ZOO 370: INTRODUCTORY NEMATOLOGY (3 UNITS)

Course synopsis

1. Principal characteristics of nematodes, morphology, position and outline of classification of nematodes.

2. Morphology and biology of important plant parasite nematodes and their economic importance. Nematological techniques. General principles and methods of controlling plant nematodes.

3. The role of soil environment in the life of nematodes. Nematological techniques. General principles and methods of controlling nematodes.

Lecture notes on Soil Environment

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.

Biological factors

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 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.

Soil texture refers to sand, silt and clay composition. Soil content affects soil behavior, including the retention capacity for nutrients and water. Sand and silt are the products of physical weathering, while clay is the product of chemical weathering. Clay content has retention capacity for nutrients and water. Clay soils resist wind and water erosion better than silty and sandy soils, because the particles are more tightly joined to each other. In medium-textured soils, clay is often translocated downward through the soil profile and accumulates in the subsoil.

Uses

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

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.

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.

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.

While soil acidification of alkaline soils is beneficial, it degrades land when soil acidity lowers crop productivity and increases soil vulnerability to contamination and erosion. Soils are often initially acid because their parent materials were acid and initially low in the basic cations (calcium, magnesium, potassium and sodium). Acidification occurs when these elements are removed from the soil profile by normal rainfall, or the harvesting of forest or agricultural crops. Soil acidification is accelerated by the use of acid-forming nitrogenous fertilizers and by the effects of acid precipitation.

Soil contamination at low levels is often within soil capacity to treat and assimilate. Many waste treatment processes rely on this treatment capacity. Exceeding treatment capacity can damage soil biota and limit soil function. Derelict soils occur where industrial contamination or other development activity damages the soil to such a degree that the land cannot be used safely or productively. Remediation of derelict soil uses principles of geology, physics, chemistry and biology to degrade, attenuate, isolate or remove soil contaminants to restore soil functions and values. Techniques include leaching, air sparging, chemical amendments, phytoremediation, bioremediation and natural attenuation.

Biotic indicators of soil ecological health or condition can be used to assess the current status of vital ecological processes in soil and change in processes through time. Any indicator should reflect the structure and(or) function of ecological processes and respond to changes in soil condition that result from land-management practices. Furthermore, there must be sufficient taxonomic knowledge to identify organisms accurately and efficiently. For regional or national monitoring programs, additional criteria constrain choices of possible indicator taxa. For example, they must be applicable to all geographic locations, soil types, and vegetation types.

Biologically, soil ecosystems support a diversity of microbes (fungi, bacteria, and algae), microfauna (protozoa), and mesofauna (arthropods and nematodes). Appropriate cautions are necessary when choosing organisms for use as bioindicators. For example, perspective may be narrowed by personal experience. An expert on a particular plant-pathogenic species, e.g., *Meloidogyne incognita,* may initially consider the species to be a good indicator because its presence and abundance are associated with development of economically important epidemics of root rot on cotton or tomato. However, individual species are not applicable across all plant species, soil types, or geographic climates. Caution must also be exercised on the other extreme—when choosing entire kingdoms for study, e.g., soil fungi and bacteria (sometimes pooled as the ‘‘microbial community’’). Although microbial communities are known to play critical roles in ecological processes, such as nutrient cycling, and also respond to environmental disturbances of soil, such as contamination by heavy metals

Furthermore, it is tedious, indeed impossible, to identify all bacteria and fungi in a sample, and databases of biochemical profiles are either incomplete or inadequate, especially for free-living taxa. Soil fauna have advantages over soil microbes as bioindicators. First, by being one or two steps higher in the food chain, they serve as integrators of physical, chemical, and biological properties related with their food resources. Second, their generation time (days to years) is longer than metabolically active microbes (hours to days), making them more stable temporally and not simply fluctuating with ephemeral nutrient flushes. Nematodes and mites are two groups of mesofauna that have been considered for use as biological indicators. Of these three groups, nematodes have been evaluated most often for their use as indicators. Nematodes (free-living and plant-parasitic) may be the most useful group for community indicator analysis because more information exists on their taxonomy and feeding roles.

Nematodes possess several attributes that make them useful ecological indicators. Soil nematodes can be placed into at least five functional or trophic groups and they occupy a central position in the detritus food web (Moore and de Ruiter, 1991). A small fraction of soil fauna depends directly on primary producers, feeding on plant roots and their exudates. The subgroups of these organisms that form parasitic relationships with plants and their roots are the best known of soil organisms because of the damage they cause to agricultural crops—such as decreasing plant production, disrupting plant nutrient and water transfer, and decreasing fruit and tuber quality and size

Role of Nematodes in Soil Health

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.

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.

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.

Use of Nematodes as Indicators

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

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

Nematodes

Nematodes or eel worms are small, non-segmented worms. They are only 50 microns in diameter and about 1mm long or less. They have a resistant cuticle (skin) and an ability to adapt well to environmental change which has enabled them to become the most abundant multicellular animals on earth. Most nematode species have a beneficial role in the soil, but we tend to know more about the pest species because of their impact on agricultural production. Nematodes live mainly in soil where they feed on fungi, bacteria and other soil organisms and in some cases plant roots.

Types of nematodes

There are three functional groups of nematodes:

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.

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

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

Mouthparts

Nematodes are described by their different feeding type or mouthparts. Bacterial feeding nematodes have a tube like structure to suck up bacteria. Fungal feeding nematodes have a piercing needle (stylet) which penetrates fungal cells and enables the nematode to suck up cell contents. Root feeding nematodes also have a stylet to pierce root cells. Predators feed on other nematodes and small soil organisms.

What do nematodes do in the soil?

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

A Nutrient cycling

Nutrients such as ammonium ($NH4$ +), 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.

B 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 parasitised by some bacteria and fungi, which helps their dispersal through the soil.

C 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.

Where are nematodes found?

As with most of the organisms that live in the soil nematodes are found in the top few centimetres of the soil. They live in the thin films of water surrounding soil particles, as they require water to move. They are generally found in well-structured soils with large pore spaces, or coarser soils, where food is easily available.

Management effects on nematodes

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.

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.