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Плодородие степных почв Республики Хакасия

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Проведено почвенно-геоботаническое обследование основных эрозионно-опасных сельскохозяйственных ландшафтов степной зоны Республики Хакасия путем закладки шести реперных участков на полигонах, выбранных методом дистанционного зондирования Земли. На основании морфологического описания разрезов выделены следующие виды почв: обыкновенный и южный чернозем, темно-каштановая и каштановая. Проективное покрытие чернозема обыкновенного составило 58%, южного – 35–66%, темно-каштановой почвы – 60%, каштановой – 40%. Растительный покров на пахотных почвах представлен культурной и сорной растительностью, на пастбищах – разнотравными ассоциациями с мелко- и крупнодерновинными растениями настоящих степей. Генетические горизонты изученных разрезов соответствуют типу почв. Плодородие почв очень низкое, обусловленное как факторами почвообразования, так и дигрессионными процессами природного и антропогенного характера. Близкое залегание карбонатов от поверхности (20–35 см) при малом количестве осадков и преобладании выпотного водного режима привело к подщелачиванию верхнего (0–20 см) слоя почвы. Среди поглощенных оснований преобладает кальций. Его содержание относительно концентрации магния в 2,5 и 5,5 раза выше на каштановых и черноземных почвах соответственно. Наиболее плодородные почвы, сформированные в наиболее увлажненной Ширинской степи, содержат до 3,3–3,4% органического вещества. В почвах более сухих степей в южной части республики наблюдается снижение содержания органического вещества до 2,1–2,9%. В соответствии с содержанием органического вещества изменялась и концентрация общего азота в пределах 0,17–0,29 мг/кг. Отмечены средняя и высокая степени биогенной аккумуляции подвижных форм фосфора и калия в пахотном слое. Так, корреляция содержания подвижных фосфатов и калия с общим азотом составила 0,45 и 0,97 соответственно. Среднее содержание подвижных фосфатов зафиксировано в черноземах и темно-каштановой почве (15,3–23,6 мг/кг), низкое – в каштановой. Обеспеченность калием изменялась от очень высокой в почвах Ширинской степи до высокой и повышенной в южных черноземах и каштановых почвах Койбальской и Уйбатской степей.

Ключевые слова: Хакасия, сельскохозяйственные почвы, почвенная морфология, агрохимия

Fertility of steppe soils of the Republic of Khakassia

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Soil-geobotanical survey of the main erosion-prone agricultural landscapes of the steppe zone of the Republic of Khakassia was carried out by laying six benchmark sites on the testing areas selected by the Earth remote sensing method. Based on the morphological description of the sections, the following soil types were identified: ordinary and southern chernozem, dark chestnut and chestnut soils. The projective coverage of ordinary black soil was 58%, southern black soil – 35–66%, dark chestnut soil – 60%, chestnut soil – 40%. Vegetation cover on the arable soils is represented by cultivated and weedy vegetation, on the pastures – by herbaceous associations with fine- and sod forming plants of true steppes. Genetic horizons of the studied sections correspond to the soil type. Soil fertility is very low due to both soil formation factors and natural and anthropogenic digression processes. The close occurrence of carbonates from the surface (20–35 cm) with low precipitation and predominance of exudational water regime resulted in alkalinization of the upper (0–20 cm) soil layer. Calcium predominates among the absorbed bases. Its content relative to magnesium concentration is 2.5 and 5.5 times higher on chestnut and chernozem soils, respectively. The most fertile soils formed in the most moistened Shirinskaya steppe contain up to 3.3–3.4% of organic matter. In the soils of drier steppes in the southern part of the republic there is a decrease in organic matter content to 2.1–2.9%. The concentration of total nitrogen also varied in accordance with the organic matter content, ranging from 0.17–0.29 mg/kg. Medium and high degree of biogenic accumulation of mobile forms of phosphorus and potassium in the arable layer was noted. Thus, the correlation of mobile phosphate and potassium content with total nitrogen was 0.45 and 0.97, respectively. The average content of mobile phosphates was recorded in chernozems and dark chestnut soil (15.3–23.6 mg/kg), low – in chestnut soil. Potassium supply varied from very high in the soils of Shirinskaya steppe to high and elevated in southern chernozems and chestnut soils of Koibalskaya and Uibatskaya steppes.

Keywords: Khakassia, agricultural soils, soil morphology, agrochemistry

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INTRODUCTION

The Republic of Khakassia, located in the Altai-Sayan mountainous region, is part of the Siberian Federal District and is part of the East Siberian economic region. As of January 1, 2021, the land fund of the Republic amounted to 6156.9 thousand hectares, of which 30.4% (1871.9 thousand hectares) was occupied by agricultural land[1]. The trends of climate aridization in the world cause a number of negative processes that reduce the productivity of agricultural land[2] [1], and the temperature increase in Russia since the beginning of the twentieth century has averaged 0.9...1.1 °C [2]. Thus, in the southern regions of Western Siberia, including the Republic of Khakassia, the main factors of land vulnerability are and are predicted to be heat waves, droughts, dust storms, dry winds, wind erosion (see footnote 2). Significant potential erosion hazard of the agricultural part of the region's territory is also indicated by the results of scientific research of the Research Institute of Agrarian Problems of Khakassia [3–5].

[1]Report on the state and use of land in the Republic of Khakassia in 2020 / Federal Service of State Registration, Cadastre and Cartography. URL: https://rosreestr.gov.ru/ (date of reference: 06.10.2024).

[2]National report “Global climate and soil cover of Russia: drought manifestations, measures of prevention, control, elimination of consequences and adaptation measures (agriculture and forestry)” / ed. by R.S.-Kh. Edelgeriev, Moscow, 2021, vol. 3, 700 p.

In general, in the typical composition of arable and post-agricultural soils on the territory of Khakassia chernozems of different subtypes prevail: low-moisture ordinary chernozems are mainly developed on hills and hills, southern chernozems lie lower on the southern slopes, medium-moisture ordinary chernozems, sometimes leached chernozems are located on the northern slopes. In the valley there are slightly saline and deeply slightly saline southern and ordinary chernozems. Chestnut soils are confined mainly to plain relief elements, which correspond to ancient river terraces [6]. According to agro-ecological zoning of the territory of Khakassia, four agrolandscape regions (dry-steppe Priabakan-Uybatsky, steppe Sayan-Altaisky, forest-steppe Sayan-Altaisky and sub-taiga Sayan-Altaisky), seven agro-ecological groups and 11 types of land have been identified in the erosion-prone agricultural part of the republic [4, 5]. The main steppe areas of Khakassia are confined to the Minusinsk Basin - transformed low-bush-grass common cattail, fescue-feather grass, sedge-fescue with common cattail and koeleria and fine-wormwood-fescue steppes[3] [7].

The present-day soil cover of Khakassia is very heterogeneous due to differences in the geomorphology of the districts and their history. The spatial distribution of soils shows latitudinal zonality and vertical belt [6, 8]. According to the degree of humus content, 41.6% (214.9 thousand hectares) of arable land are low- and low-humus soils (containing less than 4% of humus), 36.6% – medium-humus soils and only 21.8% of soils are characterized by a high degree of humus content. On the whole in the republic the soils contain 4.7% of humus, its reserves in 0–20 cm layer are 95–110 t/ha [8, 9].

The purpose of the study is to determine the current level of fertility of the main erosion-prone agricultural landscapes of the steppe zone of the Republic of Khakassia.

The objectives are:

1) laying out soil transects and conduct morphological description of typical soils of the study sites;

2) conducting a geobotanical survey of the studied agro-landscapes;

3) assessment of the fertility of the studied soils according to soil-agrochemical indicators;

4) development of the proposals on preservation and restoration of dry pastures, as well as an increase of their productivity.

MATERIAL AND METHODS

The Buryat Research Institute of Agriculture within the framework of research on the subject of “National Action Program to Combat Desertification” in the territory of the Republic of Khakassia in 2022 and 2023 six reference plots were laid out on polygons selected by the Earth remote sensing (ERS) and subsequent route soil-geobotanical survey (see fig. 1). The survey plots were located in the main erosion-hazardous landscapes of the steppe zone on the territory of three districts of the republic (see Table 1). The survey area can be divided into two aerial landscape regions with different soil-climatic potential: Sayan-Altaisky (Shirinskaya steppe) and Priabakan-Uybatsky dry-steppe (Koibalsky and Uybatskaya steppes) [5].

According to geographical zoning, the study sites are located in different geographical points of the Nazarovsk-Minusinsk intermountain depression: within the Chebakovo-Balakhtinskaya Basin in the zone of location of the Shirinskaya lake-kettlehole steppe (polygons Borets and Tselinnoye), in the Minusinsk Basin in the zone of location of the Uybatskaya (Zarya, Vesennee) and Koibalskaya steppes (Krasnopolye, Berezovka).

Climatic characteristics of the agrolandscape areas differ significantly. The Shirinskaya steppe is moderately dry with an average annual precipitation of 320-380 mm and HTC = 0.8-0.12 (according to Selyaninov). Dry Uybatskaya and

[3] *Gadzhiev I.M., Korolyuk A.Yu., Titlyanova A.A., Andrievsky V.S., Grishina L.G., Kosykh N.P., Kyrgyz Ch.O., Romanova I.P., Sambuu A.D., Smelyansky I.E.* Steppes of Central Asia. Novosibirsk, 2002, 299 p.

Рис. 1. Расположение реперных участков
Fig. 1. Location of the benchmark sites

Табл. 1. Почвенно-ландшафтная характеристика территории размещения реперных участков
Table 1. Soil-landscape characteristics of the territory of benchmark site location

Polygon	Soil	Type of degradation	District	Terrain
Borets	Ordinary chernozem	Water erosion	Shirinsky	Shirinskaya lake-kettlehole steppe. Steppe foothill terrain
Tselinnoye	Dark chestnut	»	»	The same
Berezovka	Southern chernozem	Water erosion, deflation	Altaisky	Koibalskaya steppe. Steppe South Siberian plain terrain
Krasnopolye	»	The same	»	The same
Vesennee	Dark chestnut	»	Ust-Abakansky	Uybatskaya steppe. Steppe South Siberian plain terrain
Zarya	Southern chernozem	»	»	The same

Koibalskaya steppes are characterized by more aridity: the sum of precipitation is 250–300 mm, HTC = 0.80 (according to Selyaninov)[4].

Mixed soil samples were taken from the 0–20 cm layer. The soils were described according to the classification 1977[5]. Chemical analysis of the soils was carried out in the accredited testing laboratory of the State station of agrochemical service "Khakasskaya" according to the standard methods accepted in the agrochemical service[6].

RESULTS AND DISCUSSION

In soil-geographical respect[7] the area of distribution of lakeside landscapes belongs to the Minusinsk province of ordinary and southern chernozems and the Tuva province of dark chestnut and chestnut soils. The general character and direction of soil formation process here are determined by peculiarities of bioclimatic conditions. Severity of ecological conditions connected with long freezing of soils, short vegetation period, dry spring, uneven precipitation and sharp fluctuations of daily and annual temperatures, causes essential regional differences of steppe soil formation in Khakassia from the processes occurring in the steppe zone of the European territory of Russia. Organic matter is supplied to the soils mainly by underground plant organs concentrated in the upper, most moistened and warmed thickness of the soil profile. Low productivity of phytocenoses and poor movement of soil formation products cause general low thickness and low humus of zonal soils (see fig. 2).

The formation of soil cover of the steppe zone of Khakassia is also accompanied by a significant manifestation of exogenous processes. Deflation, especially activated in dry years and in spring-early summer period, delays soil development at one stage. In this connection, the soils are often characterized by shortened profile thickness and underdevelopment[8]. Fertility of the degraded soils was studied on polygons in different soil-geographical areas of the Republic: within the Chebakovo-Balakhtinskaya (polygons Borets, Tselinnoe) and Minusinsk basins (Zarya, Vesennee, Krasnopolye, Berezovka) of the Nazarovsk-Minusinskaya intermountain depression[9].

Morphological description of typical soils of the study sites

The Borets polygon is located on the steppe plain area at the foot of the slope. The relief is plain and hilly. To characterize the morphological features of the soil, a transect 9.7 km northeast of the village of Borets was laid on arable land. The projective coverage of the field after harvesting oats is 58%. Cultural and weedy vegetation is found on the plot: *Avena sativa* (33,0%), *Setaria glauca* (2,0), *Erodium cicutarium* (1,7), *Vicia cracca* (1,0), *Milium effusum* L. (1,0), *Sonchus arvensis* (0,9), *Vicia segetalis* (0,9), *Elytrigia repens* (0,7), *Fallopia convolvulus* L. (0,5), *Lactuca tata-rica* L. (0,3%).

The soil profile is represented by the following horizons:

1. A_p (plow horizon), 0–19 cm – dark gray in color, moist, loose, the structure of soil ag-

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[4]Subregional National Action Program to Combat Desertification for the South of Middle Siberia of the Russian Federation (Republic of Khakassia, Republic of Tuva, southern districts of the Krasnoyarsk Territory) / ed. by V.K. Savostyanov, Abakan, 2000, 260 p. [5]Classification and diagnostics of the soils of the USSR. Moscow: Kolos, 1977, 224 p.

[6]GOST 26423-85. Soils. Methods of determination of specific electrical conductivity, pH and dense residue of water extract. Moscow: Standardinform, 2011; GOST 26205-91. Soils. Determination of mobile compounds of phosphorus and potassium by the method of Machigin in modification of CINAO. Moscow: Publishing House of Standards, 1992; GOST 26213-2021. Soils. Methods of determination of organic matter. Moscow, 2021; GOST 26487-85. Soils. Determination of exchangeable calcium and exchangeable (mobile) magnesium by CINAO methods. Moscow, 1986.

[7]Dobrovolsky G.V., Urusevskaya I.S. Geography of soils: textbook for students of higher educational institutions. Moscow, 2006, 458 p.

[8]*Shamshayeva V.F.* Soils of lakeside landscapes of the steppe zone of Khakassia: extended abstract of candidate's thesis in biology, Tomsk, 2003, 20 p.

[9]*Kutkina N.V., Eremina I.G.* Agrolandscape land zoning in Khakassia // Soil resources and their rational use: materials of the All-Russian scientific-practical conference dedicated to the 100th anniversary of the birth of Dr. of Science in Agriculture, Prof. P.S. Bugakov (Krasnoyarsk, 22 April, 2022). Krasnoyarsk, 2022, pp. 36-41.

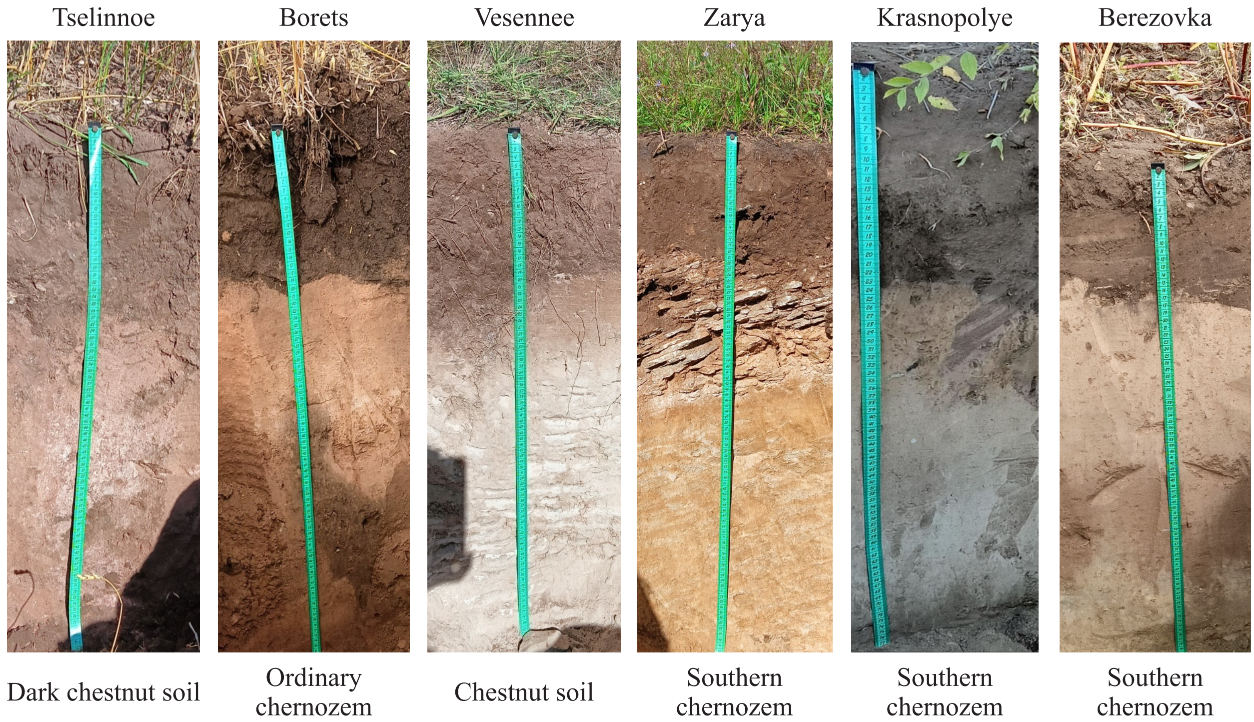

Рис. 2. Почвенные разрезы

Fig. 2. Soil sections

gregates is crumbly, there are inclusions of plant roots, no new formations, the transition to the underlying horizon is sharp in color, effervescence with HCl is vigorous, the granulometric composition is medium loamy (physical clay content is 38.7%).

2. B, 19–55 cm – light brown in color, moist, structureless, dense, no inclusions or new formations, the transition to the underlying horizon is tongued (irregular), the reaction with HCl is vigorous, the granulometric composition is medium loamy.

3. BC, 55–82 cm – brown in color, fresh (moist), structureless, dense, there are inclusions of small gravel, the reaction with HCl is vigorous, the granulometric composition is sandy loam.

Soil type – ordinary carbonate medium-loamy weakly eroded chernozem on deluvial deposits[10].

The Tselinnoe polygon is located on a plain-hilly area with elevation differences of 130–140 meters. The soil profile was established in the middle part of a gentle slope on arable land, 7.9 km northeast of the village of Zhemchuzhny. The projective cover of the field under wheat is 60%. The vegetation cover consists of the following species: *Triticum aestivum* (31,0%), *Avena sativa* (2,0), *Milium effusum* L. (2,0), *Taraxacum officinale* (1,0), *Setaria glauca* (1,0), *Sonchus arvensis* (0,9), *Erodium cicutarium* (0,9), *Fallopia convolvulus* L. (0,9), *Hordeum vulgare* (0,3%).

The soil profile is represented by the following horizons:

1. A_p horizon, 0–19 cm – dark gray in color, fresh (moist), the structure is crumbly to fine crumbly, the density is loose, there are inclusions of plant roots, no new formations, the transition to the underlying horizon is sharp in terms of density, the reaction to 10% HCl is vigorous, the granulometric composition is heavy loamy (physical clay content is 42.2%).

2. AB horizon, 19–26 cm – dark brown in color, fresh (moist), the structure of soil aggregates is crumbly to dusty, the density is compact, there are inclusions of plant roots, new formations of

[10]Classification and diagnostics of the soils of Western Siberia (instruct. materials for soil mapping). Novosibirsk, 1979, 48 p.

siliceous-gypsum concretions, the transition to the underlying horizon is distinct, the reaction to 10% HCl is vigorous, the granulometric composition is heavy loamy.

3. B horizon, 26–79 cm – light brown in color, fresh (moist), the structure of soil aggregates is dusty, the density is loose, no inclusions, new formations are white soft spots (calcareous concretions, 1.0–1.5 cm in diameter), the reaction to 10% HCl is vigorous, the granulometric composition is medium loamy.

The soil is dark chestnut carbonate medium-loamy deflated (wind-eroded) on deluvial-eluvial deposits.

The Berezovka polygon is located 6.7 km southwest of the village of Berezovka, on the upper part of a gentle slope in a buckwheat field. The relief is hilly with elevation differences of 160–170 meters. The projective cover is 60%. The vegetation is represented by the following species: *Polygonum fagopyrum* (20,0%), *Sonchus arvensis* (4,0), *Erodium cicutarium* (3,0), *Convolvulus arvensis* (3,0), *Milium effusum* L. (1,0), *Lactuca tatarica* L. (1,0), *Atriplex patula* L. (1,0), *Alopecurus myosuroides* (1,0), *Taraxacum officinale* (1,0), *Camelina sativa* (1,0), *Agrostis stolonifera* (1,0), *Galium aparine* (1,0), *Eriophorum vaginatum* (1,0), *Vicia segetalis* (1,0%).

The soil profile is represented by the following horizons:

1. A_p horizon, 0–17 cm – dark gray in color, fresh (moist), dense, the structure is fine crumbly, there are inclusions of plant roots, no new formations, the transition to the underlying horizon is sharp in terms of color and density, effervescence (with HCl) is vigorous, the granulometric composition is light loamy (physical clay content is 24.6%).

2. AB horizon, 17–45 cm – light brown in color, fresh (moist), structureless, dense, there are inclusions of roots, no new formations, the transition to the underlying horizon is gradual, the reaction to 10% HCl is vigorous, the granulometric composition is light loamy.

3. B horizon, 45–70 cm – pale yellow in color, fresh (moist), loose, the structure is dusty, no inclusions or new formations, there is no reaction to 10% HCl, the granulometric composition is sandy loam.

The soil is carbonate medium-loamy moderately eroded southern chernozem on alluvial deposits.

The Krasnopolye polygon is located 7.8 km northwest of the village of Krasnopolye, on a north-facing slope. The terrain is hilly with an elevation difference of 115–120 meters. The land use is pasture. The vegetation is represented by an elm-forb association: *Ulmus pumila* L. (9,0%), *Artemisia vulgaris* (2,0), *Artemisia frigida* (2,0) *Carex acuta* (2,0), *Teloxys aristata* (1,0), *Sonchus arvensis* (1,0), *Barbarea vulgaris* Ait. f. (1,0), *Galium aparine* (1,0), *Thlaspi arvense* Linn. (1,0), *Convolvulus arvensis* (1,0), *Vicia cracca* (1,0), *Camelina sativa* (1,0), *Taraxacum officinale* (1,0), *Phleum pratense* (1,0), *Salsola tragus* (1,0%). The projective cover is 35%.

The typical soil profile is represented by the following horizons:

1. A horizon, 0–23 cm – dark brown in color, dry, loose, the structure is crumbly to dusty, there are inclusions of plant roots, no new formations, the transition to the underlying horizon is sharp in terms of color and density, effervescence occurs at the surface, the granulometric composition is light loamy (physical clay content is 29.2%).

2. AB horizon, 23–34 cm – dark brown in color, fresh (moist), crumbly structure, the density is compact, there are inclusions of roots, the transition to the underlying horizon is distinct in terms of color, the reaction to 10% HCl is vigorous, the granulometric composition is light loamy.

3. BB horizon, 34–77 cm – pale yellow (buff) in color, fresh (moist), dense, the structure is powdery, there are inclusions of roots (mainly dwarf elm), no new formations, the reaction to 10% HCl is vigorous, the granulometric composition is sandy loam.

The soil is carbonate medium-loamy moderately eroded southern chernozem on deluvial-alluvial deposits.

The Vesennee polygon is located on a gentle slope, 9.4 km southeast of the village of Vesennoye. The terrain is plain-hilly with small elevation differences of up to 10 meters. The vegetation cover consists of small and large tussock plants of true steppes and forbs: *Stipa lessingiiana* (14,0%), *Aster amellus* (5,0), *Artemisia vulgaris* (4,0), *Artemi-sia frigida* (3,0), *Taraxacum officinale* (3,0), *Telo-xys aristata* (2,0), *Agropyron pectinatum* (2,0), *Elymus junceus* Fisch. (1,0), *Echinochloa crus-galli* (1,0), *Alopecurus pratensis* (1,0), *Iris sibirica* (1,0), *Plantago psyllium* (1,0), *Gnaphalium uliginosum* (1,0), *Myosotis arvensis* (1,0%). The projective cover is 40%.

The soil profile, established on a pasture, is represented by the following horizons:

1. A horizon, 0–20 cm – brown in color, dry, dense, the structure is crumbly to nutty, there are inclusions of stones and plant roots, no new formations, the transition to the underlying horizon is distinct in terms of color and density, effervescence is vigorous at the surface, the granulometric composition is medium loamy (physical clay content is 31.2%).
2. AB horizon, 20–33 cm – light brown in color, fresh (moist), dense, the structure is fine crumbly, there are inclusions of plant roots and carbonates, new formations include cutans, the transition to the underlying horizon is gradual, effervescence (with HCl) is vigorous, the granulometric composition is light loamy.
3. B horizon, 33–80 cm – light gray in color, fresh (moist), dense, the structure is platy, there are inclusions of stone slabs and carbonates, no new formations, the reaction to HCl is vigorous, the granulometric composition is sandy loam.

The soil is chestnut carbonate medium-loamy on deluvial-alluvial deposits.

The Zarya polygon is located on a gently hilly area with an elevation difference of 60–70 meters, 2.8 km southwest of the village of Zarya. The soil profile was established on a gentle north-facing slope in pastureland. The vegetation is steppe forbs: *Poa angustifolia* (17,0%), *Aster amellus* (15,0), *Artemisia frigida* (14,0), *Taraxacum officinale* (5,0), *Artemisia vulgaris* (3,0), *Elytrigia repens* (3,0), *Teloxys aristata* (2,0), *Barbarea vulgaris* (2,0), *Senecio vulgaris* (1,0), *Vicia cracca* (1,0), *Salsola tragus* (1,0), *Ambrosia artemisiifolia* (1,0), *Chelidonium majus* (0,7), *Linaria vulgaris* (0,3%). The projective cover is 66%.

A soil section was laid down at the site, represented by the following horizons:

1. A horizon, 0–20 cm – dark gray in color, fresh (moist), dense, the structure is crumbly, there are inclusions of stones and small plant roots, no new formations, the transition to the underlying horizon is sharp in terms of color and density, the reaction to HCl is vigorous, the granulometric composition is light loamy (physical clay content is 29.7%).
2. BCA horizon, 20–45 cm – yellow-brown in color, fresh (moist), dense, the structure is platy, there are inclusions of carbonates, no new formations, the transition to the underlying horizon is sharp in terms of density, the reaction to HCl is vigorous, the granulometric composition is light loamy.
3. BC horizon, 45–92 cm – brown in color, fresh (moist), moderately dense, the structure is granular-powdery, no inclusions or new formations, there is no reaction to 10% HCl, the granulometric composition is sandy loam.

The soil is carbonate medium-loamy southern chernozem on deluvial-alluvial deposits.

The landscape of the studied sites is predominantly plain-hilly with elevation differences of 70–170 meters. Typical polygons are located on slopes of various aspects and gradients. In this regard, the soils are erosion-prone and subject to varying degrees of deflation and water erosion. The soils are cultivated and used as arable land and pastures.

Agrochemical parameters of the soils

The fertility of the degraded soils is very low, influenced by both soil-forming factors and digressive processes of natural and anthropogenic origin (see Table 2). Acid-base properties are one of the main physicochemical indicators of soils, determining their productivity. Environmental conditions significantly affect the mi-

Табл. 2. Агрохимические показатели почв полигонов исследования
Table 2. Agrochemical indicators of the study site soils

Polygon, soil	pH $_{water}$	Organic matter (mass fraction)	N $_{total}$	P_2O_5 mobile	K_2O exchangeable	Ca^{2+}	Mg^{2+}	Solids
		%		mg/kg (according to Machigin)		mg-eq /100 g		%
Borets, ordinary medium loamy chernozem	7,9 ± 0,1	3,4	0,29 ± 0,03	19,8 ± 4,0	> 500	19,4 ± 1,0	2,50 ± 0,25	0,18 ± 0,04
Tselinnoye, dark chestnut brown medium loamy soil	7,9 ± 0,1	3,3	0,28 ± 0,03	23,6 ± 4,7	> 500	14,8 ± 0,7	6,00 ± 0,60	0,17 ± 0,03
Berezovka, medium loamy southern chernozem	7,8 ± 0,1	2,5	0,20 ± 0,02	19,3 ± 3,9	171 ± 17	12,9 ± 0,6	1,50 ± 0,19	0,15 ± 0,03
Krasnopolye, medium loamy southern chernozem	7,6 ± 0,1	2,1	0,17 ± 0,01	15,3 ± 3,1	136 ± 14	11,9 ± 0,6	0,75 ± 0,09	0,13 ± 0,03
Vesennee, chestnut medium loamy	7,7 ± 0,1	2,9	0,22 ± 0,02	9,16 ± 2,7	222 ± 22	9,5 ± 0,5	3,88 ± 0,39	0,29 ± 0,06
Zarya, medium loamy southern chernozem	7,8 ± 0,1	2,7	0,20 ± 0,02	19,7 ± 5,9	198 ± 20	12,5 ± 0,6	2,25 ± 0,23	0,15 ± 0,03

crobiological and enzymatic activity of soils, as well as the root nutrition of plants. The shallow occurrence of carbonates near the soil surface (20–35 cm), combined with low precipitation and a predominant evaporative water regime, led to the alkalinization of the upper 20-centimeter soil layer. As a result, all soil types were characterized by a weakly alkaline reaction (pH 7.6–7.9). Among the absorbed bases, calcium predominates. In chestnut and chernozem soils, its content was several times higher than that of magnesium—2.5 and 5.5 times, respectively.

The soils of the studied polygons are medium-loamy in granulometric composition, which ensures a potentially favorable water and air regime for functioning. However, under conditions of moisture deficit and prolonged seasonal frost, they have low productivity and are unable to accumulate significant amounts of organic matter. The most fertile soils, formed in the more humid Shirinskaya steppe, contain up to 3.6–3.8% organic matter. In the soils of the drier steppes in the southern part of the republic (Koibalskaya and Uybatskaya steppes), there is a decrease in organic matter content to 2,1–2,9%.

This is related not only to soil-forming conditions but also to the active development of deflation processes—the main factors of dehumification in arable soils[11]. In accordance with the content of organic matter (mass fraction), the content of total nitrogen also varied within 0,17–0,29 мг/ кг[12].

The content of available phosphorus and potassium in the soils depended on the mineral composition of the parent material and the degree of their weathering. A moderate to high

[11] *Rozhentsova A.V., Spirina V.Z.* Steppe black soils of the left bank of the Minusinsk depression // Reflection of bio-, geo-, anthropospheric interactions in soils and soil cover: Proceedings of the VII International Scientific Conference dedicated to the 90th anniversary of the Department of Soil Science and Soil Ecology TSU (Tomsk, September 14–19, 2020), Tomsk, 2020, pp. 292–296.

[12] *Biltuev A.S., Lapukhin T.P., Budazhapov L.V.* Climate, soil fertility and productivity of grain crops in the arid conditions of Transbaikalia: status and forecast. Ulan-Ude, 2015, 141 p.

level of biogenic accumulation of these elements was recorded in the plow layer. The average content of available phosphates was observed in chernozems and dark chestnut soils (15.3–23.6 mg/kg), while low levels were found in chestnut soils. The potassium availability ranged from very high in the soils of the Shirinskaya steppe to high and elevated in the southern chernozems and chestnut soils of the Koibalskaya and Uybatskaya steppes. The studied soils of Khakassia are characterized by a very significant (9–25 times) excess of available potassium compared to phosphorus. This trend is typical for most steppe soils in the republic[13]. The studied soils are not saline, and the content of the solid residue did not exceed 0.3% [10, 11].

The most fertile soils of Khakassia are located in the northern part of the republic, in the steppe Sayan-Altai aerolandscape region (Shirinskaya lake-basin steppe). The soil-forming conditions have allowed the formation of the most fertile soils here—ordinary chernozems, which possess a combination of favorable water-physical and agrochemical properties for cultivating field crops. Data from five rounds of agrochemical surveys (1966–2003) have shown a dynamic decline in the content of humus, available phosphorus, and potassium. This is due not only to insufficient application of organic and mineral fertilizers but also to the development of erosion processes on sloping lands [5, 12]. The true arid steppes are located in the southern part of the republic, in the dry-steppe Priabakan-Uybatsky agrolandscape region (Koibalskaya and Uybatskaya steppes), where the soil cover is mainly composed of southern chernozems and chestnut soils. These soils are low in humus and have low potential fertility in terms of nitrogen. Effective fertility in terms of phosphorus is moderate in southern chernozems and low in chestnut soils, while in terms of potassium, it is elevated and high, respectively. The soils require measures to increase fertility levels and reduce the impact of deflation. At the same time, the Koybalskaya steppes are the most susceptible to deflation [12, 13].

CONCLUSION

The soils of the steppe territories in the Republic of Khakassia are located in the Sayan-Altai and Priabakan-Uybatsky aerolandscape regions, which differ in natural and climatic conditions and, accordingly, in potential fertility. The most fertile ordinary chernozems predominate in the steppes of the Sayan-Altai region and are primarily used in field crop production. Due to the highly dissected relief, the soils are susceptible to water erosion. To prevent water erosion on sloping lands, anti-erosion measures developed by the Research Institute of Agrarian Problems of Khakassia are recommended. Special attention should also be paid to the fertilizer application system aimed at maintaining effective fertility.

In the southern steppes, the zonal soils are southern chernozems and chestnut soils, which are characterized by lower nitrogen and phosphorus content. The predominant agricultural activity on these lands is livestock farming, including nomadic practices. The main factor in the degradation of these soils is deflation. The existing experience in Eastern Siberia for improving pasturelands in regions with developed livestock farming shows that the primary way to improve degraded pastures in dry steppes is the rationalization of their use within a pasture rotation system. The preservation and restoration of dry pastures, as well as increasing their productivity, should focus on the following directions:

1. Rationalization of use based on a pasture rotation system. The introduction of pasture rotation fundamentally changes the technology of free-range grazing, creating opportunities for planned pasture management and differentiated,

[13] *Spirina V.Z.* Black soils of Minusinsk flexure on red-colored loams // Soil resources of Siberia: challenges of the XXI century: proceedings of the All-Russian scientific conference with international participation, dedicated to the 110th anniversary of the outstanding organizer of science and the first director of ISSA SB RAS R.V. Kovalev (Novosibirsk, 4-8 December 2017) / edited by A.I. Syso, Novosibirsk, 2017, Ch. 1, pp. 139-142.

regulated stocking rates on pasture areas, taking into account their productivity.

2. Application of the methods for fundamental and surface improvement of low-productivity and degraded pastures. At the same time, the choice of measures should be approached selectively, taking into account local specifics based on geobotanical and agrochemical surveys of the area. For overseeding grasses, it is advisable to use local seed material from natural lands with high productivity and valuable herbage. The pasture rotation system should include the mandatory application of mineral nitrogen fertilizers during grassland renovation and the period of spring grass regrowth. Mountainous areas have a high coverage of water sources. Water reclamation in these areas will significantly increase pasture productivity and improve the fertility of the degraded areas.

Since the conducted studies only determine the current status of soils and vegetation cover, monitoring surveys of the territories using spectral analysis of landscapes and Earth remote sensing are necessary to determine the rates and direction of degradation processes.

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