CHAPTER XI
ORGANISMS OF FOREST SOILS

Introduction

The soils of forests harbor multitudes of organisms living in burrows, in contact with colloidal material, and in the soil solution. Numbers of organisms per gram of soil range from several hundred thousands in sands to many millions in rich mull loams. Their total dry weight in one acre of forest soil is often as high as 20,000 pounds.

The soil organisms exert a profound influence upon both the genetical development of soil profile and the growth of forest vegetation. Nearly all members of the soil population are employed in the decomposition of organic remains. Organisms increase the availability of plant food through oxidation, evolution of carbon dioxide, and symbiotic action, or render nutrients unavailable through reduction and incorporation in the protoplasm of their bodies. The fixation of atmospheric nitrogen and carbon is primarily a biological process. Both metabolism and physical adsorption of salts on the surface of organisms aid greatly the retention of plant food in the upper soil layers. The organisms modify the mobility of soil colloids and affect the formation of soil aggregates. Some forms hasten the germination and distribution of seeds, while others destroy the seed, root systems and other plant tissues.

The entire soil population, or "edaphon", includes bacteria, fungi, actinomycetes, algae, protozoa, nematodes, worms, insects, rodents, moles, shrews, and other soil-inhabiting animals.

Bacteria

The bacterial population of soil falls into two broad groups determined by the mode of nutrition:

(1) **Autotrophic bacteria** which live wholly or partially without organic matter, utilizing elements or simple compounds for energy and deriving body carbon from carbon dioxide. To this group belong nitrite and nitrate-forming bacteria and bacteria oxidizing sulfur, iron, hydrogen, or carbon monoxide, methane and similar carbon compounds.

(2) **Heterotrophic bacteria** which do not assimilate carbon dioxide and feed chiefly on organic matter. To this group belong free and symbiotic nitrogen-fixing bacteria, bacteria decomposing fats, proteins, cellulose and other carbohydrates, and some denitrifying bacteria. A considerable portion of heterotrophic forms live in the absence of oxygen and are called "anaerobic" in contrast to "aerobic" forms developing in the presence of air.

The outlined division is of a great practical importance in relation to forest soils, particularly in relation to the management of forest nursery soils. The organic matter is essential in tree nutrition, as well as in the maintenance of soil fertility. The normal nutrition of trees cannot proceed without participation of soil bacteria. Some of these organisms live on
organic residues, which they tend to destroy, while others not only prefer purely mineral substances but may even be injured by the presence of organic matter. Under natural conditions all of these seemingly paradoxical tendencies are in perfect correlation, at least in regard to the nutrition of tree species native to a definite set of soil conditions. However, unskilled silvicultural practices, such as inappropriate cuttings, introduction of unsuitable new species, and especially unbalanced application of organic matter and mineral fertilizers, may easily destroy the existing equilibrium of bacteria and upset the nutrition of forest stand or nursery stock. Thus, the maintenance of the soil microorganisms in a state of natural balance and in harmony with the higher forest vegetation is one of the important problems of modern silviculture.

The following outline covers the more important nutritional effects exerted by various groups of bacteria.

(a) **Protein-Decomposing and Ammonifying Bacteria**

The bulk of nitrogen in soil, forest litter and organic fertilizers is in the form of proteins and their derivatives. These substances cannot be utilized by trees directly and must first be broken down into simple compounds such as ammonia and nitrates. The process of decomposition of proteins into carbon dioxide, water and mineral salts is accomplished by combined action of chemical, enzymatic, and biological agents. Among the latter a prominent role is played by both aerobic and anaerobic bacteria (Bac. mycoides, Bac. subtilis, Bact. vulgare, Bac. putreficus, and many others).

In the course of decomposition of proteins a great number of intermediate compounds and by-products are formed. Their nature depends upon degree of soil moisture, aeration, reaction and other conditions. In some instances, the chain of these transformations is included, by accumulation of ammonia which is released as a final waste product of metabolism of ammonifying bacteria. Under aerobic conditions, however, ammonia may be further transformed into nitrates by nitrifying bacteria.

(b) **Nitrifying Bacteria**

The transformation of ammonia nitrogen into nitrates is accomplished by two groups of aerobic bacteria. Some of these oxidize ammonia to nitrites (Nitrosomonas), whereas others oxidize the nitrites into nitrates (Nitrobacter), according to the following approximate equations:

\[
2 \text{NH}_3 + 3 \text{O}_2 \rightarrow 2 \text{HNO}_2 + 2 \text{H}_2\text{O}
\]

\[
2 \text{HNO}_2 + \text{O}_2 \rightarrow 2 \text{HNO}_3
\]

Good aeration, adequate supply of water, fairly high temperature, presence of buffers, and the absence of large quantities of soluble organic matter or highly concentrated salts are essential for the success of nitrification. As a rule, nitrification is promoted by a reaction approaching neutrality, although some organisms specifically adapted to acid media produce nitrates in forest soils having a reaction as low as pH 4.3.
The maintenance of soil in a condition suitable for the propagation of nitrifying bacteria is important chiefly in dealing with deciduous, lime-loving tree species requiring nitrogen in the form of nitrates. On the other hand, certain deviations from the nitrification optimum may be tolerated in stands and nurseries with acidophilous and especially saprophytic conifers, as such species readily utilize the nitrogen of ammonia, and possibly amino-acids.

(c) **Denitrifying Bacteria**

Under anaerobic conditions certain bacteria derive their oxygen supply from the oxides of nitrogen. In this process the nitrate is reduced to nitrite and further to elementary nitrogen with the simultaneous oxidation of other food substances by the microorganism involved. The group of bacteria capable of denitrification includes hundreds of autotrophic and heterotrophic species greatly diversified in their other activities.

The reduction of nitrates to nitrites usually takes place in a neutral or somewhat alkaline medium. In acid soils nitrates are likely to be reduced to ammonia with nitrites as an intermediate product.

Denitrification exerts an adverse influence upon the growth of trees, especially hardwoods, by depriving them of nitrogen in general, or of readily available nitrates in particular. In some instances, denitrification and subsequent formation of ammonia prevents the loss of available nitrogen from leaching.

(d) **Nitrogen-Fixing Bacteria**

Although an abundant supply of elementary nitrogen is always present in the atmosphere, it is not available to trees until it is converted into the form of simple organic or mineral compounds. A rather negligible portion of this conversion is accomplished by electrical discharges, and the rest by the activity of nitrogen-fixing organisms, particularly bacteria. The bacteria utilizing or "fixing" elementary nitrogen occur in nature either as free organisms or in symbiosis with higher plants. The latter group forms nodules on the roots and are commonly referred to as "nodule bacteria." The process of nitrogen fixation, resulting in an accumulation of proteins in the bodies of bacteria, is somewhat similar to the formation of carbohydrates by green plants.

The free nitrogen-fixing organisms include aerobic and anaerobic forms. Aerobic forms (Azotobacter) are extremely sensitive to the acidity of soil and other conditions, and their distribution is confined chiefly to well-aerated loam soils with reaction above pH 5.0. Consequently, these bacteria are of secondary importance in the maintenance of forest soil fertility. The anaerobic forms (Clostridium or Amylobacter), occur nearly universally in soils, with the possible exception of acid peat bogs, and play an important part in the growth of both forest stands and nursery stock. A reaction not lower than pH 5.5, an adequate supply of organic matter and mineral plant food, and a fairly high temperature are essential for the optimum activity of these organisms.
In the symbiotic fixation of nitrogen, leguminous plants provide nodule bacteria with carbohydrates and in return receive nitrogen compounds. The nitrogen accumulated by nodule bacteria is likely to be directly available and is transferred to the plant at a rather constant rate.

The nodule bacteria (Rhizobium) are usually quite specific in their host requirements. They can withstand about the same pH as their respective hosts. The forms associated with soybeans and lupines can survive at pH 4.0, thus permitting their advantageous use in forest nurseries. In spite of the great tolerance of certain legume bacteria to acidity, the rate of nitrogen fixation is usually increased by the addition of lime. Mineral fertilizers and organic remains are also indirectly effective, due to increased growth of the host plant.

In the great majority of cases inoculation of seeds or soil with the proper culture of bacteria is necessary to obtain satisfactory results with leguminous green manure crops. Some forest trees, such as black locust, are dependent in their nitrogen nutrition upon bacteria and may also require artificial inoculation. Although the bacteria are often present in nursery soils, their viability is greatly influenced by pH, organic matter, moisture, temperature, and toxic agents. Consequently, it may prove wise to inoculate seed with a known effective culture rather than to depend upon the presence of the organism in the soil.

**Carbohydrate-Decomposing Bacteria**

Carbohydrates comprise the greatest portion of organic matter. They include sugars, starches, cellulose and hemicelluloses. Cellulose is the most abundant constituent and the process of its decomposition has a particularly important bearing upon soil productivity.

The role of cellulose in plant nutrition is of a complex nature as it may exert either beneficial or harmful influences. Cellulose serves directly or indirectly as a source of energy for nitrogen fixing bacteria and other useful organisms, but has no value as a plant nutrient or base exchange material. In large quantities it encourages the growth of organisms capable of utilizing ammonia and nitrates and thus may cause the nitrogen starvation of trees. For this reason, the productivity of soil, as well as the quality of composted fertilizers, may be greatly decreased by an accumulation of undecomposed cellulose.

The bacteria employed in decomposition of cellulose include both aerobic and anaerobic forms; (Cellulomonas, certain Spirochaetes and Clostridia). In compost piles with a high temperature, these organisms may be partly replaced by thermophilic bacteria (Clostridium thermocellum). The mechanism of cellulose decomposition varies depending upon the conditions of environment and the organisms involved. However, the end products usually include: carbon dioxide, methane, hydrogen, other gases, intermediate products such as acids and alcohols, and bacterial cells mixed with other decay-resistant substances.
The aerobic cellulose-decomposing bacteria are very intolerant and of poor aeration and soil acidity. Their activity ceases completely at a reaction lower than pH 5.5. Consequently, they are confined chiefly to hardwood mull loams and nonpodzolic pine sands. The anaerobic bacteria withstand both strong acidity and deficiency of oxygen and occur abundantly not only in poorly drained and acid forest soils but also in deposits of peat and over-watered compost piles.

The activity of some bacteria in anaerobic media is greatly stimulated by the addition of nitrate salts. Under such conditions, the nitrate is reduced to gaseous nitrogen and the released oxygen is used by organisms in respiration. This relationship may be advantageously used to accelerate the decomposition of raw organic remains in poorly aerated compost pits.

Raw organic remains used in forest practice as fertilizing material usually contain about 40 per cent of carbon and 2 per cent of nitrogen. When such remains are added to a nursery soil, cellulose-decomposing bacteria multiply rapidly, using for their cells both carbon and nitrogen. As the bacterial cells are composed approximately of one part of nitrogen and five parts of carbon the supply of nitrogen present in both soil and organic remains may be soon exhausted. Unless the soil receives a new supply of nitrogen in the form of fertilizers this condition will arrest the process of decomposition and bring about the starvation of nursery stock. Such utilization of nitrogenous compounds by cellulose-decomposing bacteria often takes place in preparation of composted fertilizers and may also be prevented by applications of soluble nitrogen salts, such as ammonium sulfate.

Fortunately, the decomposition of cellulose is accomplished not only by bacteria, but also by fungi which assimilate considerably smaller amounts of nitrogen per unit of carbon and hence work more economically.

A process similar to the micro-biological utilization of nitrogen may affect some other available nutrients, particularly phosphorus and sulfur. Consequently, in the application of peat, raw humus and green manure crops to nursery soils, careful attention should be paid, not only to the carbon-nitrogen ratio, but to the availability of other nutrients as well.

The decomposition of hemicelluloses and other carbohydrates is on the whole similar to that of cellulose, except that it proceeds more rapidly and has a lesser effect upon the fertility of soil.

(f) **Sulfur Bacteria**

From the standpoint of nutrition, sulfur is closely related to nitrogen and undergoes similar biological transformations. The oxidation of elementary sulfur and sulfides, including hydrogen sulfide, into available sulfates is accomplished primarily by a specific group of sulfur bacteria (*Thiobacillus, Beggiatoa, Thiothrix*) according to the following reactions:
\[
\begin{align*}
2 \ H_2S + O_2 & \rightarrow 2 \ H_2O + S_2 \\
S_2 + 3 \ O_2 + 2 \ H_2O & \rightarrow 2 \ H_2SO_4 \\
H_2SO_4 + CaCO_3 & \rightarrow CaSO_4 + H_2O + CO_2
\end{align*}
\]

The accumulation of sulfuric acid or sulfates, resulting from the process of oxidation, is followed by an increase in soil acidity. Since the acidification of nursery soils supporting coniferous stock is often aimed for, the sulfur-oxidizing bacteria and their well-being attain a considerable importance in forestry practice. The activity of these forms is stimulated by additions of sulfur flowers and various organic remains, viz. green manure, peat, duff, or compost.

The oxidation of sulfur is of further benefit in the preparation of composted fertilizers where the sulfuric acid formed converts the insoluble rock phosphates into available mono-calcium phosphate or phosphoric acid.

The process of the reduction of sulfates or other sulfur oxides to hydrogen sulfide is similar in its nature to denitrification and may be accomplished by a wide variety of both autotrophic and heterotrophic organisms capable of carrying on anaerobic respiration. Vibrio desulfuricans, a strictly anaerobic spirillum, plays an outstanding part in this transformation. The reduction of sulfates takes place prevalingly in poorly-drained soils, especially peat and muck. The accumulated hydrogen sulfide exerts a toxic affect upon the roots of the trees and is, at least partially, responsible for the development of superficial root systems.

(e) Iron Bacteria

A number of bacterial forms, (Crenothrix, Leptothrix, Gallionella) derive their energy from the oxidation of ferrous iron, thereby converting it into the difficultly-soluble ferric precipitate. This process may play a certain part in the development of iron-rich horizons of forest soils, especially the ortstein in podzols.

Aside from the activity of the iron bacteria proper, a number of other bacteria may cause development of a hardpan or bog-ore by using the organic fraction of soluble iron humates and leaving iron hydroxide as a residue.

Attached drawings, adapted from standard microbiological texts, give a general idea of the more important forms of soil bacteria and other soil organisms.

Fungi

Fungi are multicellular chlorophyll-free lower plants deriving their energy from decomposition of organic matter. They occur in soil either as free molds or as symbiotic fungi forming mycorrhiza on the roots of higher plants. Both of these groups include minute forms with microscopic filaments as well as the higher mushroom fungi.
Fungi tend to dominate raw organic remains, such as the litter and duff horizons of forest soils. At the same time, they are strongly influenced by the supply of available nutrients in striking contrast to bacteria, which are more dependent upon organic matter than mineral salts. Many of the fungi can withstand a greater acidity than bacteria and occur in great numbers in acid forest soils. The number of fungi increases with soil moisture content, provided there is adequate aeration. Although the greatest density of fungal population is found in the upper few inches, fungi occur more or less uniformly distributed in the soil profile to a depth of 4 or 5 feet. Fungi in greater or lesser quantity occur throughout the entire range of soil conditions suitable to forest growth. Aspergillus, Botrytis, Fusarium, Monilia, Mucor, Oidium, Penicillium, Phytophthora, Pythium, Rhizoctonia, Rhizopus, Sclerotium, Trichoderma, Verticillium, Zygorhynchus, Armillaria, Amanita, Boletus, Cortinarius, Merulius, Phoma, and Russula are the most common genera found in soils.

The role of fungi in soils, especially in forest soils, cannot be over-emphasized. Fungi are greatly responsible for the decomposition of proteins, cellulose and most of the other carbohydrates.

Under ordinary conditions, the activity of fungi proceeds very efficiently with comparatively little consumption of energy materials and results in the accumulation of a highly nitrogenous residue of fungal mycelia.

The accumulation of large quantities of available nitrogen takes place, because the fungi consume primarily the carbohydrate fraction of the protein compounds and release ammonia as a waste product. In some instances, however, fungi temporarily remove the soluble nitrogen compounds and other mineral nutrients as do bacteria. They release them only after the source of energy i.e. carbohydrate fraction is exhausted and the dead mycelia are decomposed. While the inhibition of nitrogen may have a temporary depressing effect upon the seedlings, it preserves the soluble nitrate and ammonia compounds from leaching by rain or artificial watering.

Fungi may modify considerably the reaction of soil by the liberation or consumption of organic acids and by the formation of ammonia. In some instances they benefit the growth of trees by liberated carbon dioxide. The fixation of atmospheric nitrogen and the possible conversion of difficultly-soluble compounds into available form by mycorrhizal fungi, has an especial significance in the growth of trees and is discussed at length separately.

Some of the fungi do not draw an exact line between the dead and alive organic matter and cause the destruction of tissue of seedlings and older trees. The so-called "damping-off" fungi, Rhizoctonia, Pythium, Fusarium, Phytophthora and a few other genera, attack forest seedlings shortly after germination and are frequently responsible for great losses of nursery stock. In close relation to damping-off forms are root-rot fungi which cause the decay of the older seedlings and transplants. Among the fungi attacking the roots of older trees, black shoestring fungus,
Armillaria mellea, and some members of the Polyporaceae, have the most wide and the saddest reputation in both American and European forestry practice.

**Mycorrhizae**

The roots of forest trees, especially conifers, are often invaded with fungi searching for an available supply of synthesized carbohydrates. The penetration of mycelium, however, is in most instances arrested by the live root either in epidermal cells or in the inner parts of the root. The intrusion of hyphae causes certain differentiation and rearrangement of root tissue and results in the development of permanent root-fungus growths, referred to as mycorrhizae. The mycorrhiza is classified as "ectotrophic" or "endotrophic" depending upon whether the hyphae penetrate only the epidermis or the deeper cortical cells of the root.

In the majority of cases a mycorrhiza is a symbiotic association in which the fungus derives carbohydrates from the root and in exchange supplies the tree with nutrients, particularly nitrogen. The nitrogen supply is accumulated by fungus either through the decomposition of soil organic matter or possibly by fixation from the atmosphere. The root may receive the soluble nitrogen as by-product of fungus metabolism, or may obtain it by digesting the fungus tissue. Since the formation of mycorrhizae often leads to the complete degeneration of root hairs, the entire intake of water and mineral salts may be accomplished via fungal hyphae or the fungal mantle. This in turn may enable trees to utilize difficultly-soluble phosphates, potash, and other nutrients occurring in soil in the form of unweathered minerals.

Mycorrhizae are formed chiefly by Hymenomycetes, such as Boletus, Amena, Tricholoma, Lactarius, Cortinarius and Russula, and are confined chiefly to acid soils, poor in nutrients. On soils having a fairly high amount of soluble salts, or a reaction higher than pH 6.0, true mycorrhizal fungi degenerate and may be replaced by so-called "pseudo-mycorrhizae", produced by Fuscor, Verticillium, and other common soil fungi. Some of the mycorrhizal fungi, like Boletus, invade only a few certain tree species, whereas others, for example Amanita, may associate with a wide variety of tree genera.

The occurrence of mycorrhizae on roots of forest trees, namely on pine, chestnut and hazelnut was first revealed as early as 1856 by Gasparini. Since that date mycorrhizae have been detected on the majority of forest trees, shrubs, and ground cover plants by Frank, Müller, Gibelli, Roess, Vyssotzky, Sarrauw, Stahl, and others. The most recent studies of this problem were made by Melin in Sweden and Hatch in the United States.

Although the theories advanced by different writers are somewhat contradictory, there is enough factual evidence to consider mycorrhizae as non-pathological developments, often essential for the normal nutrition of forest trees. Particularly convincing evidence of this has been obtained from the observation of the tree growth on drained peat soils in Sweden. In such localities the seedlings lacking mycorrhizae showed symptoms of nitrogen starvation and eventually died, while seedlings infected with mycorrhizal fungi grew successfully. Nursery failures in
Australia have been traced to the lack of mycorrhizal fungi, as satisfactory growth of seedlings was obtained by the importation of soil infected with the proper organisms. Likewise, it was recently reported that seedbed inoculations have saved a new nursery from abandonment in Southern Rhodesia. All successful plantations of introduced pine in the Philippines are known to have an abundant infection of mycorrhizal fungi. A striking illustration of mycorrhizal importance has presented itself recently in the U. S. Forest Service Nursery at Licking, Missouri where the growth of shortleaf pine seedlings appears to be ultimately dependent upon the infection of roots with fungi.

The development of mycorrhizae often is associated with the shortening of roots and their branching in a fork-like fashion. In extreme cases, this condition may materially decrease the resistance of nursery stock to drought, and may have to be counteracted by an application of phosphate fertilizers.

**Actinomycetes**

Actinomycetes are generally classed as fungi although they exhibit characteristics of both fungi and bacteria. The body of these organisms consists of mycelia with branching non-septate hyphae similar to those of higher fungi. The mycelium is brightly colored and is easily broken into short rods resembling bacteria. Most species produce a typical earthy odor of fresh soil.

Actinomycetes occur primarily in forest soils where their main function is the decomposition of lignin-like substances. These substances are resistant to the activity of all the other soil organisms.

In contrast with fungi, actinomycetes are very sensitive to acidity, and disappear almost completely in soils having a reaction of a pH 4.7 or lower. This may have a direct bearing upon the development of the highly ligneous duff layers of so-called "raw humus" forest soils. Some actinomycetes have the ability to reduce nitrates to nitrites and may be detrimental.

**Soil Algae**

Algae are chlorophyll-bearing organisms generally occurring in filaments or colonies.

The algal flora of the soil is confined to three groups: Cyanophyceae or blue-green algae; Chlorophyceae or green algae, and Bacillariaceae or rod-shaped diatoms.

Algae hasten the solubility of minerals, particularly carbonates, and thus aid in processes of weathering. Being capable of photosynthesis, they utilize carbon dioxide and increase the content of soil organic matter. It is very likely that algae in symbiosis with bacteria promote the fixation of atmospheric nitrogen. A noticeable increase in growth of spruce and pine seedlings in nitrogen-free quartz cultures was observed when algae were allowed to accumulate on the soil surface for a period of 3 years. Lichens which are a symbiotic association of algae and fungi are of great importance in initiating plant
succession and development of soil on unweathered rocks and other barren soil parent materials.

Because algae can be readily "invited to life" by an addition of small amounts of mineral salts, several attempts were made to cultivate them in natural ponds and artificial basins as a source of organic matter for humus-deficient forest nurseries. Slight improvement in growth of white spruce seedlings was noted when colloid-free sand cultures received an application of dried green algae grown in dilute solution of potassium phosphate. However, no positive results were reported thus far in regard to large scale applications.

It is possible that the growth of the higher plants on poorly-drained soils is benefited by the oxygen given off by the algae.

**Protozoa**

Protozoa are one-celled animals, varying in size from a few microns to several centimeters with protoplasm either naked or enclosed in a membrane and containing one or more nuclei.

Soil-inhabiting protozoa are classified into three groups according to their organs of mobility. Sarcina - moving by means of pseudopoda or temporary extensions of the body; Flagellata - provided with one or more permanent flexible whip-like flagella; Ciliata - with numerous short hair-like cilia confined to certain parts of the body or covering the entire organism.

Protozoa participate in the decomposition of organic remains, serve as a source of energy for other soil organisms, and destroy certain parasitic, as well as useful organisms, particularly bacteria. In recent times, a theory has been advanced that protozoa materially decrease the fertility of agricultural soils, or even cause a so-called "soil sickness" by feeding on ammonia and nitrate-forming bacteria. Such a condition may be expected in over-watered heavy nursery soils high in organic matter, i.e. a medium favoring the multiplication of protozoa.

Since protozoa are less resistant to heat than bacteria, a method of partial sterilization was advanced as a means of increasing soil fertility. However, this has not found an application in nursery practice. In several instances partial sterilization promoted the development of parasitic fungi, presumably due to the destruction of hyperparasites.

**Rotifers**

Rotifera, or "wheel animals", are minute animals deriving their name from a ciliated corona at the anterior end of an elongated body. The corona serves for locomotion and obtaining food.

Rotifera occur primarily in poorly-drained soils. Humification is the only function thus far ascribed to these organisms.
Nematodes

Nematodes are transparent, non-segmented, spindle-shaped, worm-like organisms. The soil-inhabiting forms are microscopic or nearly microscopic in size. They occur in great numbers in the humic horizons of forest soils and include parasitic, saprophytic and free-living species (Tylenchus, Iota, Mononchus, Rhabditis and Alaimus).

Nematodes play an important role in decomposition of organic matter and improve soil aeration. They consume bacteria, fungi, protozoa, and other nematodes and may be either injurious or beneficial depending upon the nature of destroyed organisms. By distributing parasitic fungi throughout nursery soil they may increase the extent of damping-off disease. Recent evidence from Wisconsin and New Zealand has shown that some of the nematode species (Rhabditis) invade the tissue of live coniferous seedlings, producing the same effect as damping-off disease, or at least completing the destructive work of fungi.

Earthworms

The worms inhabiting soil include chiefly the members of two families: Oligochaeta-Terricolae, having segmented bodies with four rows of bristles, and Oligochaeta-Limicolae, characterized by whitish color and presence of more than two straight bristles in some of the bundles. Lumbricus, Allolobophora, Eisenia, Helodrillus, Enchytraeus, Fredericia and Anachaea are the most important species.

With very few exceptions, the occurrence of earthworms is confined to moist soils rich in organic matter and of moderately acid reaction. Loam and silt loam soils, high in bases and supporting hardwood stands, often have especially abundant earthworm population and are sometimes referred to as "earthworm mull soils." The number of specimens per acre in such soils according to Wisconsin studies varies from 500,000 to 1,000,000 per acre.

Earthworms drag fallen leaves into their burrows and use them either as litter or food, thus preventing the accumulation of duff. In the process of nutrition they pass great quantities of soil and organic remains through their bodies, thereby promoting humification and the incorporation of humus with mineral soil. As a result, the upper layer of soil attains a typical crumbly structure which increases aeration, diminishes runoff, and to some extent facilitates the root penetration of germinating plants.

Undoubtedly the activity of earthworms has considerable beneficial influence upon the productivity of soils, as was originally stressed by Darwin in his work "Vegetable Mould and Earthworms." However, the presence of earthworms in forest soil is not always an indication of high soil productivity. Very often the abundant population of earthworms is found in soils with a high ground water level, where the growth stagnates due to deficient aeration of the deeper soil layers.
Mollusca

The mollusc population of soil is limited to snails and slugs. These moisture-loving forms occur predominantly in heavy soils with a fairly high ground water level. Both vegetarian and carnivorous mollusces feed largely upon the surface whenever the ground is wet. Their waste products make a certain contribution to the content of soil humus.

Arachinda

Soil-inhabiting Arachinda include mites, ticks, and spiders. They are as a rule confined to the upper one-inch layer. In well-humified mull soils the total number of arachinda may reach several hundred thousands per acre. Being primarily carnivorous, arachinda play certain role in the maintenance of biological equilibrium of the soil population and to some extent contribute to the processes of humification. Recently claims were made that mites are responsible for the injury of young seedlings.

Insects

A great majority of insects spend a certain portion of their life cycle in the soil, and the total insect population of forest soil per acre may be estimated in terms of millions. Some of the insects feed on root systems (Helolontha) or on soil organisms (Carabidae), while others live saprophytically (Colembola) or simply use soil as a shelter (Formicidae). Finally, some insects occur in soil only in the pupal stage (Lepidoptera).

The insects benefit forest soils by addition of organic matter, its humification and improvement of soil structure. Certain forms (Ichneumonidae and Eracnidae) destroy cutworms and other parasitic organisms. Among the injurious insects, the white grub, wireworms, cutworms and root borers are of greatest importance. The first two destroy the roots of seedlings and transplants, whereas the latter cut the stems of young plants near the ground and feed upon the exuding sap.

In some tropical forests termites act as a particularly outstanding soil factor by decomposing vast amounts of dead and living plants and by greatly increasing the soil porosity with their numerous passages.

References

(1) France, R. H. 1921. Das Edaphon, Stuttgart.
Representative forms of soil organisms. Bacteria (x 700): (a) Nitrosomonas; (b) Nitrobacter; (c) Azotobacter; (d) Clostridium; (e) Rhizobium; (f) Bac. cellulose; (g) Bact. vulgare; (h) Pogostepex; (i) Gallionella ferruginea. Fungi: (j) Rhizopus (x 40); (k) Mucor; (l) Trichoderma (x 250); (m) Penicillium (x 600); (n) Actinomycetes. Algae: (o) Pleurococcus; (p) Phormidium; (q) Nodularia; (r) Anabaena; (s) Chlamidomonas (x 1000); (t) Diatoms (x 1000). Protozoa (x 800): (u) Amoeba; (v) Ciliate; (w) Flagellates. (x) Nematodes (x 100).
Selected References