Clay Minerals as a Factor Influencing the Biochemical Activity of Soil Microorganisms

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ABSTRACT. The results of the study confirm the significance of clay minerals as a factor influencing the biochemical activity of soil microorganisms. The soil microflora is influenced both by the direct effect of clays on the microbial cells and indirectly, by their effect on the environment. The direct effect is projected into fundamental processes of the cycle of biogenic elements, including humification processes. The character and mechanism of the effect depend on the species of microorganism, on the quality and quantity of the mineral sorbents present in the soil and on other ecological factors. A further study will be carried out to investigate different aspects of the influence of clay minerals on the incidence, growth and biochemical activity of soil microorganisms.

The study of the influence of the environment on the composition and activity of the soil microbial population is one of the main tasks of the biochemical ecology of microorganisms. The biochemical ecology of soil microorganisms is largely concerned with biochemical aspects of their interrelationships with their environment and with biochemical relationships between microbial populations as manifested in the soil (Alexander, 1964, 1968). The environmental factors influencing the soil microflora are extremely complex and they include actual soil factors proper (biotic and abiotic) and climatic and topographic factors. From the regulative and nutritive aspect, soil factors are the most important. The number of special studies which have been published on the effect of their various components, e.g. soil organic matter, humidity, temperature, atmosphere, pH, osmotic pressure, oxidation reduction processes, soil structure, etc., is very large. Although clay minerals are a very important regulative factor in soil, their influence has not yet been evaluated systematically, however, as even reviews published in recent years (Kas, 1966; Stotzky, 1967; Zviagintsev, 1967; Kas et al., 1969; Marshall, 1971) do not cover all the problems of relationships between soil microorganisms and clay minerals. The present study therefore attempts to evaluate systematically the existing known facts on the significance of clay minerals as a factor influencing the main manifestations of the physiological activity of soil microorganisms. Detailed information on the influence of clay minerals will be found in monographs by Chukhrov (1955), Jasmund (1955), Konta (1957), Beutelspaer and van der Marel (1968), Grim (1968) and Gregor and Cičel (1969) and in the abundant special studies cited by these authors. The findings to date indicate that, because of their characteristic properties, and particularly their large active surface and high exchange capacity, clay minerals influence chemical and physical properties of soil significant from the aspect of the ecology of microorganisms and higher plants.

Sorptive interactions between microorganisms and clay minerals

Clay minerals actively influence the properties of soil and thus have an indirect effect on the development and activity of soil microorganisms. Direct interactions, manifested in sorption, also occur between clay particles and microbial cells, however. Since two studies on this question have been published only recently (Müller and Hickisch, 1970a; Marshall, 1971), only basic information will be presented here. The sorption of microbial cells on clays, or of clay particles on microbial cells, is influenced by the type, concentration and particle size of the sorbent, by the type of cation with which the sorbent is saturated, by the age and type of the microorganism and by the character of the environment in which the interaction takes place. Both Gram-positive and Gram-negative microorganisms (Novogrudskii, 1936; Peele, 1936; Fuller and Hickisch, 1970c) and motile and non-motile cells (Khudiakov, 1926; Müller and Hickisch, 1971) are adsorbed on clay minerals and other sorbents. Small cocci and rods are sorbed more readily than larger cells (Filip, 1970a; Marshall, Stout and Mitchell, 1971). Microorganisms usually adhere to a sorbent by their
Clays to reduce the soil temperature range and limit overheating of the soil and soil dehydration. The phenomenon is undoubtedly associated with the ability of montmorillonite clay minerals to still sorb cells of another species (Zviagintsev, 1962). Microorganisms can also displace one another (Eisenberg, 1918; Rubentchik, Roizin and Belianskii, 1936). The mechanism of the connection between microorganisms and clay minerals and other sorbents is not evaluated uniformly.

Importance is attached to partial reduction of the negative charge on the surface of the sorbent, which thereby becomes more readily available for similarly (i.e. negatively) charged cells (Oksentian, 1940). It was found that cells subject to strong sorption were usually capable of secreting cohesive aids their sorption (ZoBell, 1943). More recently it was stated (Zviagintsev, 1962; Santoro and Stotzky, 1969) that sorption between microbial cells and clay minerals increased in inverse proportion to the electrokinetic potential of the particles in the presence of multivalent cations. Hydrogen bonds and van der Waals forces can participate in sorption. Zviagintsev and Guzev (1970), who studied sorption to Dowex anionite in five species of bacteria, concluded that the process resembled ion exchange. The interaction between the microbial cells and the OH form of the sorbent followed the scheme:

\[(\text{sorbent})^+ \cdot \text{OH}^- \rightarrow (\text{cell})^- \rightarrow (\text{sorbent})^+ \cdot (\text{cell})^- + \text{OH}^- .\]

In this interaction, the both mentioned authors ascribe a significant role to carboxyl groups on the surface of the bacterial cells; if these are blocked, sorption does not occur. They also state that the sorptive interaction is a reversible process, but that desorption is not always complete. It was found (Zviagintsev et al., 1971) that microbial cells were sorbed on the surface of the solid phase by a force of \(4 \times 10^{-7}\) to \(4 \times 10^{-4}\) din/cell. The quantity of firmly-sorbed cells fell with the age of the culture. The authors attribute the particularly strong sorption of some microorganisms (Serratia marcescens, Staphylococcus aureus) to the presence of very thin cell wall processes, the existence of which was found by examining the culture in an electron microscope. Marshall et al. (1971) also described such processes in some, but not all, sorbed cells.

The sorbent particles are not infrequently found to be smaller than the microbial cells. Such particles are usually seen to be sorbed on the surface of the cells (Karpinskaya, 1926; Lahav, 1962; Marshall, 1968a, 1969). Cells with a preponderance of carboxyl ions on their surface sorb up to twice the amount of clay sorbed by cells with a carboxyl and amino ion complex. An increase in the concentration of mineral particles on the cell surface is accompanied by greater electrophoretic mobility of the cells, especially in the zone of low electrolyte pH values. It can be assumed that the sorption of fine clay particles on the surface of the cell wall influences the intake of nutrients and the release of exoenzymes or other metabolites by the microbial cell.

Sorptive interactions between microorganisms and mineral sorbents are very important from the aspect of the ecology of soil microorganisms, as they can significantly influence the (steady) state of a microbial population. The majority of soil microorganisms are sorbed on the surface of solid particles, where they form microcolonies (Aristovskaya, 1963). The regulatory influence of solid particles is manifested more in soils with a fine texture and high exchange capacity, in which the numbers of sorbed cells rise very sharply, both in absolute values and in relation to the cells dispersed in a soil solution. It was stated (Zviagintsev and Galkina, 1967) that on desorbing microbial cells by ultrasound instead of in the normal way (suspending them by shaking), the number of microorganisms found in podzolic soil rose 2- to 5-fold, in chernozem more than 20-fold and in humic gley soil more than 1,000-fold.

The presence of clay minerals can influence antagonism and competitive relationships between different species of microorganisms. For instance, a significantly lower incidence of pathogenic fungi (Fusarium culmorum, Fusarium oxysporum f. cubense, Histoplasma capsulatum) was found in soils containing a montmorillonite type of mineral than in localities where no such mineral was present (Skinner, 1956; Stotzky et al., 1961; Stotzky and Post, 1967). The same correlation was found for bacteria causing enzootic leptospirosis and for the incidence of various other human pathogens (Stotzky, 1970). Apart from antagonistic microorganisms whose development a changed soil reaction can contribute, altered physical conditions, e.g. a decrease in the number of noncapillary pores and poorer aeration of the soil in the presence of swelling clays, can also play a role. Wolf-Straub (1970) concluded that the diminished proportion of actinomycetes and microscopic fungi in the microflora of brown soil with a high clay content was due mainly to these factors. Soils naturally containing montmorillonite type clay minerals and sandy soils with added montmorillonite likewise reduce the sensitivity of bacteria (e.g. rhizobes) to desiccation, high temperatures and X-rays and thereby significantly promote their survival (Marshall and Roberts, 1963; Marshall, 1964; Müller and Schmidt, 1966). This phenomenon is undoubtedly associated with the ability of montmorillonite clays to reduce the soil temperature range and limit overheating of the soil and soil dehydration. The