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Research Article

The Influence of Slope Exposure, Profile Depth and Erosion Processes on Changes in the Content of Potassium, Phosphorus and Humus in Brown Soils of Mountain Pastures of Uzbekistan

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Abstract: Humus, potassium, and phosphorus are key components of soil that play crucial roles in ecosystem productivity, plant growth, and development. They control a wide range of processes, including greenhouse gas fluxes, nutrient cycling, infiltration, and water retention. This article presents the results of evaluating humus, potassium (K), and phosphorus (P) content in the profile of brown soils in mountain pastures of Uzbekistan, as well as their distribution within these soils. The brown soils studied in the mountain pastures of Uzbekistan have a loamy granulometric composition, with the clay fraction not exceeding 20%. The carbonate content is low (2.5-9%), with the maximum amount found in the carbonate horizon. The soils exhibit weak leaching. The total humus content in the upper horizon varies from 1 to 6.6%. It was observed that the soils on the more moistened northern and western slopes contain more humus than those on the southern and eastern slopes, indicating a dependence of high humus content on slope exposition. For the first time, the article allocates phosphorus and potassium of near, labile, and potential reserves (as a percentage of the total content) to estimate the change in the nature of brown soils under economic use. It was found that the potential reserve of phosphorus and potassium (35.5-90%) prevails in soils. Further study of the features of humus, potassium, and phosphorus, their accumulation, and restoration in brown soils is essential for developing recommendations for the rational use, anti-erosion protection, and increased productivity of mountain pastures in Uzbekistan.

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1. Introduction

Humus, potassium, and phosphorus are critical soil components that profoundly impact ecosystem productivity, plant growth, and development. They regulate various processes, including greenhouse gas fluxes, nutrient cycling, infiltration, and water retention (Lehmann et al., 2020; Kassa et al., 2021). Their presence in soils effectively reflects both the dynamic and static changes in soil formation conditions, including those induced by anthropogenic activities like soil contamination. Agricultural land cultivation and its intensive use often result in the loss of soil fertility (Haddaway et al., 2017; Chen et al., 2020; Franzluebbers, 2021). Therefore, reducing the rate of soil dehumidification while enhancing agricultural production efficiency is a critical challenge in land management, particularly in regions facing agricultural land scarcity due to unfavorable climatic conditions or topography.

In Uzbekistan, agriculture is a key sector of the economy, implementing a development strategy aimed at ensuring the country's food security. The country's territory is characterized by vast areas of infertile desert soils unsuitable for cultivation. The most favorable conditions for agriculture are found in river valleys, where farming on irrigated alluvial soils is traditional, and in the gentle sub-mountain zones and foothill plains, where low-productivity desert steppes on serozem are used as pastures and meadow-serozem soils as irrigated arable land (Kuziev et al., 2016). The Law on Pastures (2019) and the Agriculture Development Strategy of the Republic of Uzbekistan (2019) for 2020-2030 (both adopted in 2019) have spurred the more intensive use of mountainous areas in agriculture as pastures and hayfields. However, excessive grazing, leading to overgrazing, disrupts slope stability, promoting soil erosion, dehumidification, and a reduction in arable land area, restoration of which is challenging in mountainous terrain (Chen et al., 2019; Dou et al., 2022).

Despite numerous studies on humus, phosphorus, and potassium content and the factors influencing their dynamics in local soils (Akhatov et al., 2018; Kadirova et al., 2018; Normuratov et al., 2018; Raupova, 2018; Raupova and Abdullayev, 2018; Akhatov and Murodova, 2021; Askarov et al., 2021; Rakhmatov et al., 2021; Ruzmetov, 2021; Tashkuziev and Shadieva, 2021; Aliboeva et al., 2022; Turaev et al., 2022; Nabieva et al., 2023; Gafurova et al., 2024), the subject remains topical, especially given the current climate change trends in the region (Li et al., 2020). Of particular interest are the depletion of humus, potassium, and phosphorus reserves and the causes and factors of dehumidification of brown soils, which are widespread in the middle and low mountains and constitute the main part of the country's land fund. Therefore, this research aims to estimate the content of humus, potassium, and phosphorus, and their distribution in the profile of brown soils in mountain pastures in Uzbekistan.

2. Material and Methods

2.1. Areas and objects of research

The research was conducted in seven agricultural districts of the country between 2020 and 2023 (Table 1). Brown soils under mountain pastures (Gorbunov et al., 1975) were selected as the object of research. According to the World Reference Base for Soil Resources (IUSS Working Group WRB, 2015), the studied soils belong to Cambisols and Kastanozems, with the most eroded variants belonging to Leptosols.

Table1. Geographic location of key soil profile cuts

№ section	Coordinates Latitude	Longitude	Absolute height, m	Georeferencing of the section
74	40°57′41′′N	70°46′05′′E	1044	Kuraminsky ridge, western macro slope, near the settlement of Chodak, slope of western exposure, typical brown, calcareous, slightly eroded, medium humus, medium loamy soil on loess
54	39°52′21′′N	68°22′24′′E	924	Turkestan ridge, northern macro slope, near the settlement of Zomin, slope of western exposure, brown soil, leached, slightly eroded, medium humus, medium loamy on loess
40	39°30′38′′N	66°44′11′′E	885	Zarafshan ridge, western spur, northern macro slope, near the village of Sazagon, slope of eastern exposure, brown leached, slightly eroded, medium humus, medium loamy soil on loess loam
66	41°35′29′′N	70°07′17′′E	1382	Western Tien Shan, Koksu Range, southwestern slope, near the settlement of Burchmulla, slope of southern exposure, brown leached, medium eroded, medium humus, medium loamy soil on loess-like deluvium of granites

Table1. Geographic location of key soil profile cuts (continued)

№ section	Coordinates		Absolute height, m	Georeferencing of the section
	Latitude	Longitude		
28	40°25′47′′N	66°02′20′′E	839	Nuratau mountains (South-Nurata ridge), Aktau ridge, northern macro slope near the village of Chuya, slope of the northern exposure, brown leached, slightly eroded, medium humus, medium loamy soil on loess-like loam
13	39°12′54′′N	67°04′10′′E	1112	Zarafshan ridge, southwestern spur, western macro slope, near the village of Varganza, south-facing slope, south-facing slope, brown leached, medium eroded, medium humus, medium loamy soil on loess-like loam
1	37°42'24′′N	66°44′55′′E	824	Hissar ridge, southwestern spurs, Kugitangtau ridge, eastern macro slope, near the village of Pashkhurt, slope of southern exposure, slope of southern exposure brown leached, eroded, low humus, medium loamy soil on loess

Brown soils are widespread in the mountains of south-eastern and eastern Uzbekistan, where they occupy slopes of different steepness and exposition at altitudes from 800 to 1800 m. Soil-forming rocks are dealluvial and loess loams, carbonate rocks (Gorbunov et al., 1975). The climatic conditions are strictly continental, with an absolute maximum temperature of +45 ºC, and an absolute minimum of -30 ºC. Total solar radiation in the mountaisreaches up to 8350 MJ/m^2. In the foothills, precipitation ranges from 300-400 mm, increasing to 600-800 mm on the western and south-western slopes of mountain ranges. The highest amount of precipitation occurs in spring, reaching up to 600 mm, while the summer season experiences the lowest amount, with less than 100 mm. In the foothills (from 300-400 to 600-1000 m above sea level), stable snow cover does not form every winter. In the mountain zone (above 600-1000 m above sea level), snow cover begins at 800-1000 m and can reach a maximum thickness exceeding 1.5 m in some locations (Chub, 2007). The vegetation is represented by herb-bunchgrass steppes including pubescent wheatgrass (*Elytrigia aucheri* (Boiss.) Nevski), bulbous barley (*Hordeum bulbosum* L.), bulbous bluegrass (*Poa bulbosa* L.), bonfire (*Bromus* L.), prangos tall *(Prangos pabularia* Lindl*.)*, ferula (*Ferul*aspp.), cocksfoot (*Dactylis glomerata* L.), mortune oriental (*Eremopyrum orientale* L. Jaub. & Spach), bindweed pilose (*Convolvulus subhirsutus* Regel & Schmalh), cousinias hady (*Cousinia umbrosa* (Bunge) Kuntze) and others. On dry slopes, the growth of juniper-shrub forests with (*Juniperus turkestanica* Kom.), honeysuckle (*Lonicera* spp.), briar (*Rosa* spp.) is often observed (Gorbunov et al., 1975). In the whole country, desert pastures occupy 77%, piedmont pastures - 16%, mountain pastures - 4%, and high-mountain pastures - 3%. The natural foothill and mountain pastures of Uzbekistan occupy about 5 million ha, but their yields are low and amount to 3-7cwt ha^{-1}of air-dry mass, but in some areas and under favorable weather conditions this number can reach 12 cwt ha^{-1}.

In the Western Tien-Shan, brown soils typically form a distinct altitudinal belt. In the lower part of the belt, there is a subtype of slightly leached brown soils, while in the upper part, a subtype of typical brown soils is found. These soils are prone to erosion, and therefore, eroded types are often encountered to varying degrees. The typical profile of brown soils is characterized by a significant thickness, well-differentiated into humus-accumulative, metamorphic (median), and carbonate-illuvial horizons (Gorbunov et al., 1975).

The humus-accumulative horizon exhibits a gray or dark gray color with a brown tint, a loamy to medium loamy composition, a cloddy-flaser structure, and is saturated with roots (grassy sod). Carbonate types of soils effervesce at 10% hydrochloric acid from the surface. The median horizon is distinguished by its brown coloring, clayey granulometric composition, and nutty compound structure. The illuvial-carbonate horizon is compacted and easily identified by its whitish color, containing abundant new formations of secondary carbonates (loess with lime nodules, impregnation, pseudomycelium).

In strongly eroded brown soils, the profile is often broken to the carbonate horizon, with the upper part of the profile frequently absent. In moderately and slightly eroded soils, the upper part of the profile is fragmentary, and the differentiation into horizons is poorly expressed.

Seven profile cuts of brown soils with similar granulometric composition on slopes of different exposures were laid out for the studies.

2.1.1. Research methods

The objectives of the research included field studies of the morphological profiles of brown soils, soil sampling, and subsequent laboratory and analytical work. Field studies, sampling, and sample preparation followed generally accepted methods (Arinushkina, 1970; Rozanov, 1983). The degree of soil erodibility was evaluated according to Sobolev (1961). The total organic carbon and humus content were determined in the samples using the method of Tyurin (1937); inorganic carbon was determined using the method of Arinushkina (1970). Clay fractions were separated by centrifugation according to the method of Shaimukhometov and Voronina (1972). The carbonate content was determined by the acidimetric method (Scientific research Institute for Cotton Growing SoyuzNIKhI, 1963). The total potassium and phosphorus content was determined in one sample, with subsequent colorimetric determination using the method of Maltseva (Scientific research Institute for Cotton Growing SoyuzNIKhI, 1963). Mobile potassium and phosphorus (direct reserve) in soils and clay fractions were determined in a 1% $(NH_4)_2CO_2$ carbon-ammonium extract using the method of Machigin (Scientific research Institute for Cotton Growing SoyuzNIKhI, 1963).

The primary focus of the research was on a more detailed division into so-called potassium and phosphorus reserves and their calculation, carried out according to the method of calculating nutritional elements by Gorbunov (1978). In calculating reserves, the initial values were the overall content of potassium and phosphorus in the fraction less than 0.001 mm, in the agrochemical extract, and the quantity of the fraction less than 0.001 mm in soil, all expressed as a percentage. All calculations were made in milligrams per 100 g. The direct reserve (DR) represents the water-soluble, mobile form and is equal to the amount of potassium (phosphorus) in a 1% carbon-ammonium solution. The near reserve (NR) was defined as the potassium (phosphorus) in the clay fraction, considering a clay fraction of <0.001 mm (%). The potential reserve (PR) was obtained by subtracting the immediate and near reserve potassium (phosphorus) from the total reserve. All types of reserves were summed, and the percentage of each type of reserve was calculated from the sum (Gorbunov, 1978). Potassium and phosphorus reserves were calculated using the following equations:

$$NR = (P_{cl}\ x\ CF)/100 \tag{1}$$

where, NR is the near reserve of potassium (phosphorus), in mg 100 $g^{-1}$of soil;
P_{cl}- potassium content in the clay fraction, in mg 100 $g^{-1}$of soil
CF is the proportion of clay fraction, in %.

$$PR = TR - DR + NR \tag{2}$$

where, PR is the potential reserve of potassium (phosphorus), mg 100 g^{-1};
TR – total reserve of potassium (phosphorus), mg 100 g^{-1};
DR is the direct reserve of potassium (phosphorus), mg 100 g^{-1};
NR is the near reserve of potassium (phosphorus), mg 100 g^{-1}.

3. Results and Discussion

The total humus content in the upper horizon of the studied brown soils ranges from 1 to 6.6% (Table 2). The type of humus is defined as fulvate and humate-fulvate. The degree of erosion significantly affects the humus content of soils: Highly eroded soils show significant dehumidification due to almost destruction of the humus-accumulative horizon. Moderately eroded soils belong to the category of low-humus soils and contain, on average, 2-3% of humus, while slightly eroded brown soils have a higher humus content (4-5% of humus). The issue of preventing water erosion in the mountain regions of the country remains relevant. The vertical distribution of humus in the studied soils follows a regressive-accumulative pattern. The maximum amount of organic matter is concentrated in the upper

50-70 cm layer, with the humus content nearing 1% at a depth of about 1 m. The influence of exposure is noted in the distribution of humus: Soils on northern and western slopes accumulate a slightly higher amount than those on southern and eastern slopes.

Table 2. Content of humus, carbon and carbonates in mountain brown soils of Uzbekistan

Depth, (cm)	Humus, %	CO_2 carbonates, %	Soil C content, %			Content of the clay fraction, %	Humus Clay fraction, %	C_{org} Clay fraction, %
			C_{org}, %	C_{anorg}, %*	C_{total}, %			
Section 74								
0-7	6.58	3.82	3.82	1.04	4.86	3.0	16.93	9.82
7-26	2.79	1.62	1.62	0.44	2.06	8.3	6.81	3.95
26-75	2.38	1.38	1.38	0.38	1.76	8.6	6.81	3.95
Section 54.								
0-9	4.24	1.32	2.45	0.36	2.81	11.1	10.34	5.00
9-31	2.74	1.46	1.59	0.40	1.99	17.5	6.69	3.88
31-52	2.43	1.52	1.41	0.41	1.82	18.3	5.93	3.44
52-85	0.92	1.63	0.53	0.44	0.97	18.3	2.22	1.29
85-121	0.85	1.94	0.49	0.53	1.02	17.5	2.07	1.20
Section 40								
0-7	3.68	1.15	2.13	0.31	2.44	12.7	8.96	5.20
7-11	1.50	1.48	0.87	0.40	1.27	13.5	3.65	2.12
11-27	1.27	1.96	0.74	0.53	1.27	12.7	3.12	1.81
27-50	1.03	2.02	0.59	0.55	1.14	11.9	2.52	1.46
50-80	1.03	2.69	0.59	0.73	1.32	11.1	2.52	1.46
80-160	0.95	2.70	0.55	0.74	1.29	12.7	2.31	1.34
Section 66								
0-5	2.76	1.26	1.60	0.34	1,94	5.0	6.73	3.90
5-29	1.30	1.27	0.75	0.35	1,10	5.2	3.15	1.83
29-63	1.05	1.20	0.61	0.33	0,94	3.6	2.57	1.49
63-90	0.81	1.34	0.47	0.37	0,84	4.0	1.98	1.15
90-122	0.33	2.27	0.19	0.62	0.81	2.9	0.79	0.46
Section 28								
0-8	2.69	2.33	1.56	0.64	2.20	4.8	6.57	3.81
8-53	2.00	3.19	1.16	0.87	2.03	4.0	4.88	2.83
53-98	1.28	3.18	0.74	0.87	1.61	3.2	3.12	1.81
98-136	0.65	3.88	0.38	1.06	1.44	4.0	1.60	0.93
Section 13								
0-9	2.60	1.10	1.51	0.30	1.81	6.3	6,34	3.68
9-45	1.32	1.34	0.76	0.37	1.13	12.2	2,50	1.45
45-85	1.14	1.32	0.66	0.36	1.02	14.5	2,78	1.61
85-136	0.84	1.49	0.49	0.41	0.90	11.6	2,07	1.20
Section 1								
0-8	1.19	1.05	0.59	0.29	0.98	12.6	2.90	1.68
8-38	1.02	1.22	0.59	0.33	0.92	13.5	2.48	1.44
40-69	1.00	2.02	0.58	0.55	1.13	14.8	2.45	1.42
69-105	0.92	1.95	0.53	0.53	1.06	16.3	2.22	1.29

It is known that organic (C_{org}) and inorganic (C_{carb}) carbon constitute a single pool of soil carbon (Tan et al., 2014). In arid regions, the proportion of C_{carb} often dominates, while in more humid regions, its proportion is lower in the upper leached strata and increases in deeper ones, which may also be due to the influence of carbonate soil-forming rocks (Tan et al., 2014). In the brown soils we studied, the assessment of the organic and inorganic carbon content showed that the latter is present in an amount of about 12-76% of the total carbon (Table 2). At the same time, the vertical profile of C_{carb} repeats the general distribution of carbonates by depth. The level of carbonate in brown soils varies from low to medium (2.5-9% in terms of $CaCO_3$). The vertical distribution is eluvial with a uniform increase in content down the profile, or with a sharp increase in the carbonate horizon. The soils are weakly leached, with carbonate content above 1% in the surface horizon. The granulometric composition of the studied soils is middle-loamy. The proportion of clay fraction varies from 2.9 to 18.3% (Table 2). The vertical distribution is relatively uniform with indistinct accumulation in the middle part of the profile, which can be explained by illuvial processes. In connection with the fact that the clay fraction in soils is an important depot of organic matter (Hassink, 1997), organic and mineral interactions cause the concentration of large amounts of C_{org} in the fraction of this dimension (<0.001mm) (Table 2.) which, as we observe, is much higher than the total amount of soil carbon.

Indicators of potassium and phosphorus in the researched soils are the following (Table 3). The total potassium content in the sod horizon of the brown soils studied varies from 1.240 to 1.685%, and phosphorus–from 0.141 to 0.350%. Exchangeable K varies from 265 to 1028 mg kg^{-1} of soil, which depends on erodibility and humus content of the soil, so in the humus layer of moderately eroded soils of sections 13, 66the indicator is from 559 to 708 mg 100 g^{-1} in slightly eroded soils of sections 40, 54, 28, 74 – from 265 to 1028 mg 100 g^{-1} (Table 3). The percentage of exchangeable potassium from the total content of potassium, in the sod horizon, varies from 15.72 to 45.56%. The mobile phosphorus varies from 12.50 to 54.00 mg kg^{-1} of soil. The percentage of mobile P from total phosphorus content varies from 6.98 to 38.30%. The tendency of decreasing total and mobile P content to lower horizons of the soil profile is noticeable (Table 3).

Table 3. The total content of potassium, phosphorus, exchangeable potassium, and mobile phosphorus in the mountain brown soils of Uzbekistan

Depth, (cm)	Total, (%)		Exchangeable K and mobile P, $Mgkg^{-1}$		Exchangeable K and mobile P from the total, (%)	
	K	P	K	P	K	P
			Section 40.			
0-7	1.685	0.248	265	21.17	15.72	8.54
7-11	1.470	0.145	241	11.10	16.39	7.66
11-27	1.120	0.098	241	13.96	21.52	14.24
27-50	0.924	0.074	217	7.84	23.48	10.59
50-80	1.032	0.065	188	5.90	18.72	9.08
			Section 13.			
0-9	1.560	0.151	559	26.23	35.83	17.37
9-45	1.461	0.143	568	16.71	38.88	11.68
45-85	1.442	0.127	442	9.12	30.65	7.18
			Section 66.			
0-5	1.554	0.164	708	43.20	45.56	26.34
5-29	1.476	0.157	686	28.80	46.48	18.34
29-63	1.464	0.107	648	16.00	44.26	14.95
63-90	1.050	0.090	600	11.20	57.14	12.44
90-122	0.930	0.037	578	8.00	62.15	21.62
0-5	1.554	0.164	708	43.20	45.56	26.34
			Section 54.			
0-9	1.442	0.350	310	48.05	21.50	13.16
9-31	1.412	0.241	304	20.48	21.53	8.50
31-52	1.288	0.215	262	12.14	20.34	5.65
52-85	1.035	0.200	213	9.21	20.58	4.61
85-121	1.005	0.152	194	8.17	19.30	5.40
			Section 28.			
0-8	1.321	0.179	271	12.50	20.51	6.98
8-53	1.488	0.103	240	8.45	16.12	8.20
53-98	1.474	0.059	228	4.31	15.47	7.31
98-136	0.967	0.052	180	0.96	18.61	1.85
			Section 1.			
0-8	1.270	0.279	443	35.14	34.88	12.60
8-38	1.165	0.209	271	25.25	23.26	12.08
40-69	1.120	0.214	190	12.46	16.96	5.82
69-105	0.930	0.145	100	7.13	10.75	4.92
			Section 74.			
0-7	1.240	0.141	1028	54.00	32.90	38.30
7-26	1.280	0.124	539	14.09	42.11	11.32
26-75	0.960	0.128	424	18.00	44.16	14.06

The numerical values for potassium and phosphorus reserves are shown in Table 4. As indicated, the direct reserve of potassium and phosphorus is available for microorganisms and plants. The vertical distribution of the direct reserve of both elements depends on slope exposure and soil erodibility, as it is mobile in a mildly alkaline environment along the soil profile. In the studied soils, the share of potassium direct reserve varies from 10 to 103 mg per 100 g^{-1}, and the share of total phosphorus direct reserve from total phosphorus content varies from 1.56 to 8.31% (Table 4).

Table 4. Changes in the content of potassium and phosphorus reserves, taking into account the clay fraction in the mountain brown soils of Uzbekistan

Depth, (cm)	Content of the clay fraction, %	In the clay fraction, %		Potassium reserves, from the total content, %			Phosphorus reserves, from the total content, %		
		K	P	Direct	Near	Potential	Direct	Near	Potential
Section 40									
0-7	12.7	3.02	0.379	2.12	2.79	75.61	8.47	19.35	72.18
7-11	13.5	2.63	0.222	1.63	4.15	74.22	7.59	20.69	71.72
11-27	12.7	2.00	0.150	2.14	2.68	75.18	14.29	19.39	66.33
27-50	11.9	1.65	0.113	2.38	1.21	76.41	10.81	17.57	71.62
50-80	11.1	1.34	0.100	1.84	4.44	83.72	9.23	16.92	73.85
Section 13									
0-9	6.3	2.79	0.234	3.60	11.28	85.13	5.96	9.76	84.11
9-45	12.2	2.62	0.231	3.90	21.90	74.20	17.22	18.54	64.24
45-85	14.5	2.58	0.219	3.05	25.94	71.01	11.89	22.38	65.73
Section 66									
0-5	5.0	2.78	0.251	4.57	8.88	86.55	26.2	7.68	65.86
5-29	5.2	2.64	0.240	4.67	9.28	86.04	18.47	7.96	73.25
29-63	3.6	2.62	0.164	4.37	6.42	89.21	14.95	5.51	79.44
63-90	4.0	1.88	0.138	5.71	7.14	87.14	12.72	6.11	81.11
90-122	2.9	1.66	0.057	6.24	5.16	88.60	21.62	5.41	72.97
Section 54									
0-9	11.1	2.58	0.558	2.15	19.83	78.16	13.15	16.99	69.86
9-31	17.5	2.53	0.369	2.12	31.37	66.50	8.75	27.08	64.17
31-52	18.3	2.31	0.329	2.02	32.84	65.14	5.58	27.91	66.51
52-85	18.3	1.86	0.306	2.03	32.85	65.12	4.4	28.0	67.5
85-121	17.5	1.31	0.233	1.89	22.79	75.32	5.3	26.97	67.76
Section 28									
0-8	4.8	2.36	0.274	2.04	8.55	89.40	7.26	7.26	85.47
8-53	4.0	2.66	0.158	1.61	7.12	91.20	8.74	5.83	85.44
53-98	3.2	2.63	0.090	1.56	5.70	93.0	6.78	5.08	88.14
98-136	4.0	1.26	0.080	1.86	5.17	92.96	1.92	6.15	92.31
Section 1									
0-8	12.6	2.27	0.427	3.46	22.52	74.01	12.55	8.99	68.46
8-38	13.5	2.09	0.320	2.32	24.21	73.48	11.96	0.57	67.46
40-69	14.8	2.00	0.322	1.70	26.43	71.86	5.61	7.43	71.96
69-105	16.3	1.66	0.221	3,.46	22.52	74.01	4.83	4.84	70.34
Section 74									
0-7	3.0	2.22	0.216	8.31	5.40	86.29	38.30	9.86	82.14
7-26	8.3	2.29	0.189	4.22	14.84	80.94	11.29	7.90	75.81
26-75	8.6	1.88	0.230	4.38	16.88	78.75	14.06	5.62	70.31

The near reserve was defined as potassium in the clay fraction, taking into account the content of the clay fraction of <0.001 mm (%). The vertical distribution of near-reserve potassium is not uniform, with an uneven decrease in content down the profile from 1.84 to 4.57%, with a poor accumulation in the middle and lower parts of the profile, which can be explained by illuvial processes. In percentage correlation in the sod horizon of soils, it ranges from 5.40 to 32.85% of the total potassium content. The maximum accumulation of near reserve in the sod horizon of brown soils in the section is 40 - 384 mg 100 g^{-1}, and the minimum in the section is 28 - 50 mg 100 g^{-1}. In contrast to potassium, the vertical distribution of near-reserve phosphorus is homogeneous, with a uniform decrease in content down the profile from 62.0 to 2.0 mg 100 g^{-1}. In percentage correlation of the upper soil horizon, it ranges from 7 to 30% of total phosphorus content. The maximum accumulation of near reserve in the humus horizon of brown soils in section 54 is 62.0 mg 100 g^{-1}, and the minimum in section 66 is 12.60 mg 100 g^{-1}. On the slopes of the southern and eastern exposition (sections 40, 13, 1) the distribution of potassium and phosphorus of the near-reserve across the profile is non-uniform since it is the southern and eastern slopes that receive less precipitation (Table 3).

In the studied brown soils potential reserve is dominating in the total content and varies on a profile - potassium from 65.12 to 93.0% (Table 4), phosphorus from 60.0 to 90.0%, it was observed that sharp decrease of indicators of phosphorus of potential reserve in sub-sod horizon of a profile and in general its vertical distribution is not uniform at both elements. The maximum share of potassium potential reserve in the humus horizon of brown soils was recorded in section 66 - 1345 mg 100 g^{-1}(up to 89% of total potassium), phosphorus in section 54 - 255 mg 100 g^{-1}(up to 70% of total phosphorus). Minimum potassium potential reserve in section 1 - 940 mg 100 g^{-1}(up to 74% of total potassium), phosphorus in section 74 - 59 mg 100 g^{-1}(up to 82.14% of total phosphorus) (Table 3).

The hydromicas (hydromuscovite) mineral is hydromorphic, as a result of which, under the influence of high humidity in the upper layers of the soil, the process of montmorillitization of hydromicas proceeds - the formation of the montmorillonite mineral. In this process, potassium is lost from the mineral structure of hydromica, which can be seen from the given crystallochemical reaction:

$$K{<}Al_2(SiAl)_4O_{10}(OH)_2 n\ H_2O + Al_2O_3\ 2SiO_2 2H_2O + 5MgO + 2Fe_2O_3 + 2SiO_2 + MgCl_2 = 2Mg_3(Si_4O_{10})(OH)_2\ (Al_2Fe)_2\ (Si_4O_{10})(OH)_2 + H_2O + 2KCl \quad (3)$$

This process occurs in the lower horizons of sections 54, 40, 13, 1, and 74, indicating that due to the high moisture content in the lower horizons of the soil profile, the process of montmorillonization of the hydrosludite mineral is more pronounced than in the humus horizon, leading to a decrease in total potassium content. Evidence of this process is the fact that the amount of exchangeable potassium in the sod horizon was 1028 mg per 100 kg^{-1} in the example of section 74.

The content of phosphorus, introduced with fertilizers and released during the decomposition of phosphorus-containing primary minerals, is typically higher in the clay fraction than in larger fractions. Under similar conditions, loamy and clayey soils have higher phosphorus content compared to soils with a lighter granulometric composition. Additionally, the phosphorus content in humus and sub-humus horizons is 1.5-2.0 times greater than in other soil horizons (Akhatov and Murodova, 2020). Phosphorus compounds undergo changes under the influence of irrigation duration and increased soil. In regions with hot and dry climates, applied phosphorus fertilizers constantly precipitate in insoluble forms due to their chemical absorption capacity (Muindi, 2019). An increasing amount of fulvic acid in the humus composition accelerates the dissolution of phosphorus precipitation, resulting in lower chemical absorption of phosphorus. For example, in order to obtain higher yields, the annual rate of phosphorus fertilizers in light grey soils under cotton is 180 kg per hectare, of which about 30% is taken up by plants, 30-35% is converted into insoluble forms, and 30% is lost through leaching (Akhatov et al., 2022).

The profile and exposure distribution of total humus in brown soils, as well as its fractions, are influenced by both the peculiarities of humus formation and erosion processes (Aliyev, 2017; Pulatov et al., 2020; Aliyev et al., 2022) The processes of humus formation occurring under generally favorable conditions have contributed to the accumulation of up to 6% of humus in the upper soil horizon, with a deep humus content noted in the profile. Erosion processes lead to the dehumidification of brown soils, and soil erosion also obscures the pattern of humus exposure distribution, reducing the general diversity and mottling of the mountain slope soil cover (Aliyev, 2017). Highly eroded soils also lose their ability to deposit carbon and lose part of it, fixed in humus, due to leaching, dissolution, and mineralization. All sections are characterized by a sharp vertical decrease in the total content of potassium and phosphorus, indicating their deep penetration. The vertical distribution of potassium and phosphorus reserves is characterized by an indistinct accumulation in the middle part of the profile, which can be explained by illuvial processes. Thus, the problem of erosion impact on soils in the region is quite acute. Additionally, the manifestation of erosion on slopes is aggravated by intensive economic use. Regular cattle grazing prevents the restoration of vegetation cover and sodding of the soil surface.

Conclusion

The studied brown soils of the mountain pastures in Uzbekistan have a loamy granulometric composition, with the clay fraction not exceeding 20%. The carbonate content is low, ranging from 2.5% to 9%. The distribution of total humus, potassium, and phosphorus, as well as their fractions, in the profile and exposure, is influenced by both the formation peculiarities and erosion processes.

The total humus content in brown soils varies widely, from 1% to 6.6%. In soils undisturbed by erosion, the vertical distribution of humus follows a regressive-accumulative pattern. Soils on northern and western slopes contain more humus than those on southern and eastern slopes. The total potassium content varies depending on the slope's exposure and erodibility. In the top horizon of the studied brown soils, the total potassium content is up to 1.685%, and phosphorus is up to 0.350%. The decrease in total potassium content is influenced by the montmorillonitization process occurring in the lower, more humid horizons. Illuvial processes explain the unclear accumulation of potassium and phosphorus reserves in the middle part of the profile. The direct reserve of potassium and phosphorus is less than one-third of the total content, with the potential reserve predominating.

The depletion of potassium and phosphorus in brown soils mainly occurs through leaching of the immediate reserve, with this process being more active on southern, less sodded slopes. The problem of erosion impact on the soils in the studied regions is significant. Erosion processes lead not only to dehumidification but also to a decrease in the content of potassium and phosphorus. Regular grazing and intensive economic use hinder the restoration of vegetation cover and sodding of the soil surface, increasing erosion on the slopes and reducing the overall diversity of the soil cover of mountain slopes. Further study of the peculiarities of humus, potassium, and phosphorus, their accumulation, and restoration in brown soils is essential for developing recommendations for their rational use, anti-erosion protection, and increasing the productivity of mountain pastures in Uzbekistan.

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