INTRODUCTION

The scientific basis of soil science as a natural science was established by the classical works of Dokuchaev. Previously, soil had been considered a product of physicochemical transformations of rocks, a dead substrate from which plants derive nutritious mineral elements. Soil and bedrock were in fact equated.

Dokuchaev considers the soil as a natural body having its own genesis and its own history of development, a body with complex and multiform processes taking place within it. The soil is considered as different from bedrock. The latter becomes soil under the influence of a series of soil-forming factors--climate, vegetation, country, relief and age. According to him, soil should be called the "daily" or outward horizons of rocks regardless of the type; they are changed naturally by the common effect of water, air and various kinds of living and dead organisms.

The outstanding soil-science specialist, P.A. Kostychev (1892), in developing the theory of soil, attaches special importance to biological factors. He considers the soil as a botanist and not as a geologist. On the question of the origin of the chernozem, Kostychev attributes the most essential role to plants and microbes. He writes that chernozem formation is involved with the geography and physiology of higher plants as well as that of lower ones which perform the decomposition of organic matter. The accumulation of soil humus depends on the intensity and completeness of the decomposition of plant residues, the roots and the parts which are above the ground. In these processes Kostychev identifies the most important role with microscopic creatures--fungi and bacteria. Being an excellent microbiologist he carried out interesting experiments on the decomposition of organic matter and the formation of humus. The experiments showed that in different cases the decay of plant residues began in a different way. Sometimes bacteria inhabit decaying matter first, and sometimes fungi emerge first. Various parts of the same decaying matter decompose differently, in one part one organism multiplies and near it an entirely different organism may be found. It is further pointed out that various forms of decomposition change consecutively according to changes in the properties of the decaying substance.

Kostychev (1889) for the first time established that humus is formed by soil fungi, Moreover, the discovery of the regularity of the relationship between carbon and nitrogen (C:N) in soil and of its importance in the development of plants and microbes must be attributed to him. Kostychev revealed the essence of the enrichment of soil humus by nitrogen. During the process of the decomposition of plant residues, which are known to contain no more than 1.5-2% nitrogen, humus with 4-5% of nitrogen is obtained. This transformation of organic matter as may be seen from Kostychev’s data occurs with the aid of microorganisms (see Kostychev, 1951).

With his works Kostychev laid the foundation of soil microbiology. He also outlined a vast program of investigations, the problems of which are at present being solved by Soviet microbiologists.

Vernadskii (1927), who expounded the theory of "bio-inert" natural bodies, wrote that the entire soil is a characteristic "bio-inert" body. All physicochemical properties of the soil would appear considerably different if the living substance in it were not taken into account. In this way Vernadskii formulated the dependence of the fundamental property of soil upon the organisms lodged in it.

Vil'yams (Russian soil scientist (1863-1939) whose name is thus spelled when translated from the Russian, though it may appear as Williams in foreign publications) developing the teachings of Dokuchaev and Kostychev introduced many new principal elements into the science of soil.

He considers the soil a natural body and a means of agricultural production, and attributes to it the new qualitative property of fertility i.e. the ability to produce plant crops. According to him, the notion of soil and its fertility are inseparable. He considers fertility an essential property, a qualitative indication of soil independent of the degree of its quantitative expression. We oppose the idea of fertile soil to the idea of sterile stone, in other words to the notion of massive rock (Vil'yams, 1949).

It must be noted, that rocks also possess fertility to some degree. Investigations show that even the hardest rock massifs are inhabited by various organisms. Lichens develop on their surfaces and often cover large spaces on mountain tops. The upper layer of rock massifs, the so-called weathering crust, is saturated with bacteria and algae, as well as fungi, actinomycetes, protozoa and other organisms. According to our data, in the upper layer of basalt rocks, the bacteria in one grain of substrate number from some tens of thousands to millions. Similar data are also given by other investigators (Novogrudskii, 1950; Glazovskaya, 1950; Parfenova, 1955; Krasil'nikov, 1949 and others).

Rocks differ in their fertility. Some of them are densely overgrown with lichens and microorganisms, others are sparsely covered. There are rocks, or more properly parts of one and the same rock, which are not overgrown with lichens, but contain only certain microbial forms--bacteria, actinomycetes and fungi (Krasil'nikov, 1949b).

Even under arctic conditions, on the islands of the northern Arctic Ocean (Franz Josef Land, Novaya Zemlya, Severnaya Zemlya and other areas) rocks and loose calcareous soils contain a considerable number of microorganisms. Tens of thousands to hundreds of millions were counted in one gram. Moreover, these organisms live actively and carry out biochemical and chemical transformations (Krasil'nikov and Artarnonova, 1958).

In order to study the properties which determine the crop capacity of soil and to increase the soil's fertility by exercising an influence on it, "it is first of all necessary to know these properties, to enumerate them, and to choose from the large number of properties and qualities of soil just those which determine the capacity of soil to produce the products necessary for mankind" (Vil'yams, 1949, p 138). Consequently, Vil'yams inseparably related the theory of soil with the theory of its fertility and its crop capacity.

The principal property of the soil fertility is determined by biological factors, mainly by microorganisms. The development of life in soil endows it with the property of fertility. "The notion of soil is inseparable from the notion of the development of living organisms in it". Soil is created by microorganisms. "Were this life dead or stopped, the former soil would become an object of geology" (Vil’yams, 1950, p 204). Kostychev and Vil'yams transferred the science of soil from the chapter of geology to the chapter of biology.

The new understanding of the biological essence of the soil-creating processes, which was established by Kostychev and Vil'yams, has given the majority of Soviet microbiologists the principal leading landmarks in their investigations. Microbiology also contributed

considerably to the development of this new direction in the science of soil, successfully solving many essential questions of soil fertility.

During the last two decades, microbiology has shown that life processes taking place in soil, were larger and deeper than it had been assumed earlier. Whereas earlier, hundreds of thousands and millions of microbial cells were counted in one gram of soil, at present, with more improved methods of investigation, hundreds of millions and billions are determined. The total bacterial mass on one hectare of the surface layer of fertile soils amounts to five to seven tons. This mass is composed of single cells which live, develop and multiply.

Along with bacteria, a very large number of fungi, actinomycetes, algae, ultramicrobes, phages, protozoa, insects, worms and other living creatures, inhabit the soil. Fungi and actinomycetes are counted in hundreds of thousands and millions in one gram, algae--in thousands and tens of thousands. Quite often their number even amounts to a hundred thousand in one gram of soil. The total mass of these organisms in the upper surface layer of the soil may amount to two-three tons in one hectare.

Analyses show that there is in the soil a great number of phages--actinophages and bacteriophages, which have very intense activity.

No less important is the soil fauna. According to different authors, amoebae, ciliata, and other protozoa are numbered in tens and hundreds of thousands in one gram (Brodskii, 1935, Nikolyuk, 1949; Dogel', 1951). In one square meter of the surface layer of soil some tens to hundreds of larger invertebrates may be found--earth worms, myriapods, larvae of various beetles, etc. The population of small non-microscopic arthropods (ticks, Collembola, and others) is numbered in tens and hundreds of thousands in 1 m^2 of cultivated soil layer, and in forest soils their number often amounts to a million individuals.

The number of nematodes is sometimes counted in millions per 1 m^2. According to the counts of Gilyarov (1949, 1953), the total mass of this fauna comprises several tons (3-4) per hectare of soil.

As seen from the data cited, every particle of soil is saturated with living creatures. The enormous mass of these creatures is in a state of continuous activity during the whole vegetative period. Separate individuals or cells of simpler creatures multiply rapidly and attain astronomical numbers. In the process of life activity the whole soil population carries out work of cosmic importance. It transforms enormous masses of organic and mineral compounds, and continuously synthesizes new organic and inorganic substances.

Various active biocatalysts--metabolites of microbes and other living creatures are found in the soil, including enzymes, vitamins, auxins, antibiotics, toxins and many other compounds. All these substances together with living organisms lend particular properties to the soil, differentiating it from a geological body or a mineral rock.

The biogeny of soil is the most significant indicator of its fertility. As soon as the activity of a microbial population begins in a rock, the first signs of fertility are manifested. The degree of soil fertility is determined by the intensity of the life processes of the microbial population.

Quantitative manifestations of biological processes are diverse and depend upon climatic, and geographical or topographical conditions, as well as the seasons of the year and other external factors.

The knowledge of life in soil, investigation of biological and biochemical processes taking place in it, are inseparably connected with the knowledge of living organisms inhabiting the soil. Consequently, investigation of the microbial world of the soil is one of the basic problems of microbiology and agrobiology. The knowledge of biological processes, caused by the living population of the soil, should be one of the most important problems of pedology and agriculture.

This work deals with present knowledge of microorganisms, mainly of bacteria, actinomycetes and partly of fungi, inhabiting the soil, of their relationships with higher plants, of the importance of different groups and microbial species in the life of higher plants, and of the effect of metabolic products on growth and yield of agricultural crops.

It should be pointed out that in recent years, in the investigation of the problem of soil fertility more and more attention is paid to biological factors. A growing interest in microbial population is displayed by plant growers as well as by soil scientists. This is not surprising, since it is impossible to solve problems of pedology, not to speak of agriculture and plant growing, without taking into account the microflora of soil.

The importance of microorganisms in the life of plants, as shown by present data, is very great but still little investigated. A lesser influence on the development and life activity of microbes in the soil is manifested by plants.

The interaction of soil microorganisms with higher plants is very complex and multiform. The effect of the former on the latter may be positive or negative. Depending upon the plant cover on the same soil under equal external climatic conditions, the composition of the microflora changes sharply. Plants are a very strong ecological factor selecting certain species of bacteria, fungi, actinomycetes and other inhabitants of soil. As a result of wrong agricultural practices and crop rotation, the soil becomes infested with harmful microbial forms. By use of suitable plants in the crop rotation, one may change the microflora of soil in the desired direction, and eliminate harmful organisms, in other words--restore the health of soil.

The influence of soil microorganisms on growth and development of higher plants is of great diversity. The role of microbes is not by any means limited to the mineralization of substances in nature. At present, microorganisms should not be considered as only a link in the circulation of substances, as agents delivering sources of mineral nutrition to plants. Microorganisms of soil display a direct, very essential influence on plants, a positive or negative one depending upon the species and external conditions.

The positive role of symbiotic root-nodule bacteria, mycorrhizal fungi and others is well known though little investigated. Great attention is paid to free-living nitrogen-fixing organisms--*Azotobacter, Clostridium* and others. Fertilizers comprising bacteria and fungi are largely used (azotogen, nitrogen, silicogen, phosphorobacterin and others).

A large chapter of science is devoted to the biology of phytopathogenic bacteria and fungi.

Little investigated and elucidated is the role of the free-living microflora, particularly that which inhabits the root zone. Investigation of the rhizosphere microflora has begun comparatively recently. The data obtained show that its effect on plants to very considerable. Among the rhizosphere microflora there is a large number of species which affect the growth of plants with products of their metabolism. Some microbial species are active producers of various biotic substances vitamins, auxins, amino acids and other substances essential to the growth of plants. Other species are antagonists of phytopathogenic bacteria, fungi and protozoa. Microorganisms of these species strengthen the immunization properties of tissues, thus protecting the plants from infections.

Among the soil microflora there are many organisms which produce toxic substances and suppress the plants; they inhibit their growth and development. It must be assumed that there are in the soil other microbial forms, as yet unknown, exerting a positive or negative effect on plants.

Representatives of useful and harmful microflora inhabit the rhizosphere. Their quantitative ratio in various soils and under various conditions of treatment is different. Consequently, the total effect of the activity of the root zone microflora will not be the same. It may be positive or negative, depending on what microbial species predominates.

In this work the latest information on the importance of this microflora for plants is given.

It is evident that in investigations of the activity of soil microflora exact knowledge of its species composition is necessary, as are exact conceptions of the soil climate and the ecological conditions of its development and accumulation. At present investigations of soil biology in general and questions of interaction of microorganisms with higher plants in particular, cannot be resolved with a merely quantitative account of the general composition of the microbes. It is necessary to establish the degree of dissemination of the different species, to investigate their biology and specificity of interaction with the plant, and their interaction with other species of soil microflora. The latter should be an important problem of soil microbiology. Microbial antagonists represent an important ecological factor of development and formation of microbial associations in general and dissemination of individual species in particular.

It is important to point out that the determination of the microbial species and particularly of bacteria is very difficult. The similarity of structure and the lack of external marks of identification do not allow the investigator to recognize, immediately or precisely, the forms and species he is faced with in the analysis of soil or other natural substrate.

We shall not be able to reveal the specificity of the root-zone microflora until we learn to identify and differentiate bacterial species. Without this it is impossible to determine the specificity of biochemical transformations in soil, and, consequently, the site of its fertility is also indeterminable.