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Assessment of biological activity in mountain chernozems and mountain-meadow chernozemic soils of natural biogeocenoses in the Central Caucasus, Russia

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Abstract

Indicators reflecting various aspects of biological properties (genetic, microbiological, biochemical) were estimated for the upper horizons (0-20 cm) of mountain chernozems (Mollic Chernozems, WRB, 2015) and mountain meadow chernozemic soils (Mollic Leptosols Eutric, WRB, 2015), that were formed in the conditions of natural biogeocenoses of the Central Caucasus (Elbrus variant of zonality within Kabardino-Balkaria). A comparative assessment was performed for the biological activity parameters (humic content and stock, microbial biomass carbon (Cmic) content and stock, the enzyme activity of hydrolases (invertase, phosphatase, urease) and oxidoreductases (catalase, dehydrogenase)) in combination with indicators of the soil density and acid-base properties of various subtypes of the studied soils (typical and leached). The obtained results showed that the studied types of mountain soils in the upper horizons are characterized by a porous loose composition (0.75-1.07 g/cm^3), neutral (pH_{H2O} = 7.0-7.4) and slightly alkaline (pH_{H2O} = 7.9-8.0) by the reaction of the soil solution, high and very high content (9.5-19.1%) and stock of organic matter (173-276 t/ha). The maximal biological activity was noted in mountain-meadow chernozemic soils, which surpass mountain chernozems in humic content (by 42%) and stock (24%), Cmic content (38%) and stock (17%), relative total activity of hydrolases (36%), but inferior in activity of oxidoreductases (32%). Based on the data obtained, the integrative index of ecological and biological condition (IIEBC) was calculated, which reflects the general level of biological activity of the studied soils. Higher IIEBC values of mountain meadow chernozemic soils (80-100%) in comparison with mountain chernozems (70-74%) are due to the unique complex of soil-forming conditions in which these soils function. The established biological parameters of mountain soils of natural landscapes are necessary for use as reference in environmental studies of anthropogenically disturbed biogeocenoses.

Keywords: Carbon of microbial biomass, Central Caucasus, humus, soil enzymes.

Introduction

Kabardino-Balkaria Republic is located on the northern slopes of the Central Caucasus, mainly in the basin of the left tributaries of the Terek River and part of the Ciscaucasian plain. The Republic occupies an area of 12470 km^2, a height difference of the terrain varies from 150 to 5642 m above sea level. This territory is characterized by a significant variety of natural landscapes associated with a complex relief and various natural and climatic conditions (Fiapshev, 1996). The specificity of the ecological and geographical conditions of this relatively small area leads to the formation of various types of soils, the number of which

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reaches 29 (Molchanov, 1990). The soil cover of the foothills and uplands of the Republic is mostly formed by various subtypes of mountain chernozems (ordinary, typical, leached) and mountain meadow-chernozemic soils (typical, leached, calcareous). The soil formation conditions, genetic, morphological, and physicochemical features of these soils are described in detail in literature (Fiapshev, 1996; Kumakhov, 2007; Molchanov, 2008). However, studies of the biological state of mountain soils were started recently by the authors of this article (Khakunova et al., 2018).

An increase in anthropogenic load under conditions of mountainous landscapes leads to a rapid and sometimes irreversible change in soil properties (Molchanov, 2008; Egli and Poulenard, 2016). That's why it is relevant to study the biological properties, reflecting the most important aspects of the functioning of soils on the northern macroslope of the Central Caucasus (within Kabardino-Balkaria). It is necessary to establish the parameters and the general level of biological activity of undisturbed natural mountain chernozems (Mollic Chernozems, WRB, 2015) and mountain meadow chernozemic soils (Mollic Leptosols Eutric, WRB, 2015) in order to monitor the degree of their change under the influence of certain exogenous factors.

Of the whole variety of parameters characterizing the biological state of soils, the researchers (Murugan et al., 2014; Merino et al., 2016; dos Santos Soares et al., 2019; Ananyeva et al., 2020; Kazeev et al., 2021; Kolesnikov et al., 2021) propose to use indicators of biological activity, which are highly sensitive to negative processes occurring in soil. It is known that these indicators change earlier than other soil characteristics (e.g. agrochemical), when a stressful situation occurs in soil (Burns et al., 2013; Kazeev et al., 2016; Martinez-Mera et al., 2017).

An approach that provides the comprehensive determination of several informative indicators of biological activity (the humic content, the intensity of soil microbial respiration, the activity of soil enzymes of two classes: hydrolases (invertase, phosphatase, urease) and oxidoreductases (dehydrogenase, catalase)) proved to be effective for the assessment of a biological state of a soil cover (Kazeev et al., 2004; Gedgafova et al., 2015; Gorobtsova et al., 2016; Khakunova et al., 2018). These parameters reflect various aspects of the soil biological properties (genetic, microbiological, biochemical), and their combination makes it possible to establish the general level of biological activity and express it through the integrative index of ecological and biological condition (IIEBC) (Kazeev et al., 2004; Kolesnikov et al., 2021). The aim of this study is to establish the parameters and the general level of biological activity of the upper horizons (0-20 cm), undisturbed mountain chernozems and mountain meadow chernozemic soils of the northern macroslope of the Central Caucasus (Elbrus altitudinal zonality in Kabardino-Balkaria).

Material and Methods

The studied area

The objects of research are various subtypes of mountain chernozems (typical and leached) and mountain meadow chernozemic soils (typical and leached) under natural biogeocenoses. The study area covers the belts of meadow steppes and steppe meadows of the Elbrus altitudinal zonality variant of the Kabardino-Balkaria belt as typified by A.K. Tembotov, 1989 (Sokolov and Tembotov, 1989). The main massifs of mountain chernozems are located on elevated relief elements and smooth slopes with northern exposure of the Chalk and on the southern slopes of the Rocky ridge. The area covered by the characterized soils is about 640 km^2. Mountain meadow chernozemic soils are distributed on the acclivous, steep and less often smooth northern slopes of the Cretaceous and Dzhinalsky ridges and occupy about 523 km^2 (Soils of Kabardino-Balkar ASSR and recommendations on exploitation, 1984). Parent rocks for the studied soils are the products of carbonate rocks weathering: eluvio-diluvium of limestones and calcareous sandstones (Fiapshev et al., 1996).

The studied soils belong to the South European facies and are formed under the conditions of the shadow effect of the mountains of the North Caucasus, which determines the increased moisture content of the territory of its distribution (Valkov et al., 2002). Typical mountain chernozems occur at an altitude of 700-800 m above sea level, on the border of low mountains and foothills and develop at higher temperatures and lower precipitation (Table 1). Leached mountain chernozems are formed under conditions of periodically flushed water regime, at an altitude of 700 to 1000 m above sea level, in contact with mountain meadow chernozemic soils located in the altitude range of 1100-2000 m above sea level (Kumakhov, 2007).

Climatic conditions

The complex topography of the territory of Kabardino-Balkaria has led to a variety of climatic conditions of high-altitude zones within the boundaries of the distribution of the characterized mountain soils (Kumakhov, 2007; Molchanov, 2008), which are reflected in the table.

Table 1. Main climatic characteristics of the study areas (Elbrus variant of zonality, within the boundaries of Kabardino-Balkaria)

Altitudinal belts	Meadow steppe belt	Steppe meadow belt
Altitude, ma.s.l.	from 400-500 to 700-800	from 600-700 to 1500
Precipitation, mm/annual	580	706
Average annual temperature, ^{o}C	+9.9	+7.9
Hydrothermic coefficient (HTC)	0.67	1.5

Plant cover

More than 50% of the foothill areas are involved in agricultural production. About 34% of the area of mountain chernozems is used for arable land; hayfields and pastures are widespread (Fiapshev, 1996; Tsepkova and Fisun, 2005). However, in some areas, natural biogeocenoses have also been preserved, their phytomass stock in the air-dry mass is 20 c/ha (Tsepkova and Fisun, 2005). The vegetation cover is represented by herb-grasses and meadow-steppe vegetation. The most common forbs are *Salvia verticillata L.*, *Scabiosa ochroleuca L.*, *Achillea millefolium L.*, and *Agrimonia eupatoria L.* Such graminoids as *Elytrigia repens (L.) Nevski*, *Brachypodium rupestre (Host) Roem. and Schult.*, and *Phleum pretense L.* are most registered. Legumes are most presented by *Coronilla varia (L.) Lassen*, *Medicago falcata L.*, *Lotus corniculatus L.*, and *Trifolium pratense L.*

Mountain-meadow chernozemic soils are characterized by high potential fertility; however, due to the complexity of the relief, they are mostly used for hayfields and pastures (Fiapshev, 1996). The natural herbaceous cover is represented by forbs and bromegrasses, fescue grasses. The stock of phytomass of plant communities in the air-dry mass is about 40 c/ha (Tsepkova and Fisun, 2005). The most common forbs are *Achillea millefolium* L., *Scabiosa bipinnata* K. Koch, *Ranunculus oreophilus* M. Bieb, *Betonica officinalis* L., *Origanum vulgare* L., *Thymus pastoralis* Iljin ex Klokov, *Salvia verticillata* L., *Centaurea iberica* Trevir ex Spreng, and *Plantago media* L. are mostly widespread. Such graminoids as *Festuca pratensis* Huds, *Festuca rubra* L., *Poa pratensis* L. and *Phleum pretense L.,* are dominant. Tall grasses are most presented by *Cephalaria gigantean* (Ledeb) Bobrov, *Aconitum nasutum* Fisch ex Rchb, *Delphinium bracteosum* Somm. et Levier and some others. The species nomenclature is given in accordance with The Plant List (2021).

Soil sampling

The collection and analysis of soil samples to determine the physical and biological properties was carried out according to the methods generally accepted in ecology and soil science (Dobrovolskiy, 2001; Ananyeva, 2003; Kazeev et al., 2016). Soils were sampled by the "envelope" method from the 0-20 cm depth in natural biogeocenoses in the first decade of July 2016-2018. 13-15 mixed samples was picked to characterize each subtype of the studied soils. Cartographic materials were used to determine the sampling point's locations (Molchanov, 1990). The altitude above sea level and geographical coordinates were determined using a GPSMAP 60 CEX system navigator: the altitude limits of the sampling points for mountain chernozems were 515-1082 m above sea level, for mountain-meadow chernozemic soils - 990-1920 m above sea level, coordinates 48.23252 - 48.61473 N, 31.5684 - 37.4681 E (Figure. 1). Classification and diagnostics were carried out according to the genetic classification of soils (Valkov et al., 2002; Classification and diagnostics of soils of the USSR, 1977; IUSS Working Group, 2015).

Physical, physic-chemical and biological analyses

Laboratory and analytical studies were performed in 3-6 replicates. The humic content (%) in the soil was determined by the method of Tyurin modified by Nikitin, the pH of the water extract of the soil was estimated potentiometrically, the field moisture and soil density was measured using the gravimetric method (Dobrovolskiy, 2001). The humus stock in the 0-20 cm layer was calculated using the soil density indices.

The rates of basal and substrate-induced respiration (BR and SIR) that characterize background and potential respiration activity of soil microbial biomass were determined in accordance with the methodological developments of Ananyeva (2003). The carbon content of microbial biomass (C_{mic}) was calculated using the formula: Cmic (µg C / g soil) = SIR (µl CO_2 / g soil / hour) × 40.04 + 0.37 (Anderson and Domsch, 1978). C_{mic} stock in 0-20 cm layer was calculated using soil density indicators. The ratio of microbial biomass carbon in the total soil organic carbon (%) was calculated as $C_{mic}/_{Corg}$.

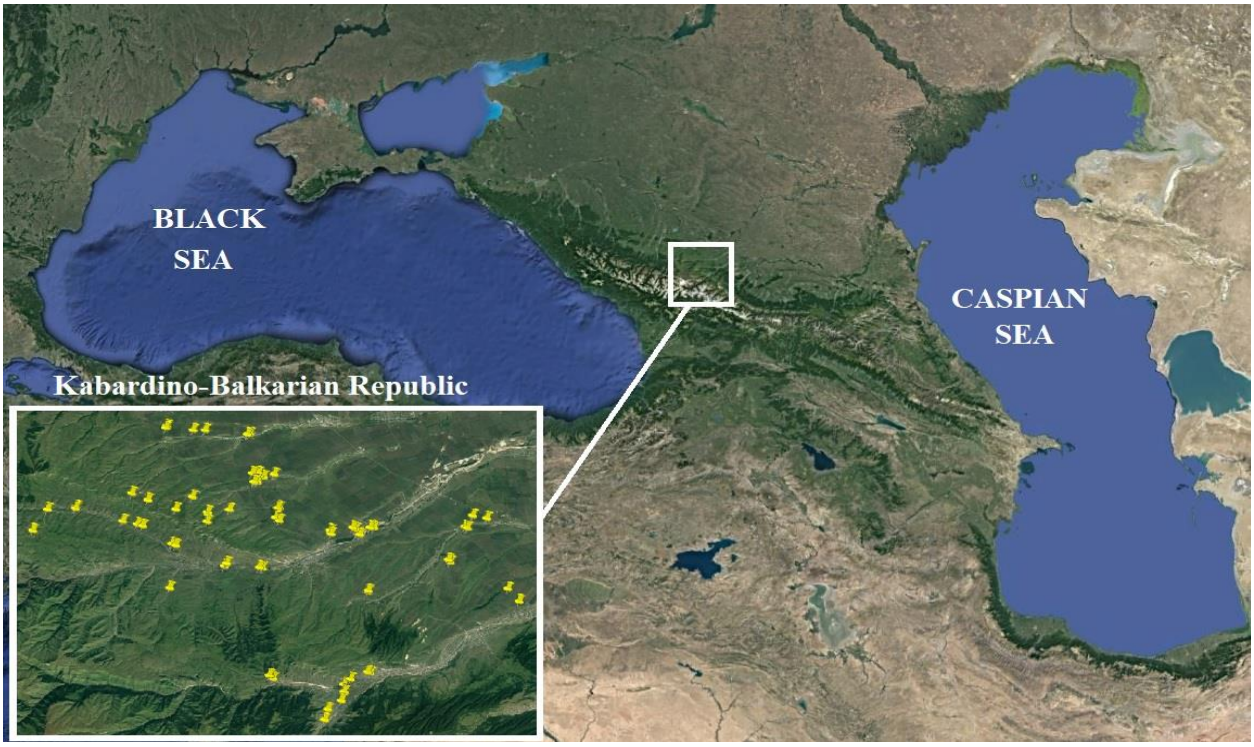

Figure 1. Map of the study area and sampling points of mountain soils of the Central Caucasus (Kabardino-Balkaria)

Activities of urease, phosphatase, invertase, dehydrogenase were measured colorimetrically; catalase activity was estimated gasometrically according to Galstyan's methods as modified by Khaziev (Kazeev et al., 2016). Sterilized soils (180°C, 3 hours) served as a control for determining the enzyme activity. The obtained biological parameters were assessed using the scale of Gaponyuk and Malakhova (1985). The calculation of the total relative enzyme activity was carried out according to the method proposed (Kazeev et al., 2016).

For a comparative assessment of the general level of biological activity of mountain chernozems and mountain meadow chernozemic soils, we used the methodology for calculating the integrative index of ecological and biological condition (IIEBC), which allows integrating the relative values of the studied parameters (Kazeev et al., 2004; Kolesnikov et al., 2021).

Statistical analysis

The obtained data was treated using STATISTICA 10 program. The significance of differences in the studied soil characteristics of the compared plots was assessed using the Student's t-test at a significance level of ≤0.05.

Results and Discussion

Physical and physicochemical soil properties

Soil biological activity to a significant extent depends on genetically-based physical and chemical parameters (soil density, acid-base conditions) and soil organic matter content (Breza-Boruta et al., 2016; Martinez-Mera et al., 2017; Ananyeva et al., 2020; Kolesnikov et al., 2021). The results of the estimation of physical and chemical properties of humus-accumulative horizons (0-20 cm) of the studied subtypes of mountain chernozems and mountain-meadow chernozemic soils are presented in Table 2.

The soil density affects the intensity of microbiological and biochemical processes (Mangalassery et al., 2019; Kazeev et al., 2004). The best conditions for the development of soil microbial biomass and catalytic activity of enzymes are formed at density values close to 1.0 g/cm^3, since the porous composition of the soil determines the hydrothermal and air regimes that are optimal for the soil biota (Kazeev et al., 2004). As the presented data show, the studied subtypes of mountain soils in the upper horizons (0-20 cm) have a porous loose composition, which is due to the activity of the root system of herbaceous plants, soil mesofauna and high organic matter content. The established values of the bulk density (Table 2) can be considered characteristic of the studied mountain soils.

Table 2. Average values ($\overline{X}$ ± m) of the indicators of the upper horizon (0-20 cm) of mountain soils of the Elbrus variant of zonality within Kabardino-Balkaria

Soils	Density, g/cm^3	pH(H_2O)	Humus	
			Content, %	stocks, t/ha
Mountain chernozems typical	1.07±0.04	8.0±0.11	9.7±0.6	194±11
Mountain chernozems leached	1.01±0.03	7.9±0.12	9.5±0.6	173±12
Mountain meadow chernozem-likes typical	0.75±0.03	7.4±0.08	19.1±0.47	276±18
Mountain meadow chernozem-likes leached	0.99±0.06	7.0±0.11	13.8±1.1	209±23

Note: $\overline{X}$ ±m is mean and error of mean. The same is in Tables 3,4.

One of the most important factors regulating the level of biological activity is the acid-base conditions of the soil solution (Margalef et al., 2017; Kolesnikov et al., 2021). A favorable environment for microbial and enzymatic activity is created when the reaction of soil solution is neutral or close to it (Kazeev et al., 2004). Analysis of the results obtained (Table 2) showed that mountain chernozems in the upper humus-accumulative horizons are characterized by a weakly alkaline reaction. The pH_{H2O} level of mountain meadow chernozemic soils is in the range of neutral values. For this parameter, statistically significant differences were established between the considered soil types (t = 6.98; P = 0.00), which is due to the peculiarities of the genesis of the considered soils. The obtained average pH_{H2O} values characterize the acid-base conditions of the studied soils as favorable for most biological processes and promoting the activity of bacterial microbial biomass and most soil enzymes.

Numerous soil characteristics are associated with the humic content that provide a certain level of biological activity (Sinsabaugh et al., 2010; Liang et al., 2017; Kolesnikov et al., 2021). The described types of mountain soils are characterized by the accumulation of a large amount of organic matter, which is due to climatic conditions and the development of rich meadow vegetation in the studied mountain landscapes (Tsepkova and Fisun, 2005). A feature of mountainous regions is a shorter warm period, where the processes of plant residues decomposition and soil organic matter mineralization are slowed down (Molchanov, 2008). As follows from the literature (Fiapshev, 1996; Egli and Poulenard, 2016; Kostenko, 2017), the general pattern for mountain soils is an increase in the humus stock as the amount of precipitation increases and the temperature decreases with the height of the terrain, which is confirmed by the presented data (Table 2).

According to the system of the humus state indicators for mountain soils (Kazeev et al., 2004), the studied mountain chernozems have high humic content, and in mountain meadow chernozemic soils it is very high. Statistically significant differences in the average content of soil organic matter were revealed between the studied soil types (t = 6.79; P = 0.00). So, for mountain meadow chernozemic typical soils that characterized by maximal humus content, the analyzed parameter is almost 2 times higher than the indicator for both subtypes of mountain chernozems (t ≥ 10.91; P = 0.00). In accordance with the rating scale (Valkov et al., 2004), humus stock in the upper horizons (0-20 cm) of mountain chernozems should be assessed as high, and in mountain meadow chernozemic soils - as very high. The difference in this parameter at the type level is 24% (t = 3.38; P = 0.00). Thus, the obtained average indicators, quantitatively characterizing the humus state of mountain chernozems and mountain meadow chernozemic soils, confirm their difference at the type level and can serve as reference characteristics in further monitoring studies.

Microbiological soil properties

One of the most important indicators of the biological activity of soils associated with the balance of organic carbon in the ecosystem are the rates of basal and substrate-induced respiration (BR and SIR) (Mangalassery et al., 2019; Zhao et al., 2019; Ananyeva et al., 2020). The studies carried out show that the BR rate (Table 3), which to a certain extent characterizes the amount of carbon available to support the vital activity of microorganisms, is higher in mountain meadow chernozemic soils in comparison with mountain chernozems, on average by 19% (t = 1.61; P = 0.11).

Higher (by 38%) values of the SIR rate, characterizing the potential activity of the soil microbial community, were also noted for mountain meadow chernozemic soils (Table 3). The differences found between the studied soil types are statistically significant (t = 5.85; P = 0.00), which indicates a higher potential of the microbial pool in mountain meadow chernozemic soils. In a number of works (Calderon et al., 2016; Liang et al., 2017; Sushko et al., 2019) it is shown that the amount of real and potential respiratory activity is influenced by the content of organic matter in soils, which is directly proportional to the formation of carbon dioxide. According to the results of the correlation analysis in the studied mountain soils, a positive relationship was revealed between the BR rate and the humic content (r = 0.33). The high correlation coefficient (r = 0.71) between the SIR rate and the amount of organic matter indicates a close relationship between these indicators.

Table 3. Average values of microbiological indicators of the upper horizon (0-20 cm) of mountain soils of the studied territories

Soil	BR	SIR	C_{mic}		C_{mic}/C_{org},
	mkg CO_2/g/h		Content, mkg C/g	Stock sg/m²	%
Mountain chernozems typical	18.8±2.1	91.2±7.6	2018±168	446±45	3.9±0.35
Mountain chernozems leached	15.1±2.2	88.7±8.2	1964±181	458±58	4.1±0.37
Mountain meadow chernozem-likes typical	24.3±3.6	157.4±9.1	3483±200	522±38	3.1±0,.1
Mountain meadow chernozem-likes leached	18.4±2.7	130.2±13.1	2881±289	571±66	4.9±0.53

Note: Assessment scale of microbial biomass carbon content (mkg C/g) in the soils: < 200 is very low; 201-500 is low; 501-1000 is average; > 1000 is high (Ananyeva, 2003).

Determination of the SIR rate also makes it possible to establish the content of microbial biomass carbon (C_{mic}), an important quantitative characteristic of the state of the microbial community of the studied soils (Xu et al., 2019; Sushko et al., 2019). Analysis of the data obtained (Table 3) shows that all the studied subtypes of mountain soils, according to the assessment scale (Ananyeva, 2003), have a very high content of C_{mic}. It is noteworthy that the average values of the Cmic content of mountain meadow chernozemic soils are significantly higher (by 38%, t = 5.85; P = 0.00) than in mountain chernozems. The difference in the indices of the Cmic stock in the compared soil types is less pronounced (17%, t = 2.47; P = 0.02), which is explained by the higher indices of the soil bulk density in the sample characterizing the upper horizons of mountain chernozems (Table 2).

The ratio of microbial carbon (C_{mic}/C_{org},%) characterizes the content of the living and active part of soil organic carbon, which is involved in the subsequent processing of all soil organic matter (Ananyeva, 2003; Purtova et al., 2017). An increase or decrease in this indicator shows a change in the nutrients availability, since the microbial biomass reacts very sensitively to any factors of disturbance, while the total soil carbon content, on the contrary, is a stable indicator. The C_{mic}/C_{org} values presented (Table 3) are close to the data previously established for chernozems in the plain part of Kabardino-Balkaria (2.8-4.7%) (Gorobtsova et al., 2016). The differences found at the level of the type of the studied soils are not statistically significant (t = 0.065; P = 0.95), and the characteristic C_{mic}/C_{org} indicator can be taken to be close to 3-4%.

Biochemical soil properties

Enzyme activity is a relatively stable and informative indicator for studying and comparing various soil types in order to characterize their biological properties (Rao et al., 2014; Merino et al., 2016; Sudina et al., 2021). To estimate the biological activity of mountain soils, the catalytic activity of hydrolytic (invertase, phosphatase, urease) and redox (dehydrogenase, catalase) enzymes was measured. The activity of oxidoreductases characterizes the redox reactions of the transformation of organic substances, the activity of hydrolases characterises the intensity of the processes of organic substances mineralization, which include the most important nutrients - nitrogen, phosphorus, etc. (Utobo and Tewari, 2015; Kazeev et al., 2016; Kashirskaya et al., 2020).

In accordance with the data of the rating scale (Gaponyuk and Malakhov, 1985), in all studied subtypes of mountain soils the activity of catalase is average, dehydrogenase activity is medium in mountain chernozems and weak in mountain meadow chernozemic soils (Table 4). In the group of hydrolases, invertase exhibits weak activity in mountain chernozems and moderate in mountain meadow chernozemic soils. For all subtypes of mountain soils, an average level of phosphatase activity was noted and a high level of urease activity. The established differences in absolute values between soil types are statistically significant for all enzymes ($t \geq 2.72$; $p \geq 0.00$), except for urease (t = 1.41; p = 0.16).

Table 4. Mean values of enzymatic activity parameters for the upper horizon (0-20 cm) of mountain soils in the studied areas

Soil	Hydrolase activity			Oxidoreductase activity	
	Invertase	Phosphatase	Urease	Dehydrogenase	Catalase
Mountain chernozems typical	11.6±1.1	23.9±0.7	42.9±6.1	8.4±1.1	7.6±0.6
Mountain chernozems leached	14.1±1.5	25.3±1.7	57.3±10.7	9.2±1.3	6.8±0.3
Mountain meadow chernozem-likes typical	32.4±1.6	37.7±3.8	68.2±9.6	6.2±0.5	6.8±0.6
Mountain meadow chernozem-likes leached	22.8±2.2	34.8±3.4	68.6±6.1	4.2±0.3	4.5±0.4

Invertase, mg glucose/1 g/24h; Phosphatase, mg P_2O_5/100 g/1h; Urease, mg NH_3/10 g/24h; Dehydrogenase, mg TPF/10 g/24h; Catalase, mg O_2/1 g/1 min.

According to the literature data (Sinsabaugh et al., 2010; Oliveira Silva et al., 2018; Kazeev et al., 2021) and the results of previous studies of the lowland chernozems of Kabardino-Balkaria (Gedgafova et al., 2015; Gorobtsova et al., 2016) the activity of hydrolytic enzymes is closely related to the organic matter content. That was confirmed in this study of the biological properties of mountain soils. According to the data of correlation analysis, in the considered series of soils mainly an average positive relationship between the activity of urease (r=0.57) and a strong one - invertase (r=0.72) and phosphatase (r=0.74) with humic content were established. The catalytic activity of oxidoreductases, according to the authors (Kazeev et al., 2004; Kolesnikov et al., 2021), is more associated with the pH of the soil solution than with the humic content, which was confirmed in the present studies. Dehydrogenase and catalase are most active in mountain chernozems with a slightly alkaline reaction of the soil solution and the least in soils with neutral pH values (mountain meadow chernozemic soils). The studied subtypes of mountain soils in terms of the total relative activity of hydrolytic enzymes are arranged in the following row in descending order: typical mountain meadow chernozemic soils (100%) > leached mountain-meadow chernozemic soils (88%) > leached mountain chernozems (65%) > typical mountain chernozems (54%). The indicators of the total relative activity of oxidoreductases form a series - typical mountain chernozems (100%) > leached mountain chernozems (99%) > typical mountain meadow chernozemic soils (82%) > leached mountain-meadow chernozemic soils (55%). The higher activity of hydrolases in mountain meadow chernozemic soils is due to the optimal soil pH_{H2O} values for the action of hydrolytic enzymes and a relatively high humic content (Table 2), which regulate the level of activity of the corresponding enzymes of nitrogen and phosphorus metabolism. The total activity of oxidoreductases is higher in mountain chernozems, which is obviously associated with the slightly alkaline conditions of the soil solution. Indicators of the total relative enzymatic activity confirm that the intensity and direction of biochemical processes to a certain extent is associated with the genetic characteristics of the studied types of mountain soils.

The best results for diagnosing the biological activity of soils are obtained by a comprehensive assessment of biological parameters using the method for determining the integrative index of ecological and biological condition (IIEBC) (Kazeev et al., 2004; Kolesnikov et al., 2021). The given values of IIEBC (%), characterizing the general level of biological activity, summarize the following biological parameters: the humic content, carbon of microbial biomass (C_{mic}) content, the activity of hydrolytic (invertase, phosphatase, urease) and redox (dehydrogenase, catalase) enzymes (Figure 2).

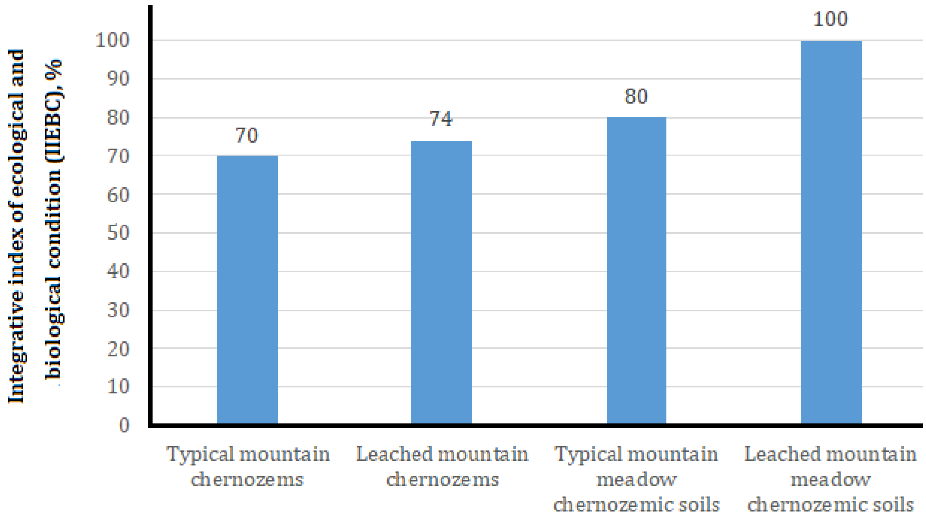

Figure. 2. Values of IIEBC (%) of the upper horizons (0-20 cm) of mountain soils of the Elbrus variant of the Kabardino-Balkaria zonality

The values of IIEBC calculated relative to this indicator for mountain meadow chernozemic typical soils are presented on Figure 2. Mountain meadow chernozemic typical soils are characterized by maximal total biological activity of the upper horizons (100%). The higher biological activity of these soils is due to the unique complex of soil-forming conditions in which these soils function (Molchanov, 2008).

Conclusion

According to the estimations, the average indicators characterizing the humus state of mountain soils make it possible to classify them as soils with high and very high humus content and reserves. It was shown that the general level of biological activity in soil types with different genesis, along with the conditions of soil formation, is regulated by the organic matter content and the acid-base reaction of the soil solution. The maximal biological activity and biogenecity were noted in mountain-meadow chernozemic soils, which surpass mountain chernozems in such parameters as humic content by 42%, humus stock - 24%, BR rate - 19%, SIR rate - 37%, Cmic content - 37% and stock - 17%, the relative total activity of enzymes of the class of hydrolases - 36% and are inferior in activity of oxidoreductases by 32%. According to the degree of decrease in IIEBC (%), the studied natural soils form the following row: typical mountain meadow chernozemic soils (100%) > leached mountain meadow chernozemic soils (80%) > leached mountain chernozems (74%) > typical mountain chernozems (70%). Higher indicators of biological activity of mountain meadow chernozemic soils are a consequence of the influence of better moisture conditions and richness of mountain meadow plant communities under which these soils were formed. The most characteristic biological indicators of mountain soils of natural landscapes have been established. These indicators can be used as reference in various environmental studies: while assessing the degree of soil cover degradation as a result of economic activities, for the needs of environmental regulation of agrogenic, pasture, or recreational load.

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