Biological activity of meadow-chernozem and sod-taiga permafrost soils of the Yeravninsky basin

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Abstract. The biological and biochemical parameters of two types of permafrost soils of the Yeravninsky basin (the carbon content of the microbial mass, different groups of microorganisms, protease, catalase and the intensity of cellulose decomposition) were studied, depending on the water-thermal properties and the type of soil formation. It is established that permafrost soils do not have an optimal combination of potential and real (actual) enzymatic activity. It is also noted that the acidic reaction of the soil solution and the low availability of nutrients in sod-taiga soils increases the development of fungal microflora. The most significant soil-ecological factor that determines the microbiological activity of meadow-chernozem and sod-taiga permafrost soils is humidity, as evidenced by a direct correlation. In turn, these microbiological indicators can be used for diagnostic assessment of the biological state of soils, and also, along with other soil properties, should be taken into account when developing methods to increase the productivity of existing hayfields and pastures on them.

1. Introduction

One of the distinctive features of the ecological conditions for the development of microbial cenosis in the meadow-chernozem and sod-taiga soils of the Yeravninsky forest-steppe permafrost basin of the Vitim Plateau is their low temperature. During 7-8 months, the soil is in a permafrost state, which determines the formation of a microbiocenosis adapted to cryogenic conditions. Extreme natural conditions of cryogenic ecosystems determine the peculiar composition and structure of the microbiocenosis, increase the vulnerability of the microbiota, at the same time contributing to their adaptability to changes in conditions. Microbial biomass, its activity and the diversity of the microbial community is an indicator of changes in the soil environment [1,2]. A common characteristic feature of microbial cenoses of the studied region is the small number of microorganisms per 1 g of soil, their high dynamism over time, variability in the taxonomic structure of microbial cenosis and the level of the natural pool, which cause unevenness, discontinuity, and varying degrees of intensity of microbiological processes [3].

Biological processes in them occur in a short growing season against the background of permafrost. The cryogenic nature of soils undoubtedly affects the structure of microbial complexes, determines their dynamics and activity, thereby determining the specifics of the process of transformation of substances, which is a key link in soil formation. In this work, the dynamics of quantitative and qualitative characteristics of microbial communities and enzymatic activity in the humus horizons of the soils of the cryolithozone of Transbaikalia are studied, depending on the water-thermal properties and the type of soil formation.
2. Models and Methods
The research area is located in the Yeravninsky basin in the south of the Vitim Plateau, where permafrost reaches a maximum capacity of 120–130 m, averaging 80–85 m [4]. The upper boundary of the permafrost lies at a depth of 1.5–3.0 m from the daytime surface, and in some places-at a depth of less than 1 m. The objects of the study are meadow-chernozem and sod-taiga permafrost soils.

The determination of the number of microorganisms in soils was carried out by direct microscopy [5]. The cells were previously desorbed with an ultrasonic dispersant UZDN-1. When quantifying the cells of soil bacteria and the mycelium of actinomycetes, the preparations were stained with an aqueous solution of acridine orange, and calcofluor white was used to colour the mycelium and spores of fungi. The work was carried out in the laboratory of soil biochemistry of the Institute of General and Experimental Biology, SB RAS. A “Micromed 3 LUM” luminescent microscope was used, carbon of microbial biomass was rehydrated by the rehydration method [6]. To characterize the intensity of individual microbiological processes in soils, enzymes were determined: catalase – gasometrically, according to Kuprevich, protease – according to the Hoffmann and Teicher method [7], the intensity of cellulose decomposition in natural conditions was determined by the application method, the data obtained were processed by mathematical statistics [8].

3. Results and Discussion
Meadow-chernozem permafrost soils begin to thaw out at the end of April, and the humus layer is completely freed from seasonal permafrost in the first decade of May. The biologically active temperature penetrates into the upper layer at the end of May. The warming process of the soil is slow at first, and then increases sharply in the second half of June, the maximum warming of the soil is observed in mid-July (Figure 1).

![Figure 1](image_url). Temperature and humidity in meadow-chernozem permafrost and sod-taiga soils during the growing seasons in a layer of 0-10 cm.

Sod-taiga soils begin to thaw out in mid-May, but depending on the weather conditions of the year, there may be deviations from this period. The humus horizon began to warm up in the year of our study to 4°C already in the second half of May, in June the temperature continues to increase, reaching maximum values in July 12-14 °C, and in August the temperature begins to decline.

Thus, the hydrothermal conditions of meadow-chernozem permafrost and sod-taiga soils are important components of the ecological situation of the soil microorganisms’ development. Soil moisture varies very widely. Anaerobic conditions are created with large amounts of atmospheric
precipitation fall. In the first half of summer, the soil under meadow-chernozem soils dries up, despite the presence of permanent permafrost. The maximum heating of the upper layers of the soil to 19°C for a short time does not provide optimal conditions for the development of the microbiota and biochemical processes.

Our studies show that the largest number of bacteria is recorded in the humus layer of meadow-chernozem permafrost soil, it is characterized by a decrease from 7.2 billion/g in 0–5 cm, 5.5 billion/g in 5–10 cm layer. The same tendency is observed in sod-taiga soils, but with a lower total number of cells than in meadow-chernozem soils from 4.9 to 3.2 billion/g (Figure 2b).

The localization of the maximum of bacteria in the upper horizons of meadow-chernozem permafrost soil is due to the concentration of a significant mass of roots and, accordingly, an increase in organic matter. Since the intensity of bacterial microflora development in the soil is mainly determined by the conditions of moisture and the presence of organic substrate, which are at their maximum in the upper horizon, so, the total quantitative indicators of microflora are 1.5 times higher here than in the lower horizons. As well as the number of bacteria, the highest content of actinomycete mycelium was observed in meadow-chernozem permafrost soil, and amounted to 120 m/g of soil, and in sod-taiga 65 m/g, (Figure 2b). The maximum number of fungal mycelium was recorded in the studied sod-taiga soils up to 1200 m/g of soil, while the length of the fungal mycelium in meadow-chernozem soils was 130 m/g of soil (Figure 2d). The acidic reaction of the soil solution (pH 5.7) and the low availability of nutrients in sod-taiga soils increases the development of fungal microflora. The nature of the development of meadow-chernozem permafrost and sod-taiga soils by microorganisms is limited by the content of Sorghum, the degree of moisture.

The highest carbon content of microbial biomass was recorded in meadow-chernozem permafrost soils, where it is differentiated by depth with a maximum in the upper part and a subsequent decrease down the profile. The content of C-biomass at the depth (0-10 cm) was 62 mg/100g of soil,
in the layer (10-20 cm) 54 mg/100g, and on sod-taiga soils the amount of carbon of microbial biomass was 34 mg/100g of soil in the layer (0-10) and 23 mg/100g in the layer (10-20 cm). It is established that a decrease in soil moisture and the size of organic matter intake in the profile of meadow-chernozem and sod-taiga soils leads to a decrease in the carbon content of microbial biomass. It is evidenced by a close direct correlation between the carbon content of humus and carbon of microbial biomass, where the coefficient for meadow-chernozem soil is equal to \( r = 0.98 \) and in sod-taiga soil \( r = 0.94 \). The direct relationship between the content of C-biomass and the resource of organic matter in the soil confirms the dependence of the growth activity of microorganisms on the presence of a substrate [9-11].

There is also a close direct correlation between the content of C-biomass and soil moisture \( r = 0.84 \) in meadow-chernozem soils and less close \( r = 0.69 \) in sod-taiga soils. This indicates that humidity plays an important role in the accumulation of carbon stock of microbial biomass.

Thus, the carbon content of microbial biomass in meadow-chernozem permafrost soils has higher indicators compared to sod-taiga soils.

Microbiological analysis of the studied soils indicates that meadow-chernozem soils have the maximum number of microflora. A high microbial mass corresponds to a high decomposition energy of organic matter, which is determined by the indicators of protease and cellulose activity.

The results of studying the potential and actual enzymatic activity of permafrost soils are summarized in (Table 1). They are given for the most active layer of 0-20 cm and represent the arithmetic average of the indicators obtained during the growing season. A comparative analysis of the data shows that the studied soils are characterized by different levels of potential and actual enzymatic activity.

| Soil type          | Potential | Current |
|--------------------|-----------|---------|
|                    | Protease, mg of tyrosine | Catalase, ml O₂ | Cellulase, % decay of cotton fabric | Protease, % decay photoemulsion |
| Meadow-chernozem   | 1.37      | 3.6     | 78      | 27         |
| Sod-taiga          | 0.53      | 2.3     | 42      | 19         |

The spectrum of proteolytic activity of the studied soils, in contrast to the cellulolytic activity, had narrower boundaries – 19-27% of the emulsion destruction. Studies of actual proteolytic activity have shown that the power of the proteolytically active layer in the studied soils is insignificant. The intensity of destruction of the emulsion layer of photographic plates was maximal in the surface horizons 0-10 cm and 0-20 cm, enriched with organic matter and characterized by better heat supply. The highest activity was observed in meadow-chernozem soils, compared with sod-taiga soils, and amounted to 27% and 19%, respectively. And at a depth of 20-30 cm, the process of proteolysis in sod-taiga soils proceeded extremely slowly – the photographic plates remained intact after one month of exposure.

The assessment of catalase activity on the D Z Zvyagintsev scale indicates that the studied soils are moderately enriched with this enzyme and close in terms of the level of oxidative processes to similar types of soils in Eastern Siberia and the Central European part of Russia [12]. At optimal conditions of the laboratory experiment, the meadow-chernozem soil was characterized by the maximum activity of redox enzymes (catalase), and the sod-taiga soil was characterized by the minimum activity.

The results of our research show that the greatest cellulose-destroying activity is inherent in meadow-chernozem soils. The decrease in the mass of flax tissue during the growing season was 78%. Cellulose mineralization in sod-taiga permafrost soils is less intense and amounts to 42% in the humus horizon, which is due to harsh climate conditions.
Thus, the cellulose-destroying activity of meadow-chernozem permafrost soils is more significant. This is due to more dynamic conditions of thermal and moisture turnover, as well as periodic receipts of plant residues. In sod-taiga permafrost soils low rates of cellulose mineralization are noted due to relatively harsh environmental, as well as unfavourable physical and chemical conditions. It is known that in harsh climatic conditions, the cellulolytic activity of the soil is strongly influenced by moisture than by temperature.

The indicators of actual enzymatic activity indicate that the studied soils are of different quality in terms of their ability to hydrolyse organic compounds in the natural environment. As it can be seen from Table 1, the intensity of cellulose destruction and proteolysis in soils was different. The hydrolysis of cellulose and, inhibited, the hydrolysis of proteins and peptides actively proceeded in the soils. The unequal ratio of the actual cellulolytic and proteolytic activity in these soils is a consequence of different conditions of production, immobilization and the work of enzymes in them.

Comparing the data of laboratory and field experiments, we can conclude that none of the permafrost soils is considering to have a favourable combination of potential and real enzymatic activity. The lack of parallelism between individual enzymatic indicators characterizing the biological activity of permafrost soils indicates the complexity of the natural factors of the region, as well as the specific features of various enzymes that require different conditions for production, immobilization and action in the soil environment. This emphasizes the need to study the biological activity of permafrost soils based on a wide range of enzymes.

4. Conclusion
1. The most significant soil-ecological factor that determines the microbiological activity of meadow-chernozem permafrost and sod-taiga soils is humidity, as evidenced by a direct correlation.
2. The acidic reaction of the soil solution (pH 5.7) and the low availability of nutrients in sod-taiga soils increases the development of fungal microflora.
3. The greatest number of bacteria in the upper horizons of meadow-chernozem permafrost soil is due to the concentration of a significant mass of roots and, accordingly, an increase in organic matter.
4. The carbon content of microbial biomass in meadow-chernozem permafrost soils has higher indicators compared to sod-taiga soils and the nature of their development by microorganisms is limited by the content of organic carbon, the degree of moisture.
5. The cellulose-destroying activity of meadow-chernozem permafrost soils is more significant. This is due to more dynamic conditions of thermal and moisture turnover, as well as periodic receipts of plant residues.
6. At sod-taiga permafrost soils, due to harsh environmental, as well as unfavourable physical and chemical conditions, low rates of cellulose mineralization and proteolysis are noted, since the volume of substrates for activating enzymatic activity decreases.
7. The assessment of catalase activity on the scale of D. Z. Zvyagintsev (1978) indicates that the studied soils are moderately enriched with this enzyme and are close in terms of the level of oxidative processes to similar types of soils in Eastern Siberia and the Central European part of Russia.

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