SOIL BIOTA

Chernov Ivan Yu
Lomonosov Moscow State University, Faculty of Soil Science, Moscow, Russia

Keywords: Soil, Biota, Biodiversity, Microorganisms, Bacteria, Fungi, Soil Animals, Soil-forming Processes.

Contents

Summary

This chapter describes specific features of the soil biodiversity. Characteristics of main groups of organisms, inhabiting soil, are presented: plants, soil animals and microorganisms. Features of soil as a habitat and different ways of adaptation of animals for life in a soil are discussed. Main processes of transformation of substances in soils and processes of the soil formation resulting from vital functions of the soil organisms are presented.

1. Introduction

When we say a “soil” we mean, first of all, that this is a natural body is able to support growth of plants, unlike rocks, grounds and deep mineral layers. This property of soils is called “fertility”. It is just the soil fertility that is one of the most important (vital) conditions of existence and prosperity of the mankind. But not all people clearly understand that the fertility is formed as a result of vital functions of organisms inhabiting soil that is the soil biota. Reasonable agricultural use of soils is not possible under conditions of the present-day civilization without knowledge of laws, which govern functioning of soil organisms. Studies of number of prominent natural scientists, such as M. Beikerink (Fig. 1), S.N. Vinogradsky (Fig. 2), S. Waksman, N.A. Krasil’nikov, E.N. Mishustin, M.S. Gilyarov, in XIX and XX centuries the soil biology was formed as a rather independent science which object of studies is the soil biota. In the last time, pragmatic importance of the soil biology essentially increased in connection with intensification of agriculture and pollution of the biosphere.

Like any developed and independent science, the soil biology is subdivided into sections those reflect the immanent structure of our knowledge about its subject, i.e. soil organisms. As such natural sections of the soil biology it is meaningful to consider the following: 1) the soil biodiversity, information about quantity, composition and structure of soil communities; 2) notion of the soil as habitat for organisms, revealing of specific features of this medium (influence of soil on living organisms); 3) study of processes of transformation of substances in soil, processes of the soil formation resulting from vital activity of soil organisms (influence of the organisms on soil).

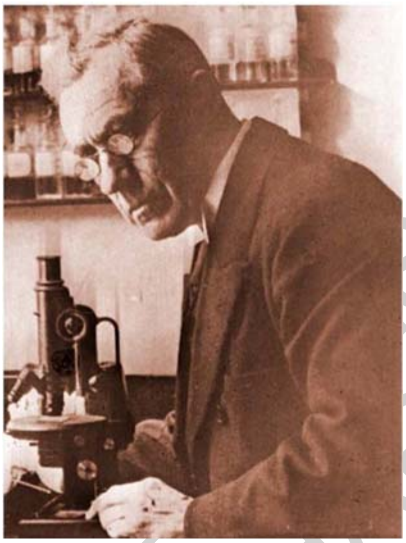

Figure 1. M.V. Beikerink (1851-1931). Holland microbiologist. One of founders of the soil and ecologic microbiology, discoverer of the symbiotic nitrogen-fixation (nodule bacteria). He had developed a method of accumulative cultures and established role of microorganisms in creation of a soil fertility.

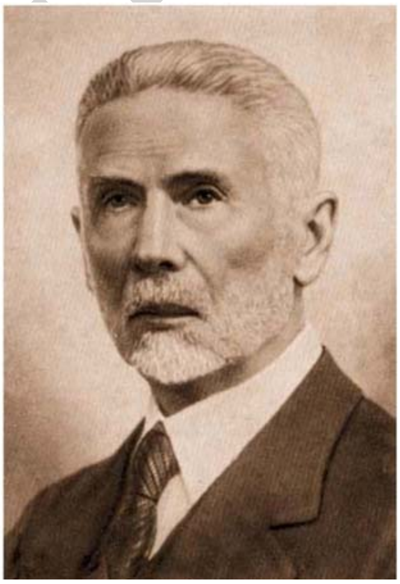

Figure 2. S.N. Vinogradsky (1856-1953). Outstanding Russian microbiologist, founder of ecology of microorganisms and the soil microbiology.

2. Biogenecity of Soil

What is a total quantity of "living matter" in the soil? It happened to be difficult to find correct answer to this question. It is relatively easy to calculate quantity and biomass of large animals in the soil, such as earthworms, or a total quantity of large roots of plants. But estimating of total quantity of soil microorganisms turned out to be extremely complicated problem as regards the methodic procedures. A large set of methods is used for this in the soil microbiology, such as methods of limiting dilution, a sowing onto dense nutritious media, direct microscopic analysis of soil by means of light or electronic microscope, measuring of different concentrations of substances which are components of microbe cells or their metabolites. But, different methods produce different results, so for the same soil they can be principally different.

One of the most important steps in development of soil microbiology became using of various modern microscope methods for observation. They had shown that quantity of bacterial cells in soil is immense and run into milliards in 1 gram. The total length of a fungal mycelium in one gram of fertile soil is close to hundreds of meter and kilometers. Total quantity of microorganisms serves as indicator of the soil fertility. The highest quantity of microorganisms is typical for the most fertile soil, such as chernozems.

Biogenecity of almost all soil types regularly decreases with a depth. As a rule, distribution of microorganisms along a soil profile corresponds to a content of organic matter: their greatest number is found in upper organogenic horizons. However, there are some exceptions to this rule. Under strong summer desiccation of soil the maximum of the number can be found at some depth where moisture is still retained. High number of microorganisms can be found in buried humus horizons or in above-permafrost horizons of the tundra soils.

3. Soil as a Habitat

According a certain number of its ecologic features, soil is a medium, which is intermediate between water and surface ones. Soil is similar to the water medium by its temperature regime, reduced content of oxygen, saturation of soil air by water vapors, and presence of salts and organic substances in the soil solutions. And, it is similar to the air medium by presence of the soil air, a threat of desiccation in upper horizons, rather sharp temperature changes in upper layers. Nevertheless, there is no doubt that it is expedient to consider the soil as absolutely independent habitat.

For large organisms, living in soil, such as earthworms or larvae of many insects, soil appears to be a fully integral medium. One of the most limiting factors that is met by large soil animals is the soil density. It is precisely a necessity to move in such a dense medium lead to formation of specific typical appearance of these animals-pedobionts. Concrete adapting mechanisms of the pedobionts are different depending on a "chosen" strategy of moving. Some animals can move along thin cracks, pore spaces or chinks. In such cases they have a flexible worm-shaped body. For example, earthworms, pot worms, millipedes, and larvae of many insects. Others use active digging mechanism of moving, thus not only widening natural chinks, but also making in soil new runs and passages. Larvae of many insects use for this purpose the front end of the head with more dense covers, mandibles or front modified limbs. At the back ends of the digging animal bodies special organs are developed. They are like cods or hooks serving for reliable fixation. By a totality of such organs typical pedobiont forms of animals are easily identified and they differ from inhabitants of other media, i.e. hydrobionts or aerobionts.

Other situation takes place when the smallest inhabitants of soil are considered those are bacteria, microscopic fungi, and one-celled protists. When one investigates microorganisms extracted from any soil, their diversity is striking, but herewith the main feature is that they often have opposite properties those seem to be incompatible for the same habitat. From the same soil sample it is possible to extract the following opposite organisms: heterotrophes and autotrophies, aerobes and anaerobes, oligotrophes and copiotrophes, saccharolytics and hydrolytics, psychrophiles and thermophiles, acidophiles and alcalophiles, as well as microbes, forming antibiotics, and species, sensitive to them. All this allows coming to conclusion that for the microorganisms soil is not a unified habitat. It is more correct to consider the soil as a system, consisting of a multitude of loci or micro-habitats with quite different conditions. A multitude of such micro-habitats can occur in each gram of soil, i.e. in each soil aggregate. The exceptional heterogeneity is the most characteristic property of soil as the habitat for microorganisms (Fig. 3).

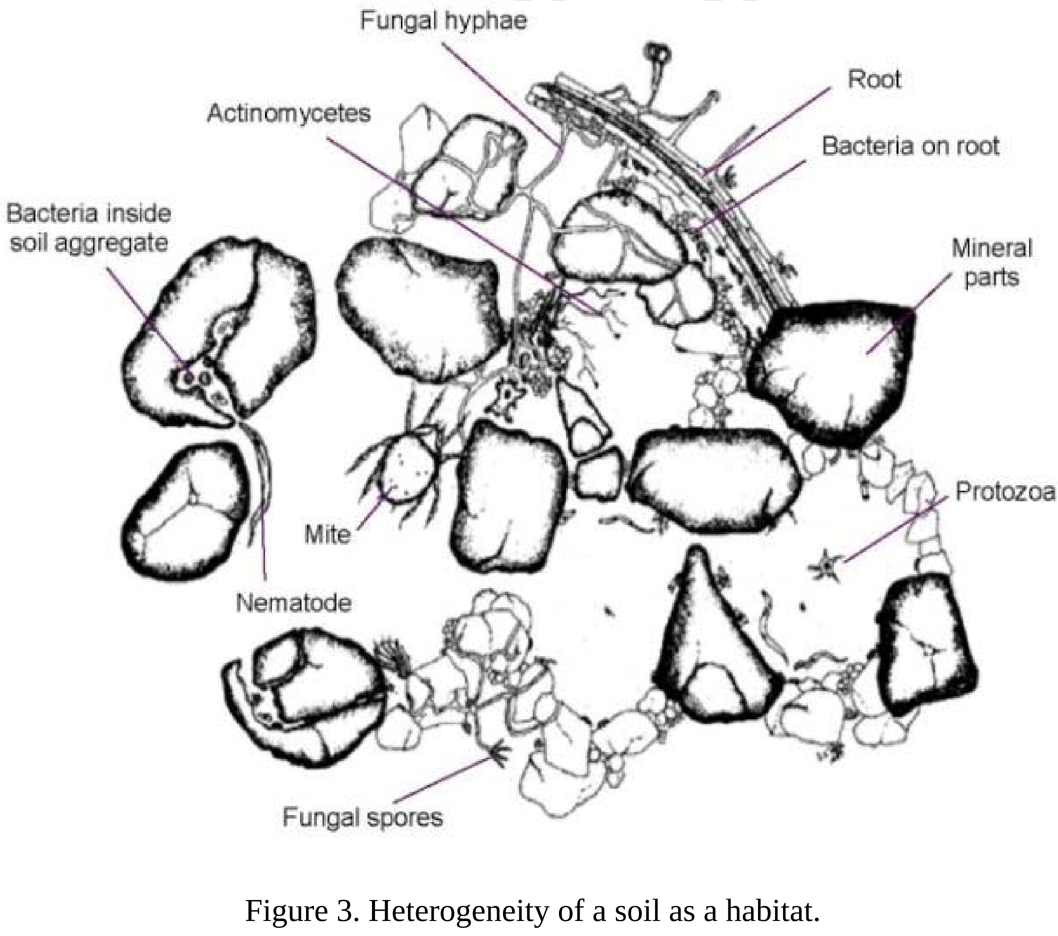

Figure 3. Heterogeneity of a soil as a habitat.

One of important results of this property is that very many microorganisms, entering a soil, can, in principle, find there micro-zones with suitable conditions and, thus, for a long time can remain in viable state. That is why microorganisms, closely connected with quite other types of habitats, are permanently found in soil. For example, epiphytic bacteria and fungi, adapted to growth on surfaces of leaves of plants are usual in soil as well as pathogen bacteria and components of normal micro-flora of animals and man, such as cholera vibrios or coliforms.

Nevertheless, we may say about some general ecological factors, which are important for existing of, at least, majority of microorganisms living in soils. One of those is presence of a boundary, separating solid and liquid phases. In such fine-dispersible media as a soil, specific surface of the phase separation is immense. It had been shown that the most part of microbe populations grow namely on the phase separation line, being at the same time in adhesive state. In such conditions physiologic state of a cell and accessibility of nutritious substances can be strongly changed. This arises one of the most important and still open questions in the soil biology, that is a necessity to understand how much properties of species of microorganisms, which, as a rule, are studied in pure laboratory cultures, correspond to the properties, which are demonstrated by the microorganisms when they live in soil. Adsorption of microorganisms on solid soil particles makes methodic difficulties of accounting them. Much attention is given in the soil microbiology to methods of preparation of a sample for analysis, desorption of the microorganisms and preparation of their water suspension.

Another factor, which in one or another way exerts influence on the most part of the microorganisms inhabiting mineral soil horizons, is a scanty content of easily accessible sources of nutrition. On the average, concentration of free sugars or organic acids is very small in deep soil horizons. But it can essentially increase in individual microlocuses owing to income of the vegetation debris or a death of soil animals. Organic substance is mainly contained in form of high-condensed polymers, among them the humic acids are the most difficult of access for utilization specific substances of the soil humus. It is often possible to reveal those or other adaptations of typical pedobiont microorganisms for existence under such conditions of a nutrition deficiency. Ways of adaptation can be different: development of strong hydrolytic enzymatic systems, including also specific humus compounds; allowing utilization of inaccessible compounds, accumulation of spare substances by cells, oligotrophy, and extremely efficient metabolism.

From ecological viewpoint the soil biologists separate all microorganisms, being revealed in soil, into two groups: allochthonous and autochthonous ones. The first ones are introduced into soil from other habitats, especially from surfaces of plants. The second ones (group of microorganisms) are true inhabitants of the mineral soil horizons, which have here their whole life cycle.

The direct microscopic studies have shown that, in spite of immense quantity of microorganisms, being contained in soil (billions of cells in gram), the microbe cells are, as a rule, collected into micro-colonies, divided by empty spaces, which exceed spaces, occupied by the microorganisms, in thousands times. In other words, one can often find in soil pure cultures of the microorganisms.

4. Soil Biota

Representatives of all kingdoms of living Nature inhabit the soil. Those are underground parts of plants, different animals, algae and protozoans, many species of fungi and bacteria. Especially great are importance and diversity of soil microorganisms, i.e. microscopic fungi and bacteria. The lists of species of microorganisms, about which we know that they are permanent inhabitants of soil, was steadily extended during the last century and still continue to be extended in present time. On one hand, it is connected with progress of biological systematics and this reflects increase of knowledge about biodiversity in general. But, at the same time, the soil biologists master new methods of observations of the soil organisms, which make possible to reveal more and more new, earlier unknown forms of life. Methodic problems are especially important in the soil microbiology. So far it was not possible to find and describe all microorganisms inhabiting soils. The main method to investigate the multiformity of the soil microorganisms was an extraction of them in form of pure cultures by means of inoculation of medium. Because of selectivity of any nutritive medium this method allows taking into account only a very small part of organisms inhabiting soils. But during the last years a certain number of specialists express very skeptical estimates of abilities of the traditional methods of the soil microorganisms. It is supposed that not more than 1-5% of the whole diversity of the soil bacteria is known. It is connected with that presently quite new approaches are developed in the microbiology to estimation of the microbe diversity of soil. First of all, those are molecular-biologic methods aimed at analysis of heterogeneity of total soil DNA. Using of DNA-sondes, marked by fluorochrom, i.e. short segments of DNA, containing nucleotide succession, unique for individual species of bacteria, makes it possible to measure quantity of these species directly in soil. These methods are very prospective for future development of our notions about the soil biodiversity, and there is no doubt they will make a basis for soil-microbiologic researches in the nearest future.

Below we consider composition of the soil biota by groups in order of their ecological importance in the biological circulation from producers to destructors.

4.1. Higher Plants

Thickness of any soil is penetrated with roots of plants. In upper horizons of the most fertile soils, which are not ploughed up, a part of roots can amount to 20% of the soil volume (Fig. 4). Root systems of plants exert influence on physical and chemical properties of soil and its biological activity. They change structure of soils, influence upon aeration, take part in the mineral decomposition, and provide microorganisms with sources of organic nutrition. One of the most important and still not completely studied problems of soil microbiology is quantity and chemical composition of secretions of the plant roots. It is precisely the intravital secretions of roots determine intensity of the microorganism developments in the root zone of the plants, often stimulating their development and causing the so called rhizospheric effect.

Figure 4. Distribution of root systems of plants in a soil.

4.2. Algae

However the most part of algae exists in the water media, life of many of them is closely connected with soil. There are ground forms of algae, which create films on soil surfaces (Fig. 5). Those are water-ground algae, living in a water phase of waterlogged soils, and properly soil ones, inhabiting a soil thickness (Fig. 6). Soil algae have a number of ecological features, allowing their life in this media. These features are as follows: abundant formation of mucus, providing absorption and retention of water; small sizes allowing their movements in soil; ability of quick transition from a latent state to active vegetation. Many soil algae have no zoospores, typical for aquatic species.

Figure 5. Algae of genus *Botrydium* on a soil surface.

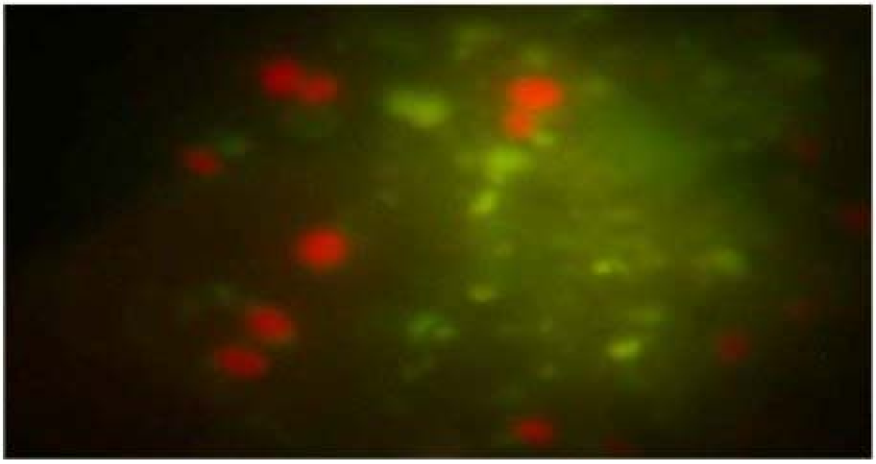

Figure 6. Soil algae in the luminescent microscope – chlorophyll illuminates red light.

Number and biomass of algae greatly varies in different soils, first of all, in dependence on humidity and illumination. Annual production of soil algae varies in different types of soils from 50 to 1500 kg/hectare. Especially great role of the algae takes place on surfaces of primitive soils, for instance, of volcanic ashes where they are very first “settlers”, starting a soil-forming process. Almost all algae are autotrophic, i.e. able for photosynthesis. That is why the main algae function in soils is accumulation of organic substances. However, in deep soil horizons where no solar light comes some algae are capable to switch to the heterotrophic type of nutrition. By their taxonomic composition the soil algae are rather specific. Diversity of algae in soils is much smaller than that in water basins. Many large taxonomic groups of algae are never found in soil. On other hand, there are specialized species of algae, which occur only in soil. Total number of the algae species, found in soils, are close to 1500. Among them, the most widely presented species are green (about 500), diatomaceous (about 300), and yellow-green (more 150) ones. Rarely found species are representatives of *Euglenoidina* and *Pyrophyte*, and almost absent ones are red algae.

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Biographical Sketch

Ivan Yu. Chernov, Dr.Sc., professor, corresponding member of Russian Academy of Sciences (RAS) was born in 1959 in Moscow (Soviet Union). In 1981, he had been graduated from the Lomonosov Moscow State University as a pedologist. A citizen of Russia, he is now one of leading Russian scientists in the field of soil microbiology. PhD (1984) thesis is “Ecology of yeast fungi in tundras of the Taimyr Peninsula”, and the Doctor one (2000) is “Synecology and geography of soil yeasts”. Areas of his studies are: regularities of geographical distributions of microorganisms, biology and ecology of yeast fungi, and taxonomy of yeasts. In 1985-1989, he worked in Moscow Technological Institute of Food Industry, in 1989-1996 – in the Institute of Geography of RAS, and in 1996-2000 he is leading scientist of Institute of Soil Sciences of the Lomonosov Moscow State University. Since 2000 he works at the Department of Soil Biology of Faculty of Soil Science of the Lomonosov Moscow State University. Since 2009 he is Head of the Chair of soil biology He is Chairman of the Soil Biology Commitee of the Dokuchaev Soil Science Society. He is the author of over 100 scientific articles, monographs, inventions and discoveries.