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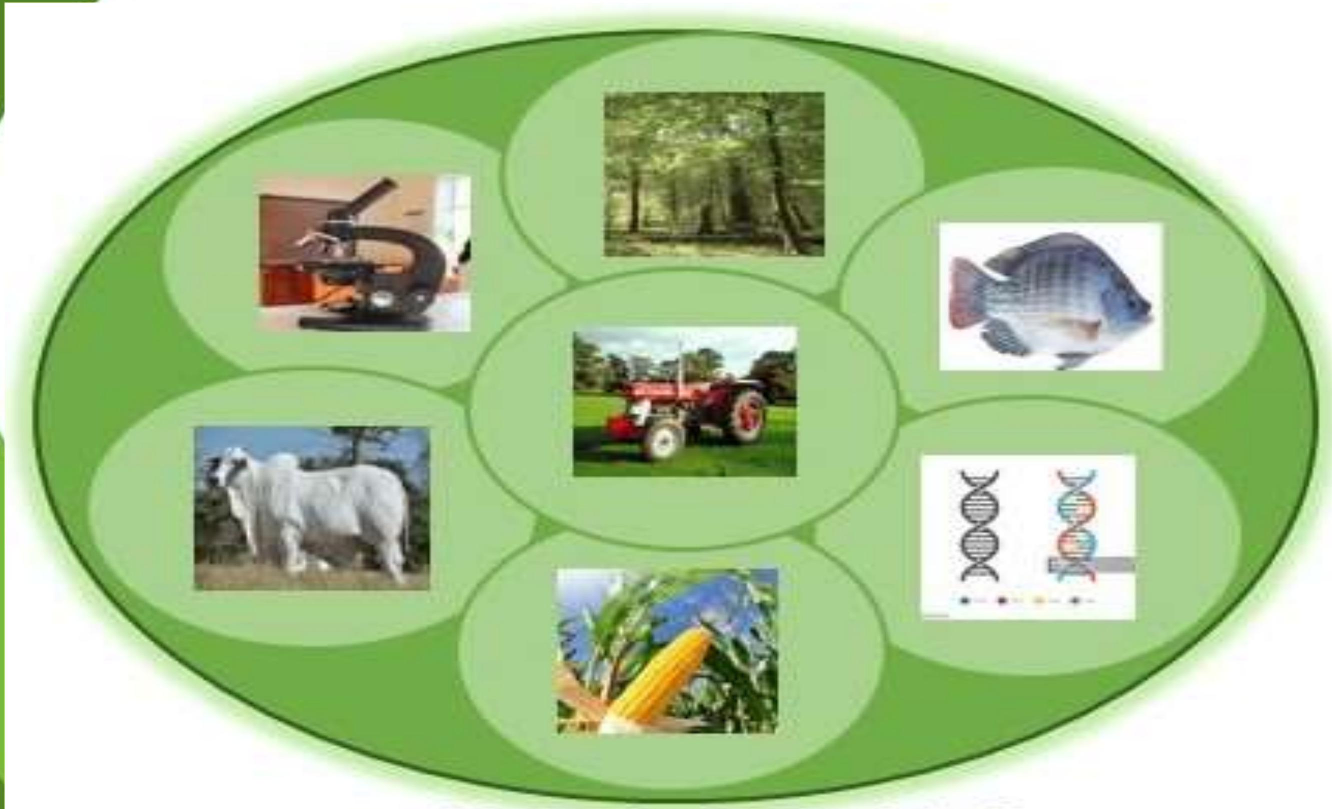

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A REVIEW ON THE BIOLOGY OF SOIL NEMATODES AND THEIR ECONOMIC SIGNIFICANCE IN AGRICULTURE

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ABSTRACT

Nematodes are roundworms similar to the animal parasites encountered in livestock and pets. Soil dwelling nematodes are both good guys and bad guys in crop production. The good nematodes, which don't get much press, feed on fungi, bacteria, and other creatures that live in the soil and thereby recycle the nutrients contained in it. Tens of millions of mostly beneficial nematodes live in each square meter of cropland; however, a few of these microscopic roundworms the plant-pathogenic nematodes give all nematodes a bad name. Most of the plant-pathogenic nematodes (referred to simply as nematodes from here) feed on plant roots, although some less common ones feed in various aboveground plant parts. The root-feeding nematodes are either ectoparasites, which feed from outside the root or endoparasites, which feed from inside the root. All plant-feeding nematodes feed by means of a stylet, a structure in the head of a nematode that allows it to pierce plant cell walls. The objectives of this work is to briefly describe the biology of nematode species including basic characteristics, the diversity classification, agricultural and ecological importance. Relevant information's from related published articles, books and other biological materials were used as my sources. Conclusively it can be said that, the science of nematology is relatively young compared to entomology and plant pathology and free living nematode species are abundant, including nematodes that feed on bacteria, fungi, and other nematodes, yet majority of species encountered are poorly understood.

Keywords: Agriculture, Soil, Nematodes, Nutrient Neutralizers, Nematology

Introduction

Nematoda is a phylum comprised of non-segmented worm-like invertebrates commonly described as filiform or thread-like, a feature reflected by the Greek origin of the taxon name nema (meaning 'thread'). Nematodes are found in various habitats, including fresh and saltwater, in the soil, or parasitizing plants and animals (including humans). Nematodes are also present in more extreme environments such as hot springs, arctic ice packs and subterranean caves. The American nematologist Nathan Cobb in 1915 described this as follows: Nematodes are aquatic organisms. A film of moisture is required to support their survival and movement.

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Therefore, abiotic factors such as soil moisture or relative humidity are crucial to the nematode's survival. To survive harsh conditions, nematodes can enter a dormant state where, metabolism and activity are slowed down in response to environmental stress (quiescence) or in an extreme dormant condition where the metabolic rate may fall below detectable levels and appear to cease (cryptobiosis/anabiosis). Nematodes that parasitize plants and animals are widely studied. It is crucial that we identify these nematodes and understand their life cycle accurately. Identification primarily relies upon morphological characteristics, although more recently there has been a shift towards exploiting molecular features, such as in DNA barcoding. However, the ideal approach is a holistic approach combining morphological characters with molecular features complemented with information on biology and behaviour (MEDUSSA, 2024).

Most research on soil nematodes has focused on the plant-parasitic nematodes that attack the roots of cultivated crops. Less attention has been given to nematodes that are not plant-feeders and play beneficial roles in the soil environment. This article describes the feeding habits and important roles played by nematodes in soil ecosystems.

Classification

One of the reasons for nematodes' large range of interactions with the physical and biological worlds is that nematodes are very diverse: there are a lot of species and they differ substantially from each other so that there are many higher taxonomic groups as well as many species. The exact number of nematode species is not definitively known. The smallest estimate of total number of nematode species is half a million, while the largest is 20 times that 10 million species (Grassle and Maciolek 1992; Hodda 2022a; Hodda and Khudhir 2022; Hugot et al. 2001; Lambshead and Boucher 2003). The extreme variance in these estimates shows how little is definitively known about nematode species. According to Perry and Moens (2011), there are more than 20000 types of nematodes defined in the phylum Nematoda today.

In addition, Nematodes are everywhere on earth in enormous diversity and numbers except the few areas where liquid water never exists like the poles and the tops of the highest mountains. Their huge numbers and potential range of foods means that they can be of great ecological importance in many situations for ecosystem function (Adams and Wall 2000; Bonkowski et al. 2000; Hodda, 2009a; Majdi and Traunspurger, 2015; Nicol et al., 2011; Shakya and Yadav 2020, Singh et al. 2013 and Trap et al., 2016). However, nematodes' great taxonomic and ecological diversity, together with the fact that they are mostly small and hard to identify, has meant that most species are still uncollected and undescribed (Hodda 2007, 2022a; Hodda and Khudhir 2022; Hugot et al. 2001; Khudhir et al. 2022). This, in turn, has meant that interpreting the likely impact of nematodes in most situations is problematic and as stated above, nematodes are found in large numbers in just about all situations on earth.

Thus, it is useful to know whether the nematodes are grazing on microbes, preying on small organisms or parasitizing larger organisms. It is also useful to know whether they are general feeders, interacting with a large number of different organisms, or specialists, consuming just a few types of food. In addition, knowing how they get their food can be useful, as this may influence the conditions under which they will feed. For example, nematodes sucking their food of small microbes from suspension in water will need wetter conditions than nematodes scraping off bacteria adhering to substrate particles. Predatory nematodes will need a variety of prey. To a certain extent this information will predict the environmental conditions under which these different groups will grow best (Hodda, 2022).

Estimates of the proportion of nematode species known vary from much less than 1% to around 5%, that is why they are the least described taxa, and certainly the least described of the mega-diverse animal phyla (Andrassy, 2007 and Hodda, 2022a). Efforts in describing nematode species has been slow, to the current rate of about 400 species per year (Hodda, 2022a). This is less than 0.1% of the estimated total number of species, but 1.5% of the number of known, described species (Hodda, 2022a). What it means is that around 13% or an eighth of described species have been described in the last 10 years (Hodda, 2022a). It is known that the number of species damaging plants is more than 4100 Plant parasite nematodes are obligate parasites and are mostly fed in the cytoplasms of their hosts (Jones et al., 2013). However, not all of these species cause economic losses in plants. Plant-parasitic nematodes can cause damage to the underground or aboveground parts of plants.

Nematode Feeding Habits

With the increasing interest of soil ecologists in the role of nematodes in ecosystem processes (roles such as nutrient cycling, biological control and economic crop loss), there is an unmet need for a concise summary of current knowledge of nematode feeding habits. The analysis of available information is made increasingly difficult by changes in nematode systematics and recent contributions to nematode ecology. When all species of nematodes can be confidently assigned to feeding groups, there will follow a better understanding of the role of nematodes in soil and how changes in environmental factors influence the composition of the nematode fauna. The first comprehensive review of nematode feeding habits was given by (NEMDUSSA, 2024).

In an attempt to produce functional groups based on feeding habits, Manzoor et al., (2022) applied to nematodes terms such as "pararhizobes" (occur in the rhizosphere and sometimes damage plants) and "dyssaprobes" (feed in decomposing material but may enter healthy tissue). Both Wasilewska (1971) and Yeates (1971) grouped plant and soil nematodes by feeding habits. The classification of Tylenchida advocated by Siddiqi (1986) has a strong "feeding habit" component. Recent ecological studies have revealed that feeding-habit groupings may not be sharply delimited. For example, abundant populations of Aphelenchoides, Tylenchus, Tylencholaimus, and Ditylenchus were discovered that could only be classified as "root/fungal feeding nematodes" Roland et al., (2024), as well as "predacious" mononchids that multiplied using bacteria as a food source. These examples demonstrate the apparently arbitrary nature of traditional nematode feed ing groups. Moreover, feeding habits of many nematodes have been inferred rather than confirmed by maintenance over many generations under biologically defined conditions. Following Petersen and Luxton (86), we use "grazing food web" and "detritus foodweb" as terms for communities based on living green plants and dead organic matter, respectively. Their comments on the merging of the two webs are particularly relevant for nematodes, which are so often abundant at interfaces between living and dead material (as in the rhizosphere).

Nematodes can be classified into functional groups based on their feeding habits, which can often be deduced from the structure of their mouthparts. In agricultural soils, the most common groups of nematodes are the bacterial-feeders, fungal-feeders, plant

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parasites, predators, and omnivores. Predatory nematodes feed on protozoa and other soil nematodes. Omnivores feed on different foods depending on environmental conditions and food availability; for example, omnivorous nematodes can be predators, but in the absence of their primary food source, they can feed on fungi or bacteria (Adams, 2000; Lavelle and Spain, 2001; Hodda, 2022).

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 (Mousumi, 2020; Majdi et al., 2020).

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 needle-like 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 (Ingham and Detling. 1984; Mosami,2020). All plant-parasitic nematodes carry stylets to feed or enter their hosts. These properties distinguish them from most of the other nematode groups (Perry and Moens, 2006). Plant- parasitic nematodes are obligate parasites and they obtain the nutrients necessary for their development from different parts of the plants. The differences observed in nutritional habits are the adaptations they have created in order to survive in their habitats (Robinson, 2003)

Bacterivores

Many kinds of free-livinsg 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.

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 (Mousami, 2020).

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 (Majdi et al., 2020)

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 (Hodda, 2022).

Decomposition

Free-living nematodes are very important and beneficial in the decomposition of organic material and the recycling of nutrients in soil. Nematode bacterivores and fungivores do not feed directly on soil organic matter, but on the bacteria and fungi which decompose organic matter. The presence and feeding of these nematodes accelerate the decomposition process. Their feeding recycles minerals and other nutrients from bacteria, fungi, and other substrates and returns them to the soil where they are accessible to plant roots (Wang et al., 2006).

According to different researchers and biological informations nematodes are invertebrate animals of living organisms that found almost everywhere in the world, from aquatic to terrestrial habitat and from free living to parasite (endoparasites and exoparasites of other animals) with varied shape of elongate, threadlike, roundworms, or eelworms active animals and nematodes are one of the most successful and adaptable of animal groups, next to insects as regards range of habitats or number of species. Many nematode species are extremely successful parasites, most are free-living, their food consisting of microorganisms like algae, bacteria, and fungi, which play an important role in decomposition and nutrient recycling. Majority of soil free living nematodes mainly feed on fungi and bacteria and their biological process is largely depending on soil moisture and temperature, and also food availability and appropriate host of both plant and animal. Nematodes are multicellular organisms on earth with vermiform invertebrate animal species, almost microscopic, of which are nearly invisible to eye while they live in the soil as habitat and as endoparasites of both plant and animals (Niles et al.,1997).

Invertebrate animal species of phylum nematodes have great importance for agricultural values and ecological benefit due to they are the second most diversified invertebrates with adaptation of various habitat range and feeding behaviour. The habitat variety of nematodes are ranging from aquatic (such as fresh water, estuarine and marine water), terrestrial (as free living in the soil) and parasitic (either endoparasites and ectoparasites of animals and plants). Based on Pokharel, and Larsen (2007) and Pokharel., et al. (2007), soil nematodes are very important in protecting the organic nature of soil, particularly low organic content soil, and phytoparasitic nematodes are feed tissue of plants, reduce the growth and productivity of plants. In addition, soil nematodes also assist colonization of microbial substrates and nutrients mineralization in the soil and also during metabolism of nematodes, important nutrients like nitrogen and vitamins also released which used to speed up bacterial growth in the soil. Many nematodes feed on bacteria and fungi within the soil as generalist predators like omnivorous and predatory nematodes which used to improve nutrient cycling and allows slow release of nutrients. The free-living nematodes used to make nitrogen available to plants and mineralization of other soil nutrients is relatively high compared to bacteria in soil ecosystems and also feed on other soil microbes including plant pathogens such as bacteria, fungi, and other nematodes. Free-living nematodes are important for any crop production system by protecting nature of soil and other nematodes are extraordinarily lethal to many impor- tant soil insect pests and yet safe for plants and animals and they are used to control many soil inhabiting insects (Poikharel et al., 2007). Therefore, this review is significant to indicate briefly the importance.

Significance of Nematodes in Agricultural Systems

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Soil is an excellent habitat for nematodes, and 100cc of soil may contain several thousand of them. Because of their importance to agriculture, much more is known about plant-parasitic nematodes than about the other kinds of nematodes which are present in soil. 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 contribute to a variety of functions within the soil system. In agricultural systems, nematodes can enhance nutrient mineralization and act as biological control agents Salih., et al. 2017).

Nematodes and Soil Fertility

Soil nematodes, especially bacterial and fungal feeding nematodes, can contribute to maintaining adequate levels of plant-available nitrogen in farming systems relying on organic sources of fertility (Ferris et al., 1998). The process of converting nutrients from organic to inorganic form is termed mineralization; mineralization is a critical soil process because plants take up nutrients from the soil primarily in inorganic forms. Nematodes contribute directly to nutrient mineralization through their feeding interactions. For example, bacterial-feeding nematodes consume nitrogen in the form of proteins and other nitrogen containing compounds in bacterial tissues and release excess nitrogen in the form of ammonium, which is readily available for plant use. Indirectly, nematodes enhance decomposition and nutrient cycling by grazing and renewing old, inactive bacterial and fungal colonies, and by spreading bacteria and fungi to newly available organic residues. In the absence of grazers, such as nematodes and protozoa, nutrients can remain immobilized and unavailable for plant uptake in bacterial and fungal biomass (Salih, et al., 2017).

Bacterial-feeding nematodes are the most abundant nematode group in agricultural soils. Their abundance closely follows that of bacterial populations, which tend to increase when soil disturbances, such as tillage, increase the availability of readily-decomposable organic matter. Nitrogen mineralization in the soil occurs at a higher rate when bacterial-feeding nematodes are present than when they are absent. The contribution of bacterial-feeding nematodes to soil nitrogen supply depends, in part, on the quality and quantity of soil organic matter fueling the system. Net N mineralization from decomposing organic residues takes place when the carbon:nitrogen (C:N) ratio of organic residue is below 20 (that is, 20 parts C to 1 part N). When the C:N ratio is greater than 30, the rate of mineralization decreases because microbes compete for nitrogen to meet their nutritional requirements. In this situation, N is immobilized in the microbial biomass. Incorporation of manure, compost, and cover crops with intermediate carbon-nitrogen ratios (ranging from 10 to 18) may stimulate bacterial growth and the abundance of bacterial-feeding nematodes, and increase soil nitrogen availability to plants Salih, et al. 2017).

Fungal-feeding nematodes are relatively more abundant in less-disturbed (e.g. notill systems) and perennial systems, where conditions for fungal growth are promoted, than in disturbed systems. Like bacterial feeding nematodes, fungal-feeding nematodes contribute to the process of nutrient mineralization by releasing nitrogen and other plant nutrients from consumed fungal tissue. However, in agricultural systems, bacterial-feeding nematodes typically release more inorganic nitrogen than fungal-feeding nematodes (Salih, et al. 2017).

Beneficial or harmful Effects of Soil Nematodes

The majority of soil nematodes are beneficial to soil health and the environment. Nematodes are often talked about in a quiet fearful voice. The image of the small microscopic worms can bring grown men to their knees. Unfortunately, like many things in our world, a few "bad" apples have ruined the entire bushel. Attention has been given extensively to a small segment of the nematode population that negatively impacts crops but those nematodes are a very small percent of the nematode population. The larger percentage of the population benefit agriculture and the environment especially soil health (Salih, et al. 2017).

Nematodes enhance soil quality in four major areas: regulate the populations of other soil organisms, mineralize nutrients into plant-available forms, provide a food source for other soil organisms and consume disease-causing organisms. Nematodes are considered grazers. They move through the soil profile devouring smaller organisms as well as distributing any bacteria or fungi that are on them as well as any that are in their digestive system. If the nematode population is low, they will stimulate the growth rate of prey populations. If the nematode population is high, they have the potential to have negative impact on soil health by devouring too much of their prey especially micorrhizal fungi. There are also predatory nematodes that balance the population of other nematodes (Poikharel et al., 2007).

Nematodes are important nutrient mineralizers. When nematodes consume bacteria or fungi they release excess ammonium ($NH4^+$). Bacteria and fungi both have more ammonium than what the nematode needs so the extra is released in a plant available form. Nematodes are not the highest organism in the soil food web. Soil micro arthropds and insects as well as bacteria and fungi feed on nematodes. As stated earlier there are also predatory nematodes in the soil that consume nematodes. A major function of soil nematodes is that they are biocontrol agents, meaning they can be used to eliminate disease causing nematodes and other organisms. This trait causes predatory nematodes to be a great resource in the battle against soil borne diseases Salih., et al. 2017).

Conclusion

Soil nematodes are very important in recycling of the essential mineral elements needed by plants which may result in enriching the soil for agricultural purposes. The science of nematology is relatively young compared to entomology and plant pathology and free living nematode species are abundant, including nematodes that feed on bacteria, fungi, and other nematodes, however, majority of species encountered are poorly understood, Accordingly, despite the significant role of nematodes in agricultural and ecological value, much is not yet understood. Therefore, this review is important for brief description of nematodes biology, habitat and diversity of nematodes, agricultural and ecological importance and also integrated management system of nematodes.

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