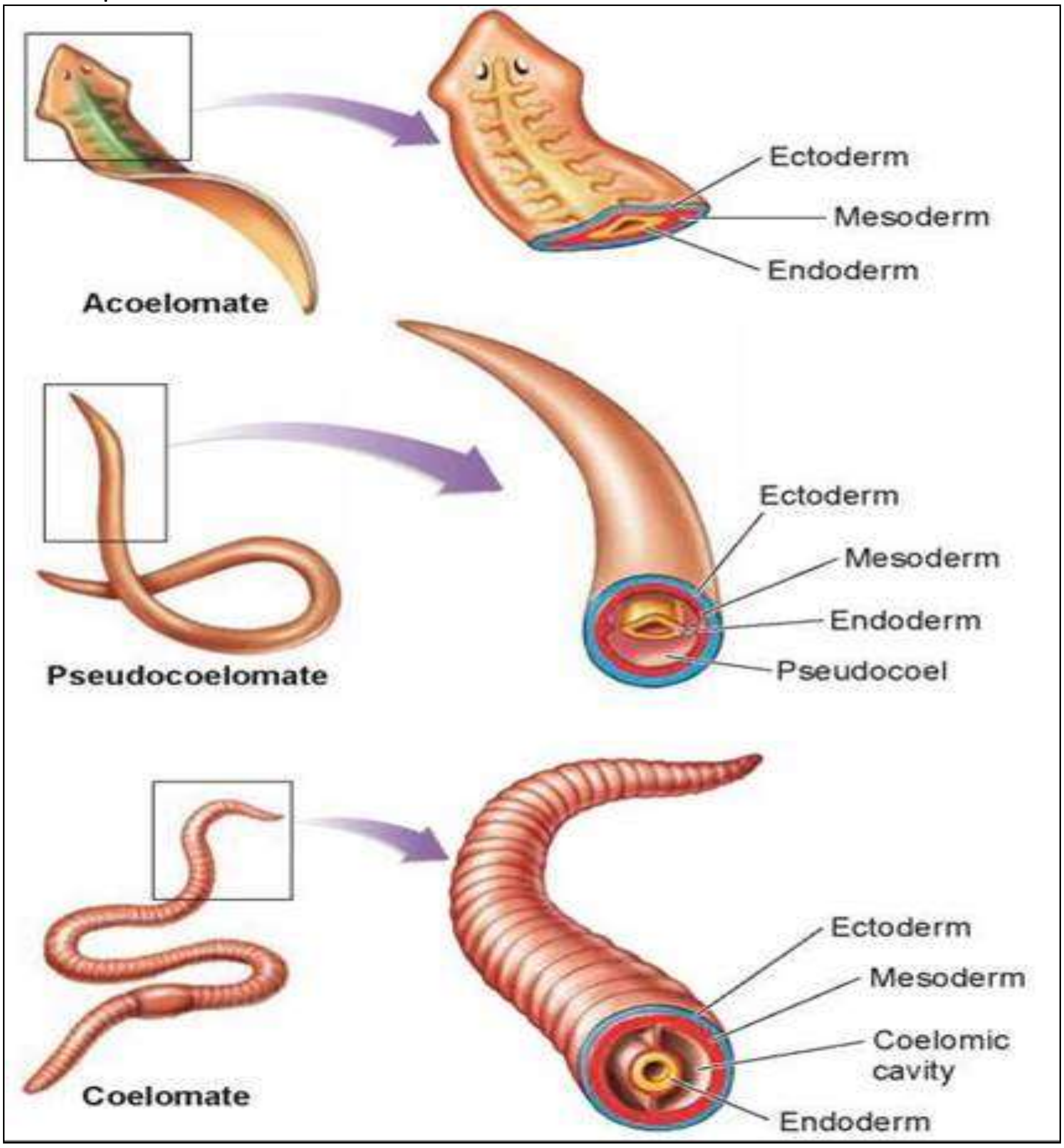
(i) The reproductive system is a hollow tube of endothelium: at the blind end germ cells (oogonia and spermatogonia) divide to produce oocytes and spermatocytes that will undergo meiosis. In females, the system is typically doubled: ovaries are separated from uteri by an oviduct in which fertilization typically occurs. Uteri flow into a common vagina that serves as a canal for expulsion of eggs and for movement of sperm upwards to the oviducts. In males the reproductive system is typically single: the testis opens into a seminal vesicle where sperm are stored. Males also have accessory copulatory structures, the spicules, which are used to transfer sperm to the vagina of the female

4. MORPHOLOGY AND ANATOMY

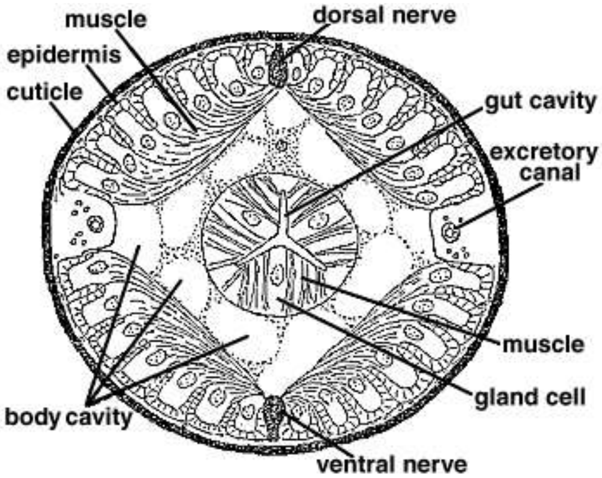
(a) Nematodes are slender worms: typically approximately 5 to 100 µm thick, and at least 0.1 mm (0.0039 in) but less than 2.5mm long. The smallest nematodes are microscopic, while free-living species can reach as much as 5 cm (2.0 in), and some parasitic species are larger still, reaching over a meter in length. The body is often ornamented with ridges, rings, bristles, or other distinctive structures.

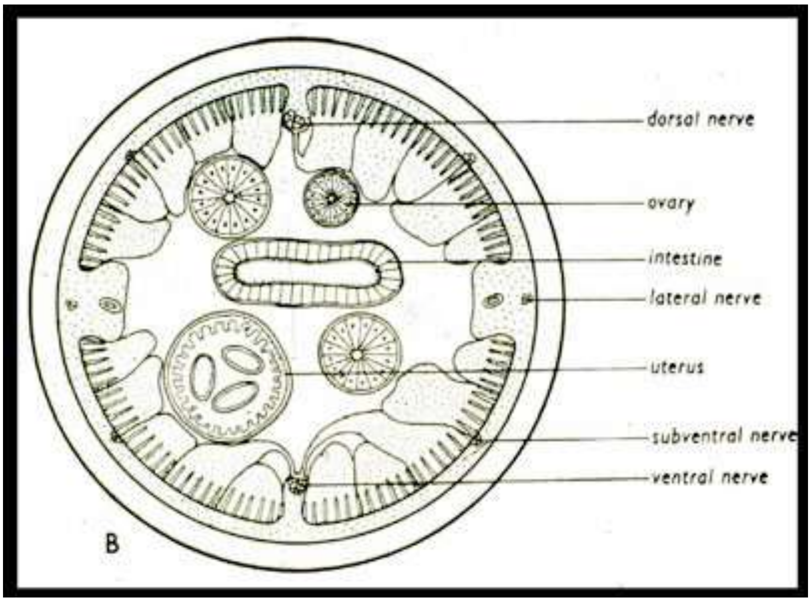


(b) Nematodes have a pseudocoelom (tube-within-a-tube). Pseudocoelomis a closed fluid-filled space that acts as a hydrostatic skeleton. It helps in circulation and dispersal of nutrients.



(c) The head of a nematode is relatively distinct. Whereas the rest of the body is bilaterally symmetrical, the head is radially symmetrical, with sensory bristles and, in many cases, solid 'head-shields' radiating outwards around the mouth. The mouth has either three or six lips, which often bear a series of teeth on their inner edges. An adhesive 'caudal gland' is often found at the tip of the tail.





(d) **Body covering:** The epidermis is either a syncytium or a single layer of cells, and is covered by a thick collagenous cuticle. The cuticle is often of complex structure, and may have two or three distinct layers. Underneath the epidermis lies a layer of longitudinal muscle cells. The relatively rigid cuticle works with the muscles to create a hydro-skeleton as nematodes lack circumferential muscles. Projections run from the inner surface of muscle cells towards the nerve cords; this is a unique arrangement in the animal kingdom, in which nerve cells normally extend fibres into the muscles rather than *vice versa*.

The cuticle serves as:

an outer skeleton(Body support)

- It is flexibility helps body movement
- It is permeable to water and gas

- The cuticle is periodically shed as it grows (four times before reaching the adult stage)

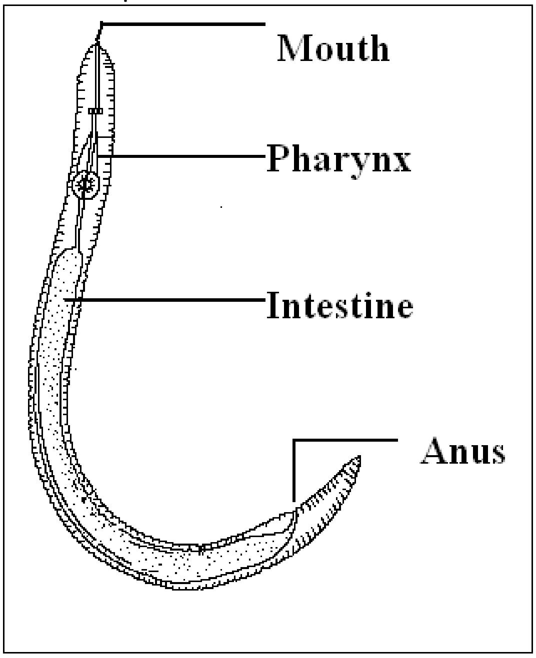
Nematodes do not have circular muscle layer. They can only bend its body from side to side, cannot crawl.

5. LIFE FUNCTIONS

5. 1 Feeding and Digestive system of nematodes

An incredible variety of nematodes function at several trophic levels of the soil food web. Some feed on the plants and algae as saprophytes (first trophic level); others are grazers that feed on bacteria and fungi (second trophic level); and some feed on other nematodes as parasites (higher trophic levels).

- The oral cavity is lined with cuticle, which is often strengthened with ridges or other structures, and, especially in carnivorous species, may bear a number of teeth. The mouth often includes a sharp stylet, which the animal can thrust into its prey. In some species, the stylet is hollow, and can be used to suck liquids from plants or animals.



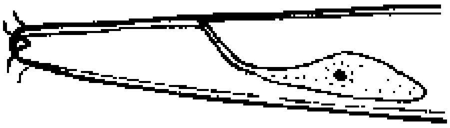
- Nematodes have a complete digestive system. It is tubular. Pharynx is muscular and the lumen of the pharynx is tri-radial

- The oral cavity opens into a muscular, sucking pharynx, also lined with cuticle. Digestive glands are found in this region of the gut, producing enzymes that start to break down the food. In stylet-bearing species, these may even be injected into the prey.

- There is no stomach, with the pharynx connecting directly to a muscleless intestine that forms the main length of the gut. This produces further enzymes, and also absorbs nutrients through its single cell thick lining. The last portion of the intestine is lined by cuticle, forming a rectum, which expels waste through the anus just below and in front of the tip of the tail. Movement of food through the digestive system is the result of body movements of the worm. The intestine has valves or sphincters at either end to help control the movement of food through the body.

5.2 Excretory system

- Nitrogenous waste is excreted in the form of ammonia through the body wall, and is not associated with any specific organs. However, the structures for excreting salt to maintain osmoregulation are typically more complex

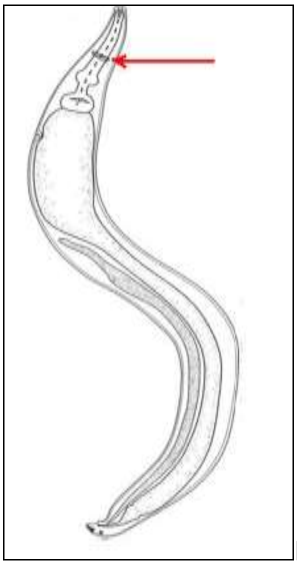


Excretory system has two lateral longitudinal tubes

- In many marine nematodes, one or two unicellular 'renette glands' excrete salt through a pore on the underside of the animal, close to the pharynx. In most other nematodes, these specialised cells have been replaced by an organ consisting of two parallel ducts connected by a single transverse duct. This transverse duct opens into a common canal that runs to the excretory pore.

5.3 Nervous system

- Four peripheral nerves run the length of the body on the dorsal, ventral, and lateral surfaces. Each nerve lies within a cord of connective tissue lying beneath the cuticle and between the muscle cells. The ventral nerve is the largest, and has a double structure forward of the excretory pore. The dorsal nerve is responsible for motor control, while the lateral nerves are sensory, and the ventral combines both functions.



Nervous system has an anterior nerve ring (brain), a ventral and a dorsal nerve cord

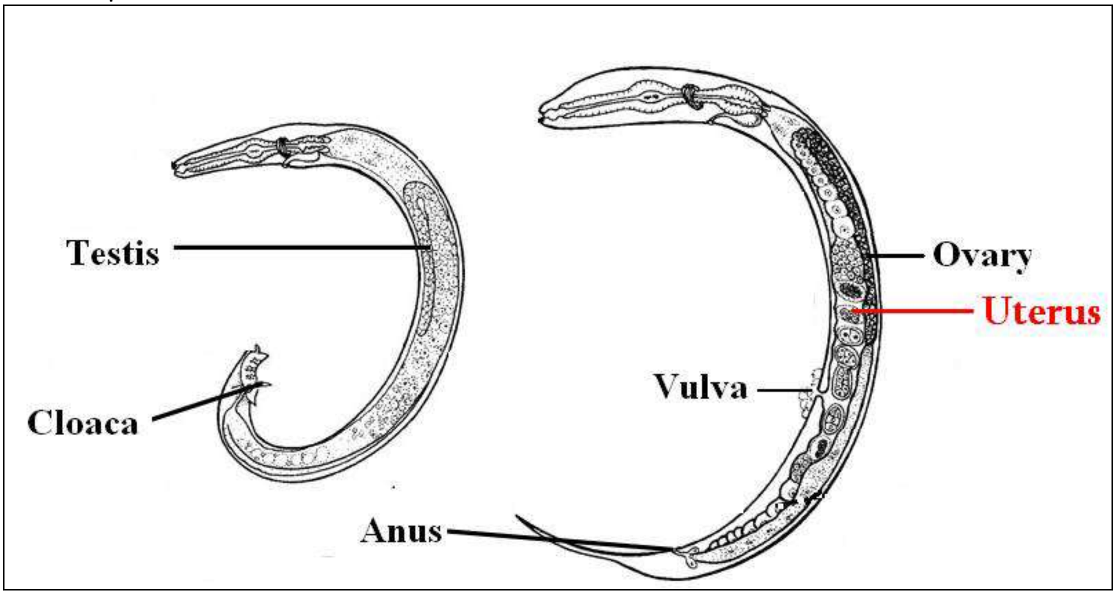
- The nervous system is also the only place in the nematode body that contains cilia, which are all non-motile and with a sensory function.

- At the anterior end of the animal, the nerves branch from a dense, circular nerve **(nerve ring)** round surrounding the pharynx, and serving as the brain. Smaller nerves run forward from the ring to supply the sensory organs of the head.

- The bodies of nematodes are covered in numerous sensory bristles and papillae that together provide a sense of touch. Behind the sensory bristles on the head lie two small pits, or 'amphids'. These are well supplied with nerve cells, and are probably chemoreception organs. A few aquatic nematodes possess what appear to be pigmented eye-spots, but is unclear whether or not these are actually sensory in nature.

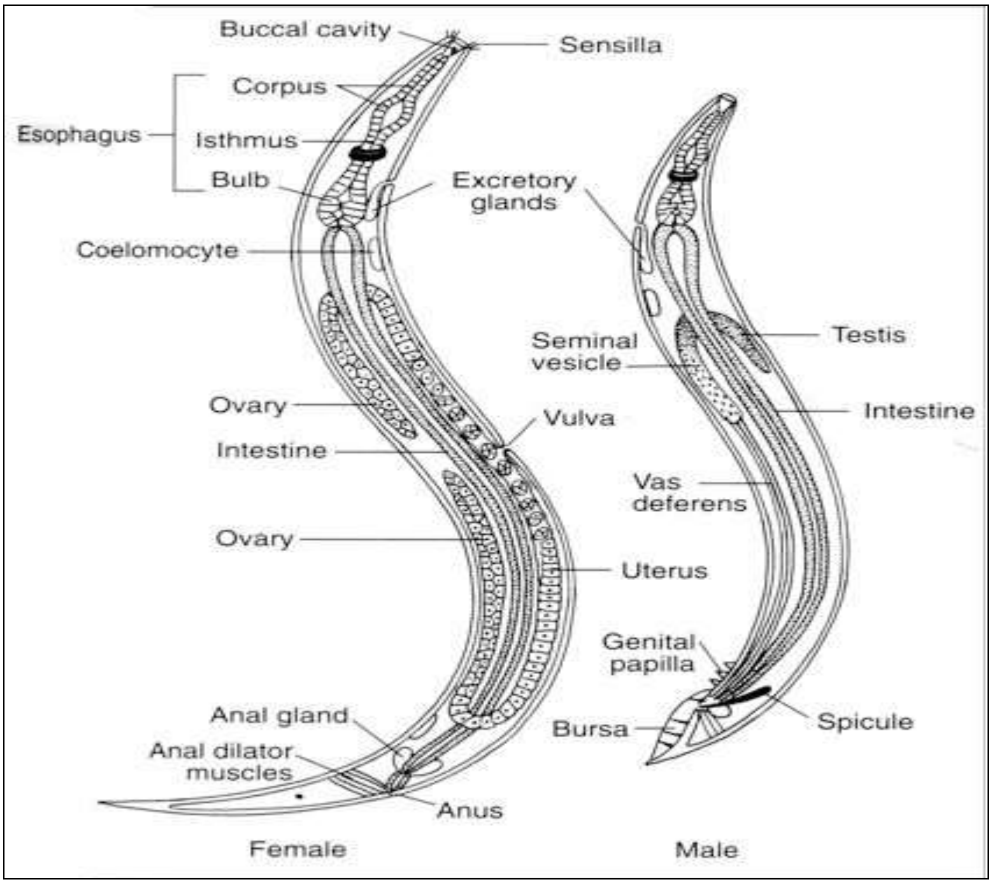
5.4 Reproduction and life cycle

- Extremity of a male nematode showing the spicule, used for copulation. Bar = 100 µm

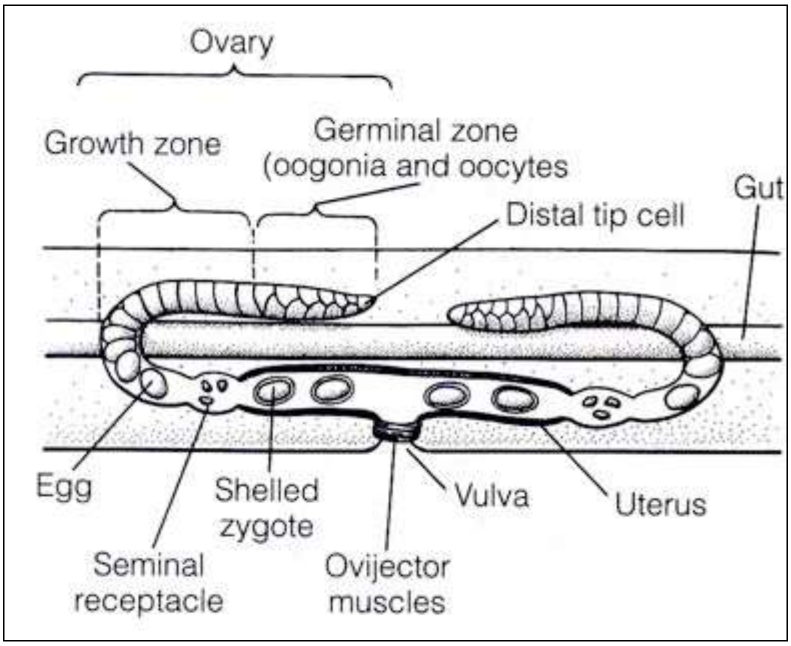


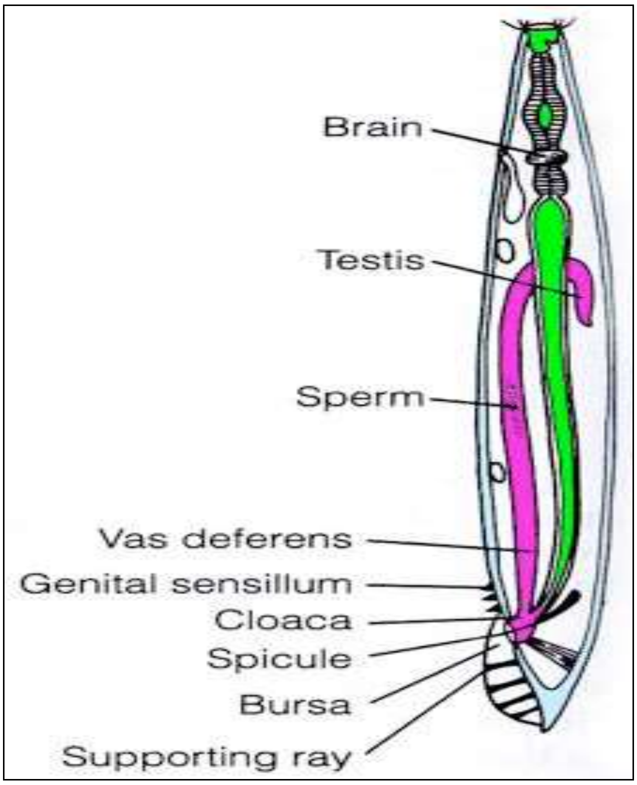
Male and Female animals are separated

- Most nematode species are dioecious, with separate male and female individuals, though some, such as *Caenorhabditis elegans*, are androdioecious, consisting of hermaphrodites and rare males. Both sexes possess one or two tubular gonads. In males, the sperm are produced at the end of the gonad and migrate along its length as they mature. The testis opens into a relatively wide seminal vesicle and then during sex into a glandular and muscular ejaculatory duct associated with the vas deferens and cloaca. In females, the ovaries each open into an oviduct (in hermaphrodites, the eggs enter a spermatheca first) and then a glandular uterus. The uteri both open into a common vulva/ vagina, usually located in the middle of the morphologically ventral surface.



- Reproduction is usually sexual, though hermaphrodites are capable of self-fertilization. Males are usually smaller than females/ hermaphrodites (often much smaller) and often have a characteristically bent or fan-shaped tail for holding the other sex. During copulation, one or more chitinized spicules move out of the cloaca and are inserted into the genital pore of the female. Amoeboid sperm crawl along the spicule into the female worm. Nematode sperm is thought to be the only eukaryotic cell without the globular protein G-actin.





- Eggs may be embryonated or unembryonated when passed by the female, meaning their fertilized eggs may not yet be developed. A few species are known to be ovoviviparous. The eggs are protected by an outer shell, secreted by the uterus. In free-living roundworms, the eggs hatch into larvae, which appear essentially identical to the adults, except for an underdeveloped reproductive system; in parasitic roundworms, the life cycle is often much more complicated

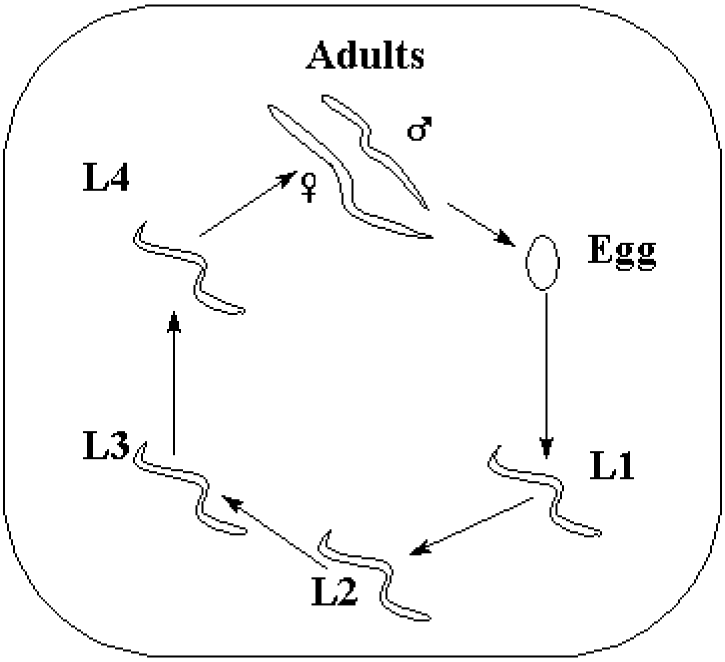


Fig. General life cycle of nematodes

- Nematodes as a whole possess a wide range of modes of reproduction. Some nematodes, such as *Heterorhabditis* spp., undergo a process called ***endotokia***

matricida: intrauterine birth causing maternal death. Some nematodes are hermaphroditic, and keep their self-fertilized eggs inside the uterus until they hatch. The juvenile nematodes will then ingest the parent nematode. This process is significantly promoted in environments with a low food supply.

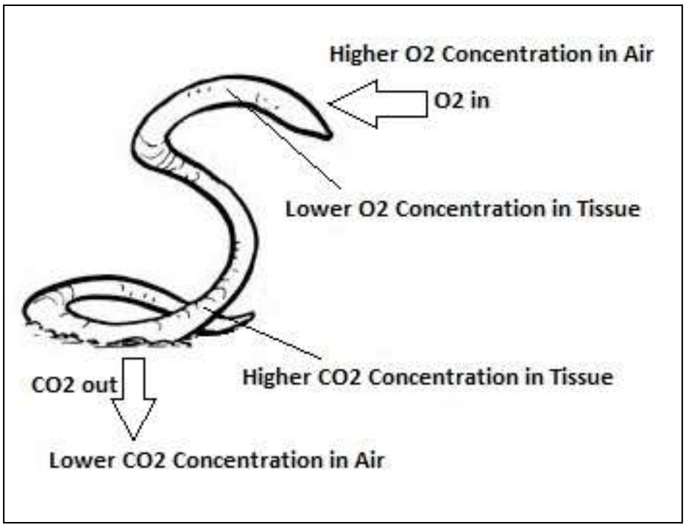
- The genus ***Mesorhabditis*** exhibits an unusual form of parthenogenesis, in which sperm-producing males copulate with females, but the sperm do not fuse with the ovum. Contact with the sperm is essential for the ovum to begin dividing, but because there is no fusion of the cells, the male contributes no genetic material to the offspring, which are essentially clones of the female

5.5 Nematode Respiration

- Like many living things, nematodes exchange gases with the atmosphere. However, unlike many living things nematodes lack a formal respiratory system. The respiratory system is responsible for performing gas exchange. In mammals and reptiles, this system consists of trachea, lungs and bronchial tubes. In the respiratory system of fish the dominant feature is gills. Nematodes do not possess any of these organs, instead, nematode respiration works in a much more simplistic manner. We will examine this in the next section.

- Roundworms do not breathe in the sense that vertebrates, such as humans and other mammals, do. Instead, roundworms (also known as nematodes) obtain the oxygen their bodies need through diffusion, a process of gas exchange commonly used among flatworms and earthworms as well. Diffusion allows roundworms to provide oxygen to their cells without the use of complex organs, such as lungs.

- Nematode respiration relies on a process called diffusion. Diffusion is when molecules, in this case gas molecules, move from an area of higher concentration into an area of lower concentration.



Nematode Respiration via Diffusion

6. TYPES OF LIVING OF NEMATODES (FREE-LIVING, ANIMAL-PARASITIC AND PLANT-PARASITIC NEMATODES)

7.1 Free-living species

In free-living species, development usually consists of four moults of the cuticle during growth. Different species feed on materials as varied as algae, fungi, small animals, fecal matter, dead organisms and living tissues. Free-living marine nematodes are important and abundant members of the *meiobenthos*. They play an important role in the decomposition process, aid in recycling of nutrients in marine environments, and are sensitive to changes in the environment caused by pollution. One roundworm of note, *Caenorhabditis elegans*, lives in the soil and has found much use as a model organism. *Caenorhabditis elegans* has had its entire genome sequenced, as well as the developmental fate of every cell determined, and every neuron mapped.

7.2 Parasitic nematodes:Types of Parasitic Nematodes

(a) Insect parasitic nematodes

Nematodes are small worms found in water, soil, plants and animals, and there are roughly 10,000 known species throughout the world. While some nematodes are free-living, others are parasitic and need other organisms (called hosts) to keep themselves alive. Once attached to their host, they divert nutrients and feed off of blood, tissues or pieces of cells to facilitate their own growth. While in some cases these parasitic nematodes can help control pests, in other cases they can cause damage, illness or death to the host organism.

Insect parasitic nematodes are called entomopathogenic. They are free-living as adults but infect a host insect during their larval stage. They remain in the host insect until they grown to juvenile stage, and then they exit the insect by rupturing a hole in the host's cuticle. While some insects survive this exit, most die. Insect parasitic nematodes are sometimes used as biological control agents because they can be produced and used in mass numbers to attack and kill insect pests such as blackflies and mosquitoes.

Eight other families of insect parasitic nematodes contain species that attack and use insects as hosts, including Allantone-matidae, Neotylenchidae, Mermithidae, Diplogasteridae, Heterorhabditidae, Sphaerulariidae, Rhabditidae, Steinernematidae and Tetradonematidae.

Insect-Parasitic Nematodes for the Management of Soil-Dwelling Insects

Insects have many types of natural enemies. As with other organisms, insects can become infected with disease-causing organisms, called pathogens. Soil serves as a natural home and reservoir for many kinds of insect pathogens, including viruses, bacteria, protozoa, fungi, and nematodes. We can take advantage of these natural enemies of insects to help manage insect pests. The use of natural enemies to manage pests is called biological control .

Insect-Parasitic Nematodes. Traditionally, soil-inhabiting insect pests are managed by applying pesticides to the soil or by using cultural practices, for example, tillage and crop rotation. Biological control can be another important way to manage soil-inhabiting insect pests. A group of organisms that shows promise as biological control agents for soil pests are insect-parasitic nematodes. These organisms, which belong to the families Steinernematidae and Heterorhabditidae, have been studied extensively as biological control agents for soil-dwelling stages of insect pests. These nematodes occur naturally in soil and possess a durable, motile infective stage that can actively seek out and infect a broad range of insects, but they do not infect birds or mammals. Because of these attributes, as well as their ease of mass production and exemption from EPA registration, a number of commercial enterprises produce these nematodes as biological "insecticides."

Fig. An Insect-parasitic nematode

Both of these nematode groups carry within their bodies insect-pathogenic bacteria -- Xenorhabdus in the case of steinernematids and Photorhabdus in the case of heterorhabditids. Steinernematid and heterorhabditid nematodes are termed entomopathogenic because of their association with these bacteria. The relationship between the nematodes and bacteria is a true obligate mutualism because the bacterium needs the nematode to carry it into the insect body cavity. The nematode needs the bacterium to create conditions in the insect suitable for its reproduction and growth, and as food. The bacteria are safe to vertebrates and only occur in association with these nematodes and infected insects. They have never been detected living freely in soil. The bacteria produce pigments, so that insects infected with heterorhabditid nematodes turn a brick-red or maroon color, and those infected with steinernematids turn ochre, tan, or brown. Nematode-infected insect cadavers do not smell putrid, and the insect cuticle stays intact until very late in the infection process.

Life Cycle of Insect-Parasitic Nematodes

1. Infective juvenile nematodes in soil enter insect body through natural openings.
2. Nematodes enter insect body cavity.
3. Nematodes develop into adults.
4. Nematodes reproduce and produce offspring.
5. Infective juvenile nematodes leave the dead insect and seek a new insect host.

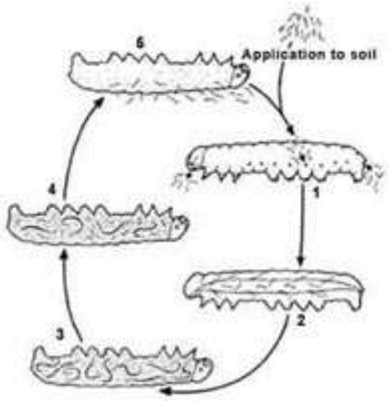


Fig. Life Cycle of Insect-Parasitic Nematodes

(b) Animal nematode parasites

(i) General: Many of these parasitic nematodes also infect animals, livestock and pets. For example, eyeworm attacks baboons as well as humans, and many species closely related to Ascaris infect dogs, cats, cattle, chickens, pigs and horses. In some cases, animals may be intermediate hosts where the nematodes enter and grow for a period of time as larvae and then become dormant cysts.

If a human eats the infected meat, the cysts become active larvae again and grow into adult worms. This is the case with tapeworms that infect cows, fish or pigs and then latch onto the intestinal wall of the human that consumes them. Similarly, the trichinella roundworm lives and mates in the intestines of pigs, rats and other animals and, when those animals are eaten by other carnivores (humans or other animals), the parasite is passed on, causing a disease called Trichinosis. Heartworm is another common animal parasitic nematode that infects pets.

(ii) Human parasitic nematodes: Nematode infections in humans include

- Ascariasis,
- Trichuriasis,
- Hookworm,
- Enterobiasis,
- Strongyloidiasis,
- Filariasis,
- Trichinosis, among others.

Recent data have demonstrated that approximately 60 species of roundworms parasitize humans. Intestinal roundworm infections constitute the largest group of helminthic diseases in humans. According to a 2005 report by the World Health Organization (WHO), approximately 0.807-1.221 billion humans have ascariasis, 604-795 million have trichuriasis, and 576-740 million have hookworm infections worldwide.

Pathophysiology of human nematode diseases

- The life cycle of parasitic nematodes is clinically important. Some nematode infections can be transmitted directly from infected to uninfected people; in others, the nematode eggs must undergo a process of maturation outside the host. In a third category, the parasites may spend a part of their life cycle in the soil before becoming infective to humans.
- As with other parasitic infections, definitive diagnosis of nematode infections depends on demonstration of the stage of the life cycle in the host. Nematodes, as with most other worms infectious to humans, almost never complete their entire life cycle in the human host.
- The life cycles of nematodes are complex and highly varied. Some species, including *Enterobius vermicularis,* can be transmitted directly from person to person, while others, such as *Ascaris lumbricoides, Necator americanus,* and *Ancylostoma duodenale,* require a soil phase for development. Because most helminthic parasites do not self-replicate, the acquisition of a heavy burden of adult worms requires repeated exposure to the parasite in its infectious stage, whether larva or egg. Hence, clinical disease, as opposed to asymptomatic infection, generally develops only with prolonged residence in an endemic region.
- Unlike with protozoan infections, a casual or a low degree of exposure to infective stages of parasitic nematodes usually does not result in patent infection or pathologic findings. Repeated or intense exposure to a multitude of infective stage larvae is required for infection to be established and disease to arise. *Anisakis* species cause erosive and/or hemorrhagic lesions in or near the main lesion, forming a tunnel through the gastric mucosa to the submucosa.

Epidemiology of some human nematode diseases

- Trichuriasis: Infection with *T trichiura* is one of the most prevalent nematode infections worldwide; approximately 800 million persons have trichuriasis worldwide, most abundantly in warm moist regions. Infection rates of up to 75% were found in young schoolchildren in Puerto Rico.
- Enterobiasis: Pin worm is also highly prevalent throughout the world, particularly in countries of the temperate zone. Children are most commonly infected. Estimated prevalence rates among children in various world regions are 4–28%.
- Ascariasis: *Ascaris,* or roundworm, infection is the common helminthic infection in humans, with an estimated worldwide prevalence of 1 billion. The causative organism, *A lumbricoides,* is cosmopolitan in distribution, being most abundant in tropical countries.
- Hookworm: Human infection with the 2 species of hookworm, *A duodenale* and *N americanus,* is estimated to affect approximately 550-750 million people.
- Strongyloidiasis: The infection is more common in tropical countries with poor sanitation, especially in countries of Southeast Asia and parts of Africa. *Strongyloides stercoralis* is also endemic in Jamaica and presumably elsewhere in the Caribbean. An estimated 30-100 million persons worldwide have strongyloidiasis.

- Trichinosis: *Trichinella* species are distributed throughout the world and are spread widely in nature among a large number of carnivorous animals, with humans acting as an incidental host. Trichinosis has been a major public health problem and has been reported in many Asian countries, including China, Japan, Korea, and Thailand.
- Dracunculiasis: Estimates of the number of people infected with *Dracunculus medinensis* in Africa, the Middle East, India, and other tropical areas range from 50-150 million. An aggressive eradication campaign has been underway to eliminate *D medinensis*, which is called the Guinea worm. This disease has been eradicated in Nigeria
- Filariasis: An estimated 120 million people are infected with *Wuchereria bancrofti, Brugia malayi,* and *Brugia timori.*
- Loiasis: *Loa loa* is irregularly distributed in Africa. It is estimated that between 3 and 13 million people in West and Central Africa are infected.
- Onchocerciasis: *Onchocerca volvulus* infects 20 million people in West, Central, and East Africa and another 1 million people in scattered foci in Central America and South America. The disease caused by this filarial worm is called river blindness.
- Anisakiasis: Approximately 20,000 cases of anisakiasis are reported annually worldwide; over 90% are from Japan and most others from Spain, the Netherlands, and Germany, depending on the habits of fish consumption.

Socioeconomic impact of human nematode diseases

Human nematode diseases are concentrated almost exclusively among impoverished populations living in marginalized areas. They are found in 100 of the poorest countries in Africa, Asia and Latin America. Each year, these nematode diseases strike millions of the world's poorest people in sub-Saharan Africa, Asia and Latin America. Nearly all the people devastated by these diseases live in countries with less than US $400 per capita income per year, where Governments are so poor that they spend an average of only US$4 per person per year on health or where health services are understaffed, under- funded and unevenly distributed.

In addition, these nematode diseases rob people of their dignity, independence and hope, result to desertation or depopulation of some major agriculturally fertile areas and consequent population maladjustment. Some of the human nematode diseases cause distressing skin diseases and or prematurely aged appearance while some cause dreadful malformations such that sufferers become withdrawn socially or stigmatized; and even sexual life may be affected if not completely hindered. The resultant economic losses due to inefficiency, low productivity, absenteeism at work as well as the cost of caring for the victims of these endemic diseases are quite prohibitive.

(c) Plant-parasitic nematodes, which constitute the main, primary, subject for this site, are present in almost every type of habitat, the limiting factors being moisture and food for survival. They represent about 20% of the described species (4,000 among 20,000) within the phylum Nematoda. As with free-living nematodes, relatively little is known about most plant-parasitic species, this despite the enormous damage that they cause in Agriculture. This has led to their being referred to as the 'unseen enemy, or hidden enemy of plants'. They possess a typical, strong buccal stylet that is essential for plant parasitism, especially in roots. Qualitative and quantitative damage result for the host plants from nematode infection; yield losses for many important crops of tropical and subtropical regions range from 5 to 50%, depending on the nematode species involved and on their population levels. In addition, some genera of phytonematodes can interact with other disease causing organisms, i.e., fungi and viruses, with the result that the losses can become even larger

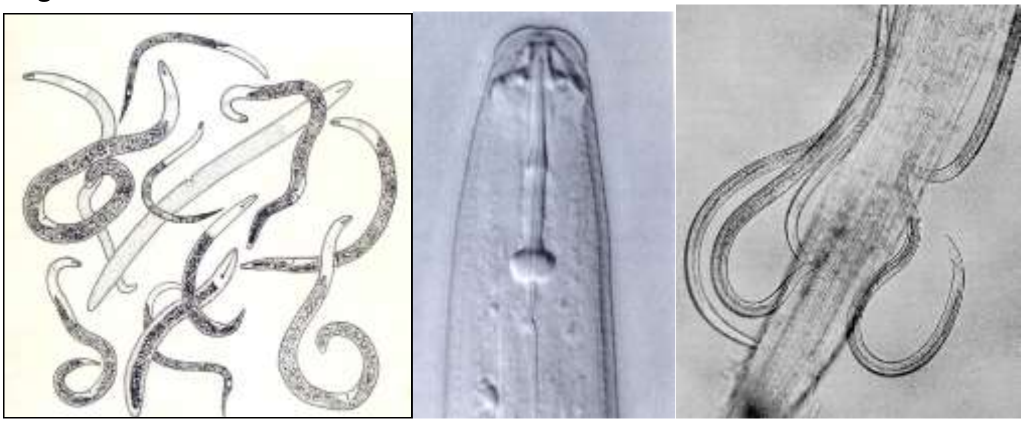


Fig. Schematic representation of different phytonematodes (left; by M. Sauer); the characteristic buccal stylet (centre; by J. Maia); nematode individuals feeding on plant root (by R. Sharma)

Plant-parasitic nematodes include several groups causing severe crop losses. The most common genera are

- *Aphelenchoides* (foliar nematodes),
- *Ditylenchus,*
- *Globodera* (potato cyst nematodes),
- *Heterodera* (soybean cyst nematodes),
- *Meloidogyne* (root-knot nematodes),
- *Pratylenchus* (lesion nematodes),
- *Trichodorus and Xiphinema* (dagger nematodes)

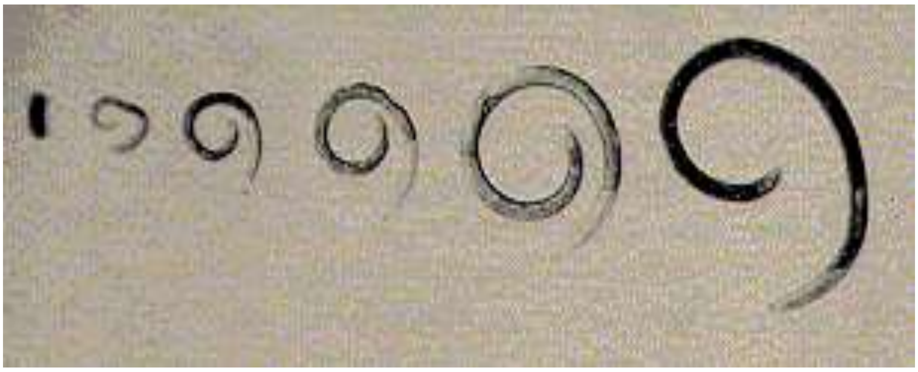
Several phytoparasitic nematode species cause histological damages to roots, including the formation of visible galls (e.g. by root-knot nematodes), which are useful characters for their diagnostic in the field. Some nematode species transmit plant viruses through their feeding activity on roots. One of them is *Xiphinema index,* vector of grapevine fan leaf virus, an important disease of grapes, another one is *Xiphinema diversicaudatum,* vector of arabis mosaic virus.

Fig. Root-knot nematode, Meloidogyne iavanica, galling on watermelon roots.

Symptoms of nematode attack to field crops are not specific, but are often helpful for diagnosing purposes. Patches of stunted plants are a good example, as well as deformation of roots and other underground organs.

Fig. Symptoms of nematode attack to crops: on lettuce (left; by R. Lordello); on carrot (centre; by L. Ferraz); and on potato (right; by A. Zem)

The life cycle of nematodes usually comprises of the egg, four juvenile stages (J1 – J4), and the adults, females and males. The biological stages are separated by moults, in which a new cuticle replaces the old cuticle (just like seen in the insects). The juveniles usually are 'miniatures', or short-sized copies, of the adults. In the case of the phytonematodes, males in several genera have a shorter life cycle and are not plant-parasitic, whereas the females continue to feed on the host plant until reach sexual maturity, and during the oviposition period. One generation is completed within 3-4 weeks, in general, but this period can be affected by temperature, moisture, host plant, and other factors.



Biological stages during nematode life cycle: (left to right => egg; juveniles (4); and adult (female)

7.4 SOIL NEMATODES

(a) Introduction:

Soil is a natural body consisting of layers (soil horizons) of mineral constituents of variable thicknesses, which differ from the parent materials in their morphological, physical, chemical, and mineralogical characteristics. It is composed of particles of broken rock that have been altered by chemical and environmental processes that include weathering and erosion. Soil differs from its parent rock due to interactions between the lithosphere, hydrosphere, atmosphere, and the biosphere. It is a mixture of mineral and organic constituents that are in solid, gaseous and aqueous states.

Most kinds of soil nematodes do not parasitize plants, but are beneficial in the decomposition of organic matter. These nematodes are often referred to as free-living nematodes. Juvenile or other stages of animal and insect parasites may also be found in soil. Although some plant parasites may live within plant roots, most nematodes inhabit the thin film of moisture around soil particles. The rhizosphere soil around small plant roots and root hairs is a particularly rich habitat for many kinds of nematodes.

Nematodes are roundworms in the Phylum Nematoda. Various authorities distinguish among 16 to 20 different orders within this phylum. Only about 10 of these orders regularly occur in soil, and four orders (Rhabditida, Tylenchida, Aphelenchida, and Dorylaimida) are particularly common in soil.

More than 15,000 species and 2,200 genera of nematodes had been described by the mid-1980s. Although the plant-parasitic nematodes are relatively well-known, most of the free-living nematodes have not been studied very much. Therefore there is a high probability that most soil habitats will contain undescribed species of free-living nematodes. Identification of these groups is extremely difficult, and there are only a few nematode taxonomists in the world who can formally describe new species of free-living nematodes to science. Therefore most nematode ecologists identify soil nematodes only to family or genus.

(b) Biological factors of the soil: Plants, animals, fungi, bacteria and humans affect soil formation. Animals and micro-organisms mix soils to form burrows and pores allowing moisture and gases to seep into deeper layers. In the same way, plant roots open channels in the soils, especially plants with deep taproots which can penetrate many meters through the different soil layers to bring up nutrients from deeper in the soil. Plants with fibrous roots that spread out near the soil surface, have roots that are easily decomposed, adding organic matter. Micro-organisms, including fungi and bacteria, affect chemical exchanges between roots and soil and act as a reserve of nutrients. Humans can impact soil formation by removing vegetation cover; this removal promotes erosion. They can also mix the different soil layers, restarting the soil formation process as less-weathered material is mixed with and diluting the more developed upper layers. Some soils may contain up to one million species of microbes per gram, most of those species being unknown, making soil the most abundant ecosystem on Earth.

Vegetation impacts soils in numerous ways. It can prevent erosion from rain or surface runoff. It shades soils, keeping them cooler and slowing evaporation of soil 2 moisture, or it can cause soils to dry out by transpiration. Plants can form new chemicals that break down or build up soil particles. Vegetation depends on climate, land form topography and biological factors. Soil factors such as soil density, depth, chemistry, pH, temperature and moisture greatly affect the type of plants that can grow in a given location. Dead plants, dropped leaves and stems of plants fall to the surface of the soil and decompose. There, organisms feed on them and mix the organic material with the upper soil layers; these organic compounds become part of the soil formation process, ultimately shaping the type of soil formed.

(c) Uses of soil

(i) Soil is used in agriculture, where it serves as the primary nutrient base for plants.

(ii) Soil material is a critical component in the mining and construction industries. Soil serves as a foundation for most construction projects. Massive volumes of soil can be involved in surface mining, road building and dam construction. Earth sheltering is the architectural practice of using soil for external thermal mass against building walls.

(iii) Soil resources are critical to the environment, as well as to food and fiber production. Soil provides minerals and water to plants. Soil absorbs rainwater and releases it later, thus preventing floods and drought. Soil cleans the water as it percolates. Soil is the habitat for many organisms: the major part of known and unknown biodiversity is in the soil, in the form of invertebrates (earthworms, woodlice, millipedes, centipedes, snails, slugs, mites, springtails, enchytraeids, nematodes, protists), bacteria, archaea, fungi and algae; and most organisms living above ground have part of them (plants) or spend part of their life cycle (insects) belowground. Above-ground and below-ground biodiversities are tightly interconnected, making soil protection of paramount importance for any restoration or conservation plan.

(iv) The biological component of soil is an extremely important carbon sink since about 57% of the biotic content is carbon. Even on desert crusts, cyanobacteria lichens and mosses capture and sequester a significant amount of carbon by photosynthesis. Poor farming and grazing methods have degraded soils and released much of this sequestered carbon to the atmosphere. Restoring the world's soils could offset some of the huge increase in greenhouse gases causing global warming while improving crop yields and reducing water needs.

Biologically, soil ecosystems support a diversity of microbes (fungi, bacteria, and algae), microfauna (protozoa), and mesofauna (arthropods and nematodes).

(d) Types of nematodes in the soil

There are three functional groups of nematodes:

(i) **Saprophytic nematodes:** Saprophytic nematodes are also known as decomposers because they break down organic matter in the soil, release nutrients for plant use, and improve soil structure, water holding capacity and drainage. They are usually the most abundant type of nematode in the soil.

(ii) **Predaceous nematodes:** These nematodes feed on other nematodes, so can be useful in controlling pest species. They eat larger nematodes by attaching themselves to their cuticle and scraping away until the prey's internal body parts can be extracted. They also eat bacteria, fungi, and small single celled organisms (protozoa). The digested pests are then added to the soil organic matter reserves. Some have become specialized predators of insects, known as entomopathogenic nematodes

(iii) **Parasitic nematodes:** Parasitic nematodes cause problems in agricultural production because they feed on plant roots and slow plant growth. In some cases they also allow the entry of fungal rots that destroy the roots. Agricultural cultivation tends to encourage an increase in parasitic nematodes over other species

(e) Feeding Habits of soil nematodes

Soil-inhabiting nematodes can also be classified according to their feeding habits. This classification is particularly useful to ecologists in understanding the positions of nematodes in soil food webs. Several important feeding groups of nematodes commonly occur in most soils. In addition, algivores (feed on algae) and various stages of insect and animal parasites occasionally are found in soil. The nematode feeding groups are called trophic groups by some authors.

(i) Herbivores. These are the plant parasites, which are relatively well known. This group includes many members of the order Tylenchida, as well as a few genera in the orders Aphelenchida and Dorylaimida. The mouthpart is a needlelike stylet which is used to puncture cells during feeding. Ectoparasites remain in the soil and feed at the root surface. Endoparasites enter roots and can live and feed within the root.

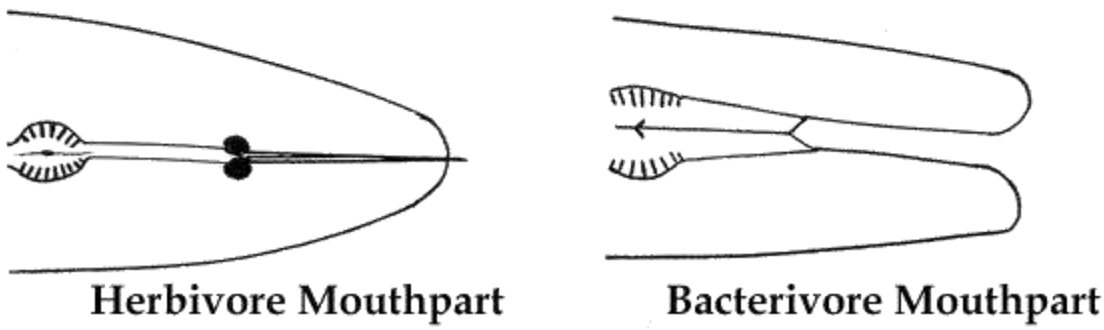


Figure 2. Diagram of head regions of a herbivore (left) and nematode bacterivore (right). In the herbivore, the mouthpart is modified into a stylet for puncturing plant cells. In the bacterivore, the mouth or stoma is a hollow tube.

(ii) Bacterivores. Many kinds of free-living nematodes feed only on bacteria, which are always extremely abundant in soil. In these nematodes, the "mouth", or stoma, is a hollow tube for ingestion of bacteria. This group includes many members of the order Rhabditida as well as several other orders which are encountered less often. These nematodes are beneficial in the decomposition of organic matter.

(iii) Fungivores. This group of nematodes feeds on fungi and uses a stylet to puncture fungal hyphae. Many members of the order Aphelenchida are in this group. Like the bacterivores, fungivores are very important in decomposition.

(iv) Predators. These nematodes feed on other soil nematodes and on other animals of comparable size. They feed indiscriminately on both plant parasitic and free-living nematodes. One order of nematodes, the Mononchida, is exclusively predacious, although a few predators are also found in the Dorylaimida and some other orders. Compared to the other groups of nematodes, predators are not common, but some of them can be found in most soils.

(v) Omnivores. The food habits of most nematodes in soil are relatively specific. For example, bacterivores feed only on bacteria and never on plant roots, and the opposite is true for plant parasites. A few kinds of nematodes may feed on more than one type of food material, and therefore are considered omnivores. For example, some nematodes may ingest fungal spores as well as bacteria. Some members of the order Dorylaimida may feed on fungi, algae, and other animals.

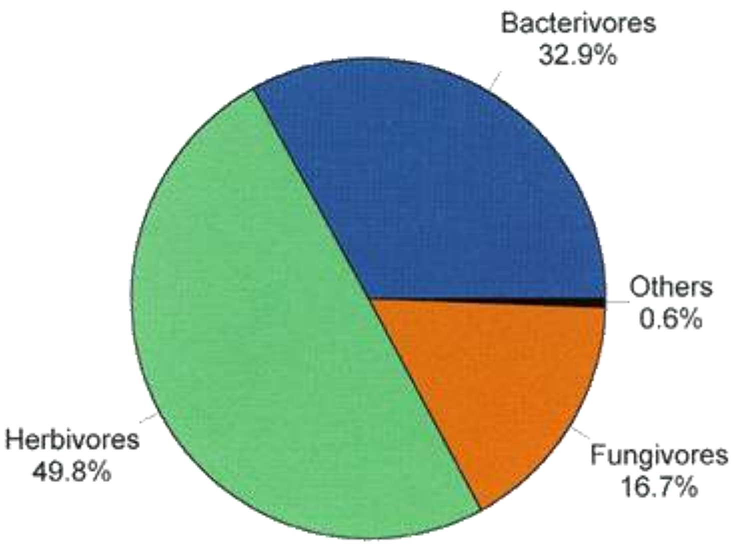


Figure . Composition of nematode groups in a soil nematode community.

(f) What do nematodes do in the soil?

Nematodes are thought to play three main roles in the soil.

(i) **Nutrient cycling:** Nutrients such as ammonium (NH_4^+), stored in the bodies of bacteria and fungi, are released when nematodes eat them. The bacteria and fungi contain more nitrogen than the nematodes need so the excess is released into the soil in a more stable form where it can be used by plants or other soil organisms. Nematodes also physically break down organic matter which increases its surface area, making it easier for other organisms to break it down further.

(ii) **Dispersal of microbes:** Bacteria and fungi cannot move around in the soil without 'hitching a ride' inside or on the back of nematodes. Nematodes are parasitized by some bacteria and fungi, which helps their dispersal through the soil.

(iii) **Disease and pest control:** Beneficial nematodes attack and kill a range of pests such as borers, grubs, thrips and beetles with negligible effects on non-target species. The life cycle of beneficial nematodes includes four juvenile stages plus adult and egg. It is during one of these juvenile stages that the nematode is able to live freely in the soil and find a host to infect. Beneficial nematodes use two strategies to find their prey. Some species wait for their prey to move past them in the soil and locate them by direct contact: this is called 'ambushing'. The ambushers function at the soil surface where they attack highly mobile pests such as cutworms. Others actively search out their prey using a 'cruising' strategy. They function at various depths in the soil and prey on slow moving targets such as grubs and weevil larvae.

When the nematode catches its prey, it penetrates the prey's body through a body cavity; one nematode genus even has a special hook to break in through soft cuticle. Once inside the body, the nematode releases bacteria from its gut. Each nematode species hosts a different bacteria species. Within 24-48 hours the bacteria cause the death of the prey. However the nematode will continue to feed on the multiplying bacteria while maturing and producing a new generation of nematodes. The life cycle of most nematodes is between 3-7 days so several cycles may be completed before a new host is needed. Once the prey has been consumed the nematode leaves to search for new prey.

(g) Role of Nematodes in Soil Health

(i) Nematodes play an important role in essential soil processes. The direct contribution of nematodes to nitrogen mineralization and distribution of biomass within plants has been demonstrated in controlled experiments.

(ii) In petri-dish experiments, more nitrogen is available in the ammonium form when bacterivorous and fungivorous nematodes are present than when they are absent. Nitrogen mineralized through microbial grazing is available subsequently to plants and has been demonstrated to affect biomass allocation in plants.

(iii) Predatory nematodes also regulate nitrogen mineralization by feeding on microbialgrazing nematodes, a conduit by which resources pass from bottom to top trophic levels. Although plants depend on nitrogen for their survival and growth, ecological disruptions such as cultivation or additions of mineral fertilizer increase nitrogen availability, sometimes in excess of, or asynchronous with, plant needs. Increased availability of nitrate and ammonium is associated inversely with successional maturity of nematode communities in cultivated mineral soils for agricultural purposes.

(h) Use of Nematodes as Indicators

Analysis of the diversity and complexity of nematode communities in the soil is a valuable tool which indicates soil biological fertility, or soil health. The different ratios of bacterial, fungal feeders and other types indicate the type of soil functions are occurring. Varying ratios can indicate if the food web is disturbed, maturing, structured or degraded.

(i) Nematodes have several biological features that reinforce their use as indicators. First, nematodes have a permeable cuticle, which allows them to respond with a range of reactions to pollutants and correspond with the restorative capacity of soil ecosystems

(ii) Second, some nematodes have resistant stages such as cryptobiosis or cysts that allow them to survive inactively during environmental conditions unfavourable to growth and (or) development.

(I)Management effects on nematodes in the soil:

To ensure nematodes remain in the earth, the soil environment must be kept as hospitable as possible. This means there must be enough food (organic matter), suitable hosts, water, and minimal disturbance of the soil. The use of pesticides that enter the soil can also affect nematode numbers in the soil. There may well be direct detrimental effects from some pesticides such as nematicides while other agricultural chemicals produce non-target effects that damage nematode populations. The loss of a specific host species from the soil when species-specific soil applied pesticides are used can also reduce food sources and thus nematode numbers.

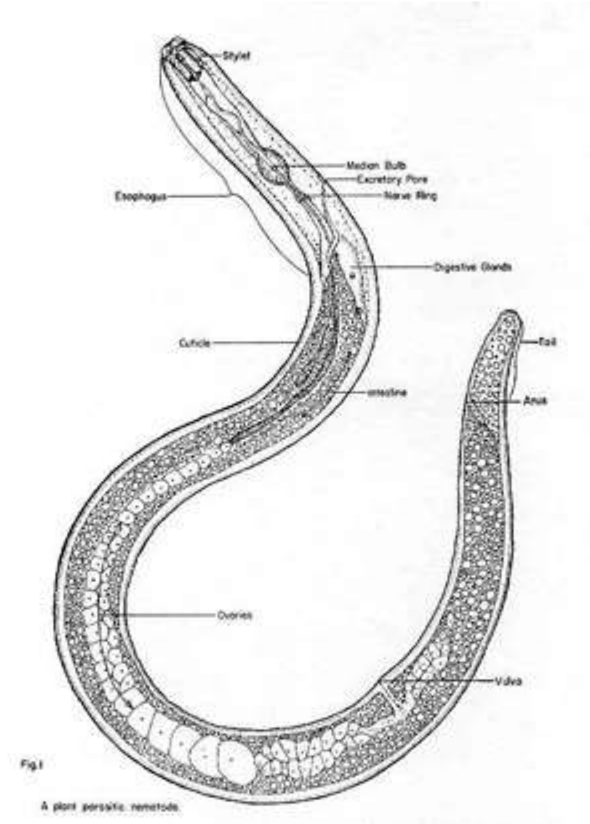


Figure 1. Diagram of a typical plant-parasitic nematode. Diagram from Florida Nematode Control Guide.

Natural pest control with beneficial nematodes

Biological Control of Pest Insects With Nematodes.

Beneficial Nematodes naturally occur in soil and are used to control soil pest insects and whenever larvae or grubs are present. Like all of our products, it will not expose humans or animals to any health or environmental risks. Beneficial nematodes only attack soil dwelling insects and leave plants and earthworms alone. The beneficial nematodes enters the larva via mouth, anus or respiratory openings and starts to feed. This causes specific bacteria to emerge from the intestinal tract of the nematode. These spread inside the insect and multiply very rapidly. The bacteria convert host tissue into products which can easily be taken up by the nematodes. The soil dwelling insect dies within a few days. Beneficial nematodes are a totally safe biological control in pest insects.

Though they are harmless to humans, animals, plants, and healthy earthworms, beneficial nematodes aggressively pursue insects. The beneficial nematodes can be used to control a broad range of soil inhabiting insects and above ground insects in their soil inhabiting stage of life. More than 200 species of pest insects from 100 insect families are susceptible to these nematodes. When they sense the temperature and carbon dioxide emissions of soil-borne insects, beneficial nematodes move toward their prey and enter the pest through its body openings. The nematodes carry an associated bacterium (*Xenorhabdus* species) that kills insects fast within 48 hours. The bacteria is harmless to humans and other organisms and cannot live freely in nature. Several generations of nematodes may live and breed within the dead insect, feeding on it as a food source. When the food source is gone, they migrate into the soil in search of a new host. When the pest population is eliminated, the beneficial nematodes die off and biodegrade. Beneficial nematodes are so effective, they can work in the soil to kill the immature stages of garden pests before they become adults.

Application:

Beneficial Nematodes are very easy to use. Mix with water and spray or sprinkle on the soil along garden plants or lawn. Put the contents of the Beneficial nematodes in a bucket of water and stir to break up any lumps, and let the entire solution soak for a few minutes. Application can be made using a water-can, irrigation system, knapsack or sprayer. On sprayer use a maximum pressure to avoid blockage, all sieves should be removed. The sprayer nozzle opening should be at least 1/2 mm. Evenly spread the spraying solutions over the ground area to be treated. Continuous mixing should take place to prevent the nematodes from sinking to the bottom. After application keep the soil moist during the first two weeks for the nematodes to get establish. For a small garden the best method is using a simple sprinkling or water can to apply the Beneficial nematodes to the soil.

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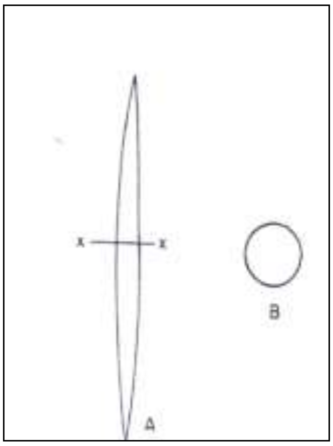
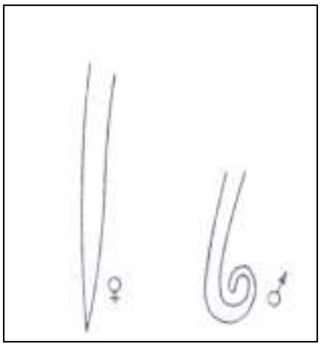
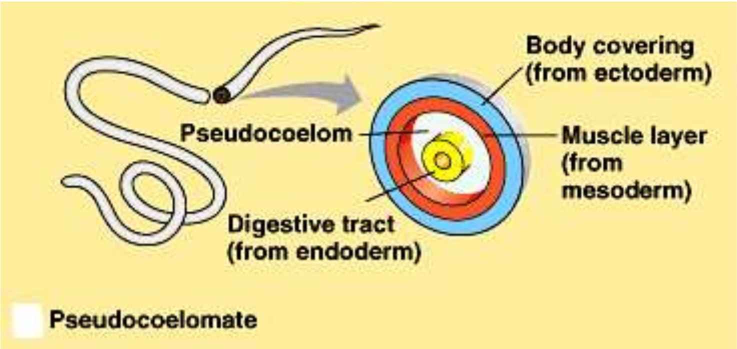
DRAW THE FOLLOWING



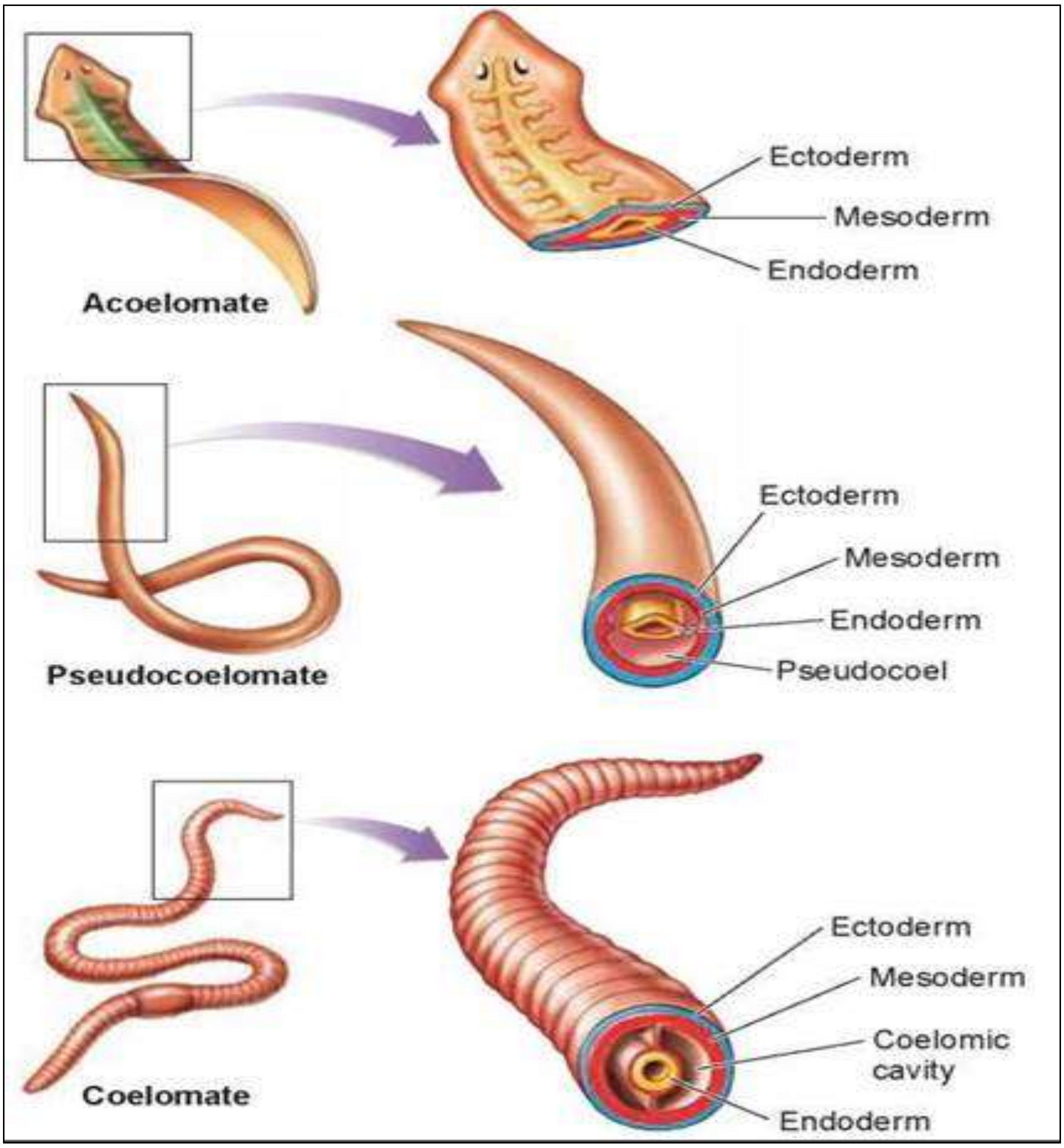
2. The external feature of nematode: A= whole body pointed at both ends and B = transverse section of body



2.Posterior end of nematode body: A= female with straight posterior end and B= male with curled tail



3. **Pseudocoelomate**


Ectoderm
Mesoderm
Endoderm
Acoelomate
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Pseudocoel
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Ectoderm
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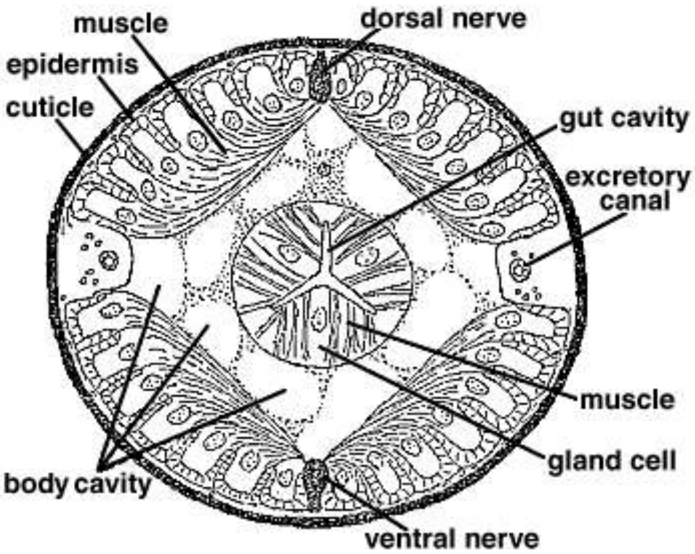
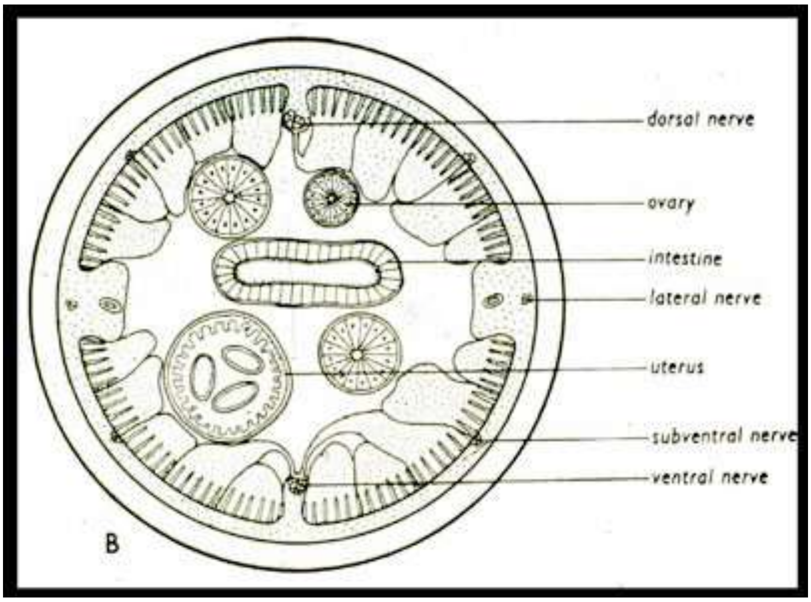
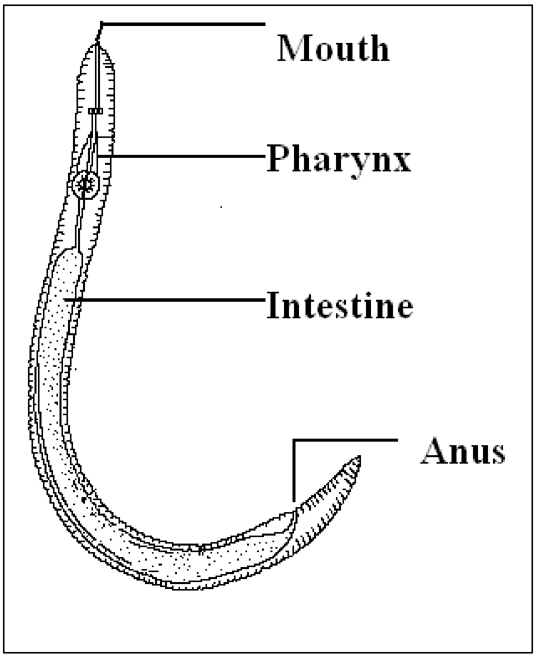
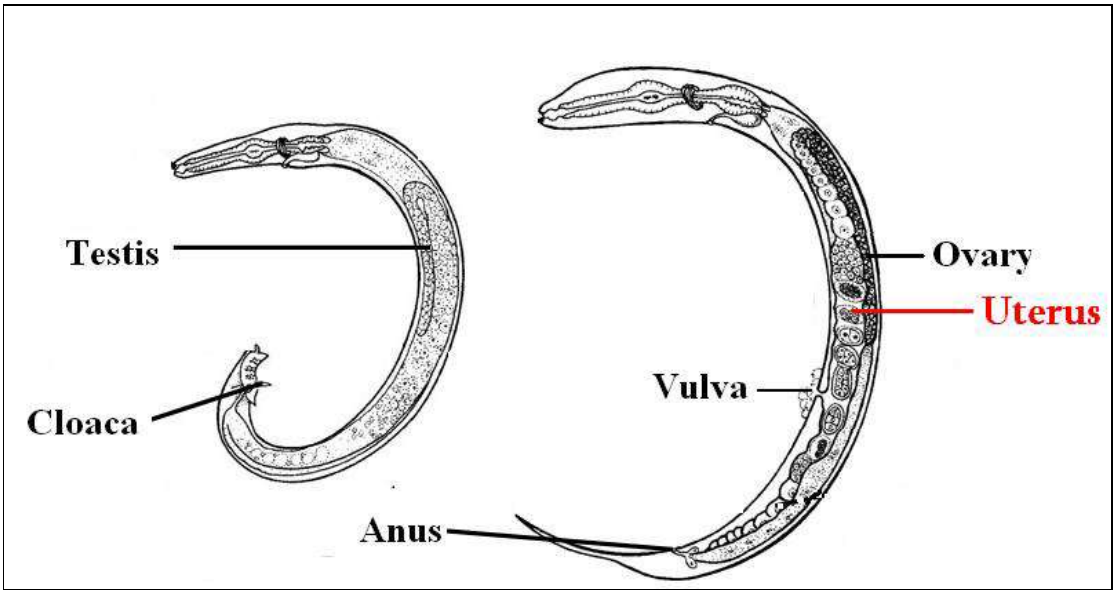
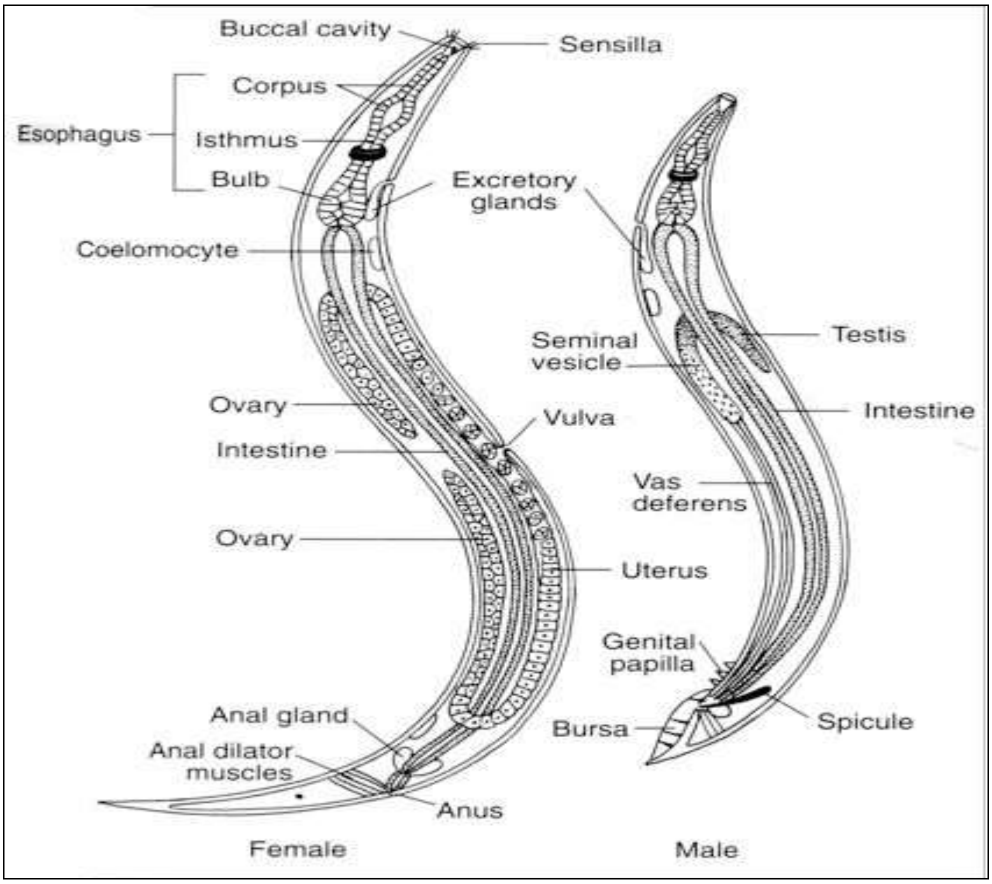
Coelomic cavity
Endoderm
Coelomate

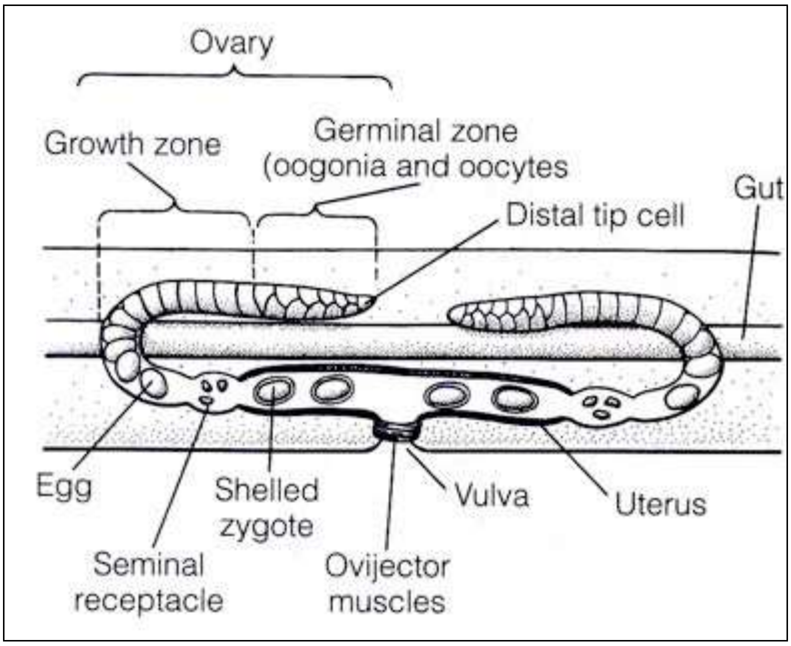

muscle
dorsal nerve
epidermis
cuticle
gut cavity
excretory canal
muscle
gland cell
body cavity
ventral nerve

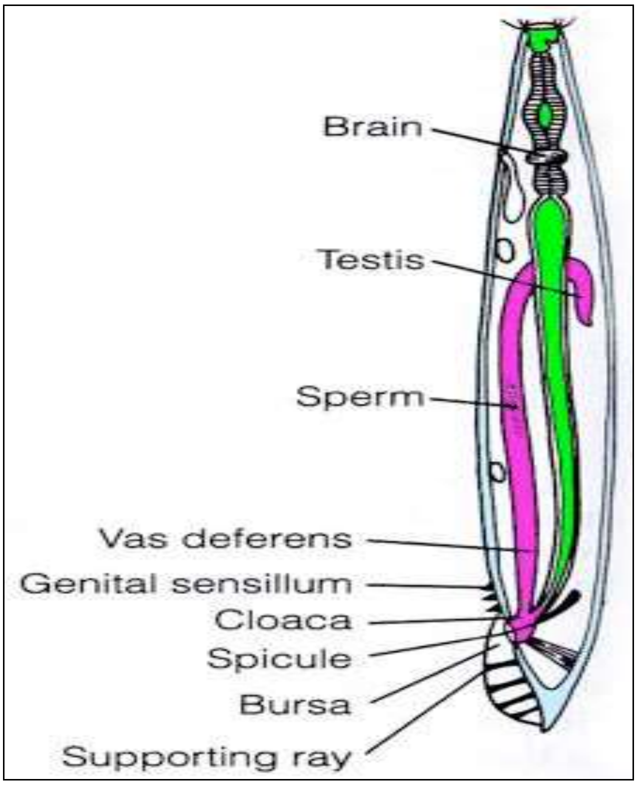

dorsal nerve
ovary
intestine
lateral nerve
uterus
subventral nerve
ventral nerve
B

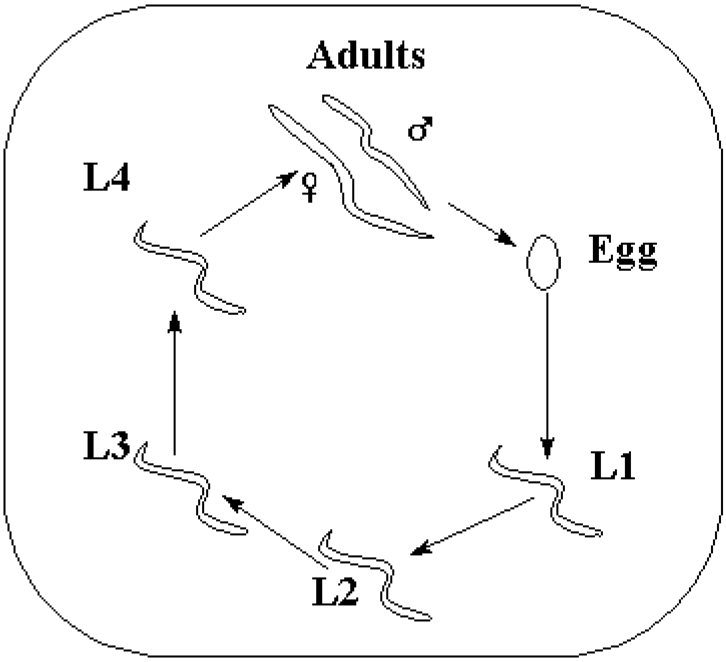

Mouth
Pharynx
Intestine
Anus


Testis
Cloaca
Ovary
Uterus
Vulva
Anus


Buccal cavity
Sensilla
Corpus
Esophagus
Isthmus
Bulb
Excretory glands
Coelomocyte
Seminal vesicle
Testis
Ovary
Vulva
Intestine
Intestine
Vas deferens
Ovary
Uterus
Genital papilla
Anal gland
Spicule
Bursa
Anal dilator muscles
Anus
Female
Male


Ovary
Growth zone
Germinal zone
(oogonia and oocytes
Gut
Distal tip cell
Egg
Shelled
zygote
Vulva
Uterus
Seminal
receptacle
Ovijector
muscles


Brain
Testis
Sperm
Vas deferens
Genital sensillum
Cloaca
Spicule
Bursa
Supporting ray


Adults
♂
♀
L4
Egg
L3
L1
L2