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GENESIS AND GEOGRAPHY OF SOILS

The Impact of Vegetation on Humus Formation and Morphology of Brown Forest Soils in Coastal Areas of the Southeastern Part of Russian Far East

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Abstract—Specific features of brown forest soils (burozems, Cambisols) in coastal areas of the southeastern part of Russian Far East are discussed. It is shown that the color of the illuvial horizons in these soils depends on the character of vegetation; it is reddish brown under oak forests and dark gray under herb–shrub and post-pyrogenic communities. These soils combine the features shaped by the humus-accumulative and humus-illuvial processes. In the soils under oak forests, the humate–fulvate type of humus predominates; in the soils under herb–shrub and post-pyrogenic communities, the fulvate–humate humus is formed. The dynamics of humus and its separate fractions in the soil profiles control the morphochromatic differentiation of brown forest soils under different vegetation communities. In the soils under oak forests, the maximum precipitation of the aggressive fraction of fulvic acids (fraction FA-1a) in the illuvial-humus horizons coincides with the maximum concentration of oxalate-extractable iron oxides; these substances ensure the reddish brown color of the illuvial horizons in these soils. In the brown forest soils under herb–shrub and post-pyrogenic communities, the illuvial horizon is the zone of accumulation of not only the aggressive fraction of fulvic acids but also the second (Ca-bound) fractions of fulvic and humic acids ensuring the dark gray color of this horizon.

Keywords: brown forest soil (Cambisol), coastal zone, vegetation, soil morphology, type of humus formation, post-pyrogenic area

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INTRODUCTION

Vegetation conditions and their dynamics, particularly in the forest zones, are important factors of pedogenesis controlling the state of soils and soil cover [12, 34].

Oceanic regions of the south of the Far East of Russia were distinguished as a specific coastal zone by Zonn [8, 9]. The bioclimatic specificity of this territory is combined with the strong geochemical influence of the sea. These factors affect the character of pedogenesis in general and the character of humification and humus accumulation, in particular. As noted by Zonn [8], in dependence on the type of vegetation, the formation of some soils "reflects the features of the forest (burozemic) pedogenesis complicated by the local specificity of humification processes, whereas the formation of other soils reflects the prairie (brunizemic) pedogenesis."

In the coastal zone of the Sea of Japan, including the southeastern part of the Far East of Russia, the relationships between soils and vegetation remain poorly studied. The soils of this region are very diverse in their morphology and physicochemical properties. They have a number of specific features. Thus, Ivanov [10] and Khavkina [38] described specific cinnamonic-brown soils under oak forests in the coastal zone on east-facing slopes of the Sikhote Alin Range. In some areas subjected to strong wind action, brown forest soils with deep humus profiles are formed under oak forests. The chemical specificity of these soils and their geographic distribution in the studied region are insufficiently known [10].

The bioclimatic conditions in the south of the Far East of Russia favor the development of brown forest soils (burozems, Cambisols) that are considered zonal soils in this region. The morphologies and chemical properties of these soils are rather diverse. These soils were actively studied in the central part of the Sikhote Alin Range [5, 10, 22, 25, 35–38]. Several pedogenetic processes are responsible for their development. The particular combinations of these processes may differ, which results in the high diversity of burozems. Diagnostic features of two major processes of humus accumulation and humus illuviation were described at the macro-, meso,- and microlevels [5, 35–37].

At present, considerable amounts of data on the pedogenetic conditions, morphology, physicochemical properties, and composition of humus in brown forest soils (burozems) developing under different vegetation successions in the coastal zone of the southern Far East of Russia are available [24, 27, 28, 30, 31]. The interpretation of these materials attests to the fact that the composition of humus in these soils is greatly affected by the anthropogenic dynamics of vegetation. The aim of our paper is to characterize the influence of vegetation on the formation of humus in burozems of the southeastern part of the Far East and on the morphology of these soils. In this context, the classification position of the burozems and the regularities of their spatial differentiation are discussed.

OBJECTS AND METHODS

Field studies were conducted on the eastern macroslope of the Sikhote Alin Range in its southern part, on Cape Ostrovnoi and adjacent coastal areas of the Sea of Japan.

This territory is clearly subdivided into three geomorphic units: the coastal zone of the Sea of Japan with numerous small bays, sand beaches, and rocky cliffs of 30 to 150 m in height; the coastal lowland; and the zone of low mountains composed of siltstone and quartzite rocks. In the latter zone, the heights vary from 100 to 300 m a.s.l., and the slopes are from 3° to 45°.

This territory has a moderately warm humid climate; it occupies a transitional position between the regions with warm humid climate in the south and moderately cold humid climate in the north [1]. The climatic characteristics are greatly influenced by the Sea of Japan. The mean January temperature is –11 to –12°C, and the absolute minimum of temperature in the coastal zone is no lower than –30°C. Winter temperatures become much colder in the inland direction. At some distance from the sea, the mean January temperature is –19 to –20°C, and the minimum temperature is –45°C. The mean annual temperature in the shore zone is 5.2°C; in the inland part of the studied territory, it lowers down to 3.5°C. The mean annual precipitation is 750–850 mm; in some years, it may be as high as 1000–1200 mm [1, 16]. Precipitation brought with southern and southeastern winds from the sea exerts the most significant influence on the local ecosystems. In general, the environmental conditions in the coastal zone of the southeast of Russian Far East favor the differentiation of the products of weathering and pedogenesis in the soil profiles.

Within the zone of low mountains, at a distance of up to 5–7 km from the sea, secondary oak and lime–oak forests with the admixture of birch, ash, and maple trees are widespread; there are also grassy open oak forests that appeared as a result of the anthropogenic transformation of the initial broadleaved–pine–spruce forests [6, 7]. Secondary oak–lime forests with a well-developed story of hazelnut shrubs, herb–hazelnut thickets with young oak and birch trees, and herb–shrub associations predominate within the studied territory.

To reveal the influence of vegetation on humus formation and morphology of burozems, we studied these soils under initial oak forests and under their anthropogenic derivatives represented by herb–hazelnut and post-pyrogenic hazelnut–lime communities.

According to the Russian soil classification system [13], the studied soils belong to the types of burozems and dark burozems; in the WRB system, they correspond to Umbric Cambisols or Mollic Cambisols [18, 33]. Classical comparative-geographic and profile-genetic methods were used in our study. The physicochemical properties of sampled soils were analyzed by routine methods [4]. The group and fractional composition of the soil humus was studied according to the scheme of Tyurin in modification by Ponomareva and Plotnikova [2].

RESULTS AND DISCUSSION

Burozems under oak forests occupy well-drained slopes and local summits in the coastal zone. These soils are characterized by a relatively low thickness of the soil profile (60–100 cm); the thickness of their humus-accumulative horizon varies from 8 to 16 cm. A distinctive feature of these soils is the reddish brown (cinnamonic-brown) color of the humus-illuvial horizon. In the typical burozems of more continental regions, this horizon has a brown or yellow-brown color [11]. In the south of the Far East (on isles of the Rimskii-Korsakov Archipelago), burozems have a grayish yellow to yellow-gray color of the humus-illuvial horizon [26].

The descriptions of two pits illustrating the morphologies of burozems under oak forests in the southeastern coastal region of the Russian Far East are given below.

Pit 5-04 was examined 50 m inland from the coastal cliff (42°83′50″ N, 133°69′69″ E), on a spur of the Sikhote Alin Range in its southern part. The pit was excavated on a moderately steep (13°) slope of southwestern aspect. In the microtopography of the area, some microelevations around the trunks could be seen. The vegetation was represented by the oak forest with an admixture of lime, birch, and maple trees; the shrub (hazelnut) layer was relatively thin. The projective cover of herbaceous vegetation with participation of sedges (*Carex humilis*), ferns (*Pteridium aquilinum*), and tall herbs (*Cacalia auriculata*) was about 30%.

O, 0–6 cm. Forest litter composed of the leaves of oak; weakly decomposed in the upper part and highly decomposed in the lower part (3–6 cm); distinct smooth boundary.

AY, 6–14 cm. Dark gray to black; slightly dry, with fine crumb–granular structure; silty loam; densely penetrated by roots (1–3 mm); with separate bedrock gravels; distinct tonguing boundary.

BMf,hi, 14–70 cm. Dark brown (7.5YR 3/4), moist, very fine to fine granular structure; silt loam; reddish brown organomineral coatings on ped faces and on gravels; the internal parts of the peds are of brown color; the portion of gravels (3–6 cm) reaches up to 70% of the soil volume; abundant roots (<2 mm); diffuse boundary.

BCbm, 70–90 cm. Heterogeneous in color: grayish to yellow brown mottles against the brown background color; moist; fine crumb–granular structure; silt loam; abundant gravels and coarse (<15 cm) siltstone debris (up to 85–90 vol. %).

Pit 11-04 was examined 300 m closer to the seashore (42°83′86″ N, 133°69′94″ E) in the upper part of a moderately steep (14°) slope of the northwestern aspect; the microtopography was represented by microelevations around the trunks. The soil was developed under the oak forest with an admixture of lime, birch, and maple trees; oak and maple trees were in the young growth. The shrub layer was composed of hazelnut shrubs. The projective cover of herbaceous vegetation with participation of ferns (*Pteridium aquilinum*), sedges (*Carex humilis*), and lily-of-the-valley (*Convallaria majalis*) was up to 30%.

O, 0–6 cm. Oak leave litter; weakly decomposed in the upper part and highly decomposed in the lower part; distinct boundary.

AY, 6–22 cm. Gray with whitish tint; slightly dry; fine crumb–granular structure; silt loam; rock fragments occupy up to 30% of the volume; densely penetrated by roots (2–3 mm); distinct tonguing boundary.

BMf,hi, 22–69 cm. Dark brown (7.5YR 4/3), moist, fine granular structure; reddish brown organomineral coatings on ped faces and on gravels; the internal parts of the peds are of brown color; silt loam; abundant roots (1–3 mm); gravels (1–2 to 7–8 cm) occupy up to 70–80% of the volume.

C, 69–75 cm. Gravels and coarser fragments of quartzite bedrock.

Thus, the studied soils developed under oak forests in the southeastern coastal regions of the Far East have the following horizonation: O–AY–BMf,hi–BCbm. The presence of reddish brown to dark brown organomineral coatings on ped faces and the brown color of the interior mass of the peds in the BMf,hi horizon prove the illuvial nature of this horizon; the boundary between the humus-accumulative and the humus-illuvial horizons has a tonguing pattern. In the modern Russian soil classification system [13], these soils correspond to the type of burozems. At the subtype level, they can be distinguished as humus-illuvial burozems. However, the diagnostic criteria for this subtype of burozems have to be specified.

The presence of reddish brown (cinnamonic) color in the illuvial horizon of brown forest soils in the coastal zone of the Far East was noted by Ivanov [11]. Later, Ivanov [10] and Khavkina [38] showed that these soils are only typical of a relatively narrow coastal zone on the eastern slopes of the southern Sikhote Alin Range and separated them as specific cinnamonic-brown soils.

The anthropogenic successions of oak forests lead to a considerable transformation of the soil profile. In the soils of secondary forests, the thickness of the humus-accumulative horizons increases up to 17–25 cm, and the thickness of the humus-illuvial horizon increases up to 20–60 cm; the latter horizon acquires gray to dark gray color. Such soils are widespread in the southeastern part of the Far East and in other coastal regions of the Sea of Japan [21, 26–29, 32]. The morphology of the soils formed under herb–shrub communities (pit 1-05) and hazelnut–lime forests (pit 13-04) can be judged from the following descriptions.

Pit 1-05 was examined on Cape Ostrovnoi, 20 m to the west of the coastal cliff (42°81′17″ N, 133°72′77″ E), on the south-facing slope of 7° with indistinct microelevations around the trunks. Herb–shrub vegetation with regrowth of oak trees had the projective cover of 100%. The shrub layer was represented rose shrubs; Wormwood (*Artemisia keiskeana*), meadow grass (*Poa pratensis*), *Miscanthus*, plantain (*Plantago*), thistle (*Carduus*), burdock (*Arctium*), lily-of-the valley (*Convallaria majalis*), and some other species composed the dense ground cover.

O, 0–4 cm. Litter horizon with undecomposed and weakly decomposed herbs; distinct transition.

AU, 4–21 cm. Dark gray; slightly dry; fine granular structure; slightly compacted light loam densely penetrated by roots of up to 4 mm in diameter; tonguing boundary.

BM1hi, 21–45 cm. Dark gray (7.5YR 4/1), with dark gray coatings on ped faces and on gravels; the interior part of the peds is of brown color; slightly dry; crumb–granular structure; silt loam; more compact; with a moderate amount of roots (<5 mm); tonguing boundary.

BM2hi, 45–73 cm. Gray, with humus coatings on ped faces and gravels; the interior part of the peds is brown-colored; moist; crumb–granular; silt loam with abundant inclusions of small gravels and roots (<3 mm); distinct wavy boundary.

BCbm, 73–105 cm. Light gray with yellowish tint; moist; fine crumb–granular structure; heavy loam; abundant fine gravels; clayey coatings are seen on quartzite gravels.

Pit 13-04 was examined 200 m from the seashore (42°83′86″ N, 133°69′87″ E) on the lower part of the northwestern slope of 14° with indistinct microelevations around the trunks. Hazelnut–lime forest with traces of ground fires; oak, birch, maple, and apple trees are admixed to the main stand; oak and maple trees are in the young growth. Sedges, ferns, lily-of-the valley, wormwood, and cow vetch compose the herb layer covering 25–30% of the surface.

Opir, 0–6 cm. Weakly decomposed woody remains and herbs with charcoal particles in the lower part; distinct boundary.

AUpir, 6–31 cm. Dark gray to black; slightly dry; very fine crumb structure; silt loam; densely penetrated by roots; loose; abundant charcoal inclusions; fine gravels (3–4 cm) occupy up to 30% of the volume; tonguing boundary.

BMhi,pir, 31–51 cm. Dark gray to black (10YR 3/1); slightly dry; very fine to fine crumb–granular structure; silt loam; dark gray coatings on gravels; inclusions of fine charcoal particles; densely penetrated by roots; gravels (3–4 cm) occupy up to 70% of the volume. Clear uneven boundary.

BC1bm, 51–84 cm. Grayish brown; moist; very fine to fine crumb structure; silt loam; inclusions of small gravels (0.5–1 cm) constitute about 60% of the volume; the number of roots is smaller than that in the overlying horizon. Distinct boundary.

BC2bm, 84–110 cm. Grayish brown; moist; fine crumb; silt loam; many roots (<2 mm); siltstone debris and gravels (1–3 to 5 cm) constitute up to 90–95% of the soil volume.

As seen from these descriptions, burozems developed under herb–shrub associations are characterized by the Opir–AU–BMhi1–BMhi2–BCbm profile; burozems under secondary forests in place of burnt areas are characterized by the Opir–AUpir–BMhi,pir–BCbm profile with distinct features of the former pyrogenesis (charcoal) in the humus-accumulative and humus-illuvial horizons. The illuviation of humus in the BMhi horizon is seen in the form of humus tongues from the AU horizon and in the dark gray to black color of humus coatings on ped faces and on gravels in the BMhi horizon. The interior part of the peds preserves its initial brown color. The greatest thickness of the AU and BMhi horizons is seen in the treeless areas with herbaceous (meadow) vegetation. In terms of the new Russian soil classification system [13], these burozems correspond to the type of dark burozems. At the subtype level, they can be distinguished at humus-illuvial dark burozems. The diagnostic features of the humus-illuvial subtype of burozems have yet to be specified.

A comparative analysis of data on the physicochemical properties of the studied burozems (Table 1) shows that they have both common and specific features. The high climatic moistening of the territory and a relatively low heat supply specify the active development of leaching processes in these soils and their high acidity.

Burozems developed under oak forests and under herb–shrub thickets are characterized by the strongly acid reaction (pH_{KCl} 3.6–4.1), whereas burozems of the post-pyrogenic association have the medium acidity (pH_{KCl} 4.7), which may be attributed to the alkalizing impact of fires [42]. The high variability of the considered soil properties is dictated not only by the differences in vegetation conditions but also by different geomorphic positions of the analyzed soil profiles. In general, the burozems under the initial forest vegetation have the lowermost values of pH_{KCl} (3.6–3.9); in the burozems under herb–shrub thickets and secondary forests on burnt plots, the pH_{KCl} values are higher (4.1–4.7). It is interesting that the burozems under oak forests on leeward slopes (in the wind shade, pit 11-04) have lower pH_{KCl} values (3.6) than the analogous soils on windward slopes (pH_{KCl} 3.9, pit 5-04). This is explained by the alkalizing effect of salts brought by the winds from the sea [23, 25]. At the same time, the strongly acid reaction of burozems in the studied region is partly due to the acid rains typical of the studied territory. Thus, the pH of precipitation from the atmosphere varies within 3.87–4.62; in some cases, it increases up to 5.05–5.35 [3, 14].

The studied soils are characterized by the well-correlated values of the exchangeable and total acidity. Thus, in the studied series of burozems (pits 1-05, 5-04, and 11-04), an increase in the exchangeable acidity (pH_{KCl} 4.1, 3.9, and 3.6, respectively) is accompanied by the rise in the total acidity (20.13, 22.75, and 24.06 cmol(+)/kg, respectively). In the burozems developed on the post-pyrogenic plot, this general regularity is preserved, but it becomes less distinct.

The high values of the exchangeable and total acidity in the studied soils are in agreement with their low base saturation, except for the pyrogenic burozems of the burnt plots. In the latter soils, the amounts of exchangeable bases in general and calcium, in particular, are high (up to 23.81 cmol(+)/kg, so that base saturation is about 81–92%. The exchangeable acidity of these soils is relatively small.

The distribution of exchangeable calcium and magnesium in the studied soil profiles has its own specificity. The maximum amounts of exchangeable bases are found in the humus-accumulative horizons. In the oak forests on windward slopes (pit 5-04), the contents of exchangeable calcium and magnesium reach 9.48 and 6.58 cmol (+)/kg, respectively. Much lower values (2.43 and 0.87 cmol(+)/kg, respectively) were found in the burozem on the leeward slope (pit 11-04). In the burozems on the post-pyrogenic plot. the exchangeable calcium content increases up to 23.81 cmol(+)/kg, which is explained by the high calcium content in the ash of plants [10, 22].

A distinctive feature of burozems on the windward slopes under both oak forests (pit 5-04) and herb–shrub thickets (pit 1-05) is an increased portion of magnesium in the composition of exchangeable cations in the humus-accumulative horizon (50–70%). As argued earlier [22, 23], this may be related to the additional input of magnesium salts from the sea onto the soils of windward slopes.

The distribution of humus in the soil profiles points to the active participation of humus-accumulative and humus-illuvial processes in the development of

Table 1. Physicochemical properties of burozems

Horizon	Depth, cm	pH		Humus, %	Total acidity	Exchangeable cations			Base saturation, %	Tamm's extract, %		
		H_2O	KCl			H^+	Ca^{2+}	Mg^{2+}		Fe_2O_3	Al_2O_3	R_2O_3
					cmol(+)/kg							
Burozem under oak forest, pit 5-04												
AY	6–14	6.0	3.9	14.08	22.75	8.14	9.48	6.58	66	0.82	0.77	1.59
BMf,hi	15–25	5.1	4.0	6.12	21.00	7.41	2.66	0.72	31	1.37	0.99	2.36
BMf,hi	40–50	5.3	4.0	2.03	16.63	6.95	0.52	1.47	22	0.95	0.97	1.02
BCbm	75–85	5.3	3.9	1.81	17.94	8.02	0.57	3.78	35	0.86	0.98	1.84
Burozem under oak forest, pit 11-04												
AY	9–17	4.5	3.6	8.52	24.06	6.71	2.43	0.87	33	0.51	0.53	1.04
BMf,hi	25–35	5.1	4.2	4.45	14.44	2.87	0.25	0.95	30	1.38	0.96	2.35
BMf,hi	50–60	5.2	4.1	4.67	15.31	2.86	0.30	1.05	32	1.46	0.97	2.43
Burozem under herb–shrub associations, pit 1-05												
AU	7–17	5.0	4.1	18.39	20.13	8.64	6.23	6.23	59	0.77	0.60	1.37
BM1hi	25–35	5.1	4.1	6.46	19.25	10.92	2.13	1.36	24	0.70	1.13	1.83
BM2hi	50–60	5.2	4.2	3.71	16.19	10.04	0.64	2.09	21	0.76	0.88	1.64
BCbm	80–90	5.4	4.1	2.20	11.81	6.23	0.73	1.69	28	0.72	0.93	1.65
Burozem under hazelnut–lime post-pyrogenic forest, pit 13-04												
AUpir	15–25	5.5	4.7	13.95	16.63	5.86	23.81	1.87	81	1.00	0.92	1.92
BMhi,pir	35–45	6.0	4.9	10.09	10.50	1.18	19.62	3.77	94	0.96	0.82	1.78
BCbm	56–66	6.2	4.5	0.87	4.81	0.51	10.16	11.16	98	0.84	0.96	1.80

burozems under the initial oak forests, herb–shrub succession stage, and secondary forest on the post-pyrogenic area. The illuviation of humus explains its relatively high content in the BMf,hi, BMhi, BMhi,pir, and even BCbm horizons. In the latter horizon, the humus content at the depth of 70–100 cm remains within the range of 1.8–2.2%. The degree of development of humus accumulation and humus illuviation in the particular soil profiles is controlled by differences in the vegetation conditions.

The humus of burozems under initial oak forests is relatively mobile, and its contents in the humus-accumulative (8.52–14.08%) and humus-illuvial (4.45–6.12%) horizons are lower than those in the burozems of herb–shrub thickets and secondary forests on post-pyrogenic plots. In the latter case, the humus content in the dark-humus (AU) horizon varies from 13.95 to 18.39%; in the BMhi and BMhi,pir horizons, it varies from 6.46 to 10.09%.

An increased content of humus in the profiles of pyrogenic burozems is related to the impact of fires on the litter horizons. As shown in [40, 41], the pyrogenic transformation of the litter is accompanied by the increased release of water-soluble organic matter with its active migration down the soil profile.

The major factor specifying the differences in the distribution of humus in the studied soil profiles is the value of total and exchangeable acidity. With an increase in the soil acidity, the mobility of humic substances also increases. This explains the high humus content both in the humus-accumulative and humus-illuvial horizons of the burozems.

The high humus content in some of the brown forest soils was noted by Ivanov [11]. He showed that acid high-humus brown forest soils are developed under secondary oak stands; the humus content in them reaches 28.5% in the A1 horizon, 16% in the A1B horizon, and 3.1–4.8% in the BC horizon). Later, Ivanov argued that the high humus content in the topsoil horizons is generally typical of the brown forest soils in the Far East region. He explained this by the high microbiological activity of these soils ensuring rapid transformation and humification of plant residues in the warm and moist summer followed by the conservation of newly formed humic substances in the cold winter season.

The differentiation of total humus in the profiles of burozems is also accompanied by the differentiation of humic and fulvic acids and their fractions (Table 2). Under the oak stands, the formation of humus follows the humate–fulvate type ($C_{ha}/C_{fa} = 0.8–0.77$). Under the herb–shrub thickets and secondary forests on post-pyrogenic plots, the formation of humus follows the fulvate–humate type ($C_{ha}/C_{fa} = 1.15–1.20$).

The fulvate–humate type of humus is typical of other burozems in the coastal areas of the Far East of Russia. This is confirmed by our earlier data [27, 30, 32] and by other researchers [8, 15, 17, 19, 20].

A characteristic feature of the group composition of humus in the burozems formed on post-pyrogenic plots is the preservation of the fulvate–humate composition of humus in the humus-illuvial metamorphic horizon BMhi (the C_{ha}/C_{fa} ratio is 1.09). In the burozems under other cenoses, the humate–fulvate humus (C_{ha}/C_{fa} 0.53–0.67) is typical of the humus-illuvial horizons. The rise in the C_{ha}/C_{fa} ratio in the soils under the impact of pyrogenesis has also been noted for forest soils in the Amur River reaches [39].

The content of nonhydrolyzable residue (humin) in the studied series of burozems is indicative of the biocenotic and geochemical specificity of pedogenesis and of the influence of the pyrogenic factor. The burozems developed on the post-pyrogenic plot are characterized by the increased contents of the nonhydrolyzable residue both in the humus-accumulative and humus-illuvial horizons (40.80–43.93%), which might be due to the presence of coal-like particles in these horizons.

In general, the first fractions of humic and fulvic acids and the second fraction of fulvic acids predominate in humus of studied soils.

The contents of humic acids and their fractional composition differ in the studied soils of different cenoses. These differences are most clearly pronounced for the first (dominant) fraction of humic acids (brown humic acids) and manifest themselves in the morphological differentiation of the soil profiles. Thus, this fraction has an accumulative distribution with a maximum in the humus-accumulative horizon in the soil profiles under initial oak forests; in the soils developed under secondary forests, it has an illuvial distribution with a maximum in the humus-illuvial horizon.

The distribution of the second fraction (Ca-bound, black) of humic acids is considered to be diagnostic of burozems. It has an illuvial pattern with a maximum in the illuvial horizons. The same is true for the third fraction of humic acids, except for the soils developed on post-pyrogenic plots, where this fraction has an accumulative distribution.

Burozems under secondary herb–shrub associations and on post-pyrogenic plots are characterized by the higher absolute and relative contents of humic acids and their first and second fractions than those in the burozems under oak forests; the content of the second fraction of humic and fulvic acids is also higher.

The distribution of particular fractions of humic and fulvic acids in the considered series of burozems has its own regularities. In all the soils, fraction 1a of fulvic acids (free fulvic acids and fulvic acids bound with oxalate-extractable sesquioxides) has a distinct maximum in the illuvial horizons. The highest contents (both absolute and relative) of this fraction are typical of the burozems under oak forests, which may be related to the high content of amorphous sesquioxides with their maximum in the illuvial horizon of these soils.

Table 2. Group and fractional composition of humus in burozems (% of the soil mass / % of C_{org})

Horizon	Depth, cm	C_{org}, %	Humic acids				Fulvic acids					Nonhydrolyzable residue	C_{ha}/C_{fa}
			1	2	3	sum	1a	1	2	3	sum		
Burozem under oak forest, pit 5-04													
AY	6–14	8.17	1.73 21.18	0.20 2.45	0.45 5.51	2.38 29.14	0.35 4.28	0.99 12.12	1.19 14.56	0.51 6.24	3.04 37.20	2.75 33.66	0.78
BMf,hi	15–25	3.55	0.64 18.03	0.05 1.41	0.18 5.07	0.87 24.51	0.56 15.77	0.34 9.58	0.39 10.99	0.36 10.14	0.65 46.48	1.03 29.01	0.53
BMf,hi	40–50	1.18	0.15 12.71	0.05 4.24	0.06 5.08	0.26 22.03	0.45 38.14	0.04 3.39	0.16 13.56	0.17 14.41	0.82 69.50	0.10 8.47	0.32
BCbm	75–85	1.07	0.15 14.02	0.05 4.67	0.06 5.61	0.26 24.30	0.26 24.30	0.03 2.81	0.14 13.08	0.16 14.95	0.59 55.14	0.22 20.56	0.44
Burozem under oak forest, pit 11-04													
AY	9–17	4.94	1.40 28.34	0.26 5.26	0.19 3.85	1.85 37.45	0.36 7.29	0.81 16.40	0.43 8.70	0.81 16.40	2.41 48.79	0.68 13.76	0.77
BMf,hi	25–35	2.58	0.26 10.08	0.22 8.53	0.06 2.32	0.54 20.93	0.65 25.2	0.03 1.16	0.08 3.10	0.19 7.36	0.95 36.82	1.09 42.25	0.57
BMf,hi	50–60	2.71	0.32 11.81	0.11 4.06	0.11 4.06	0.54 19.93	0.62 22.88	0.07 2.58	0.19 7.01	0.29 10.70	1.17 43.17	1.00 36.90	0.46
Burozem under herb–shrub associations, pit 1-05													
AU	7–17	10.67	2.02 18.93	0.35 3.28	0.37 3.47	2.74 25.68	0.25 2.34	0.45 4.22	1.20 11.25	0.39 3.65	2.29 21.46	5.64 52.86	1.20
BM1hi	25–35	3.75	0.84 22.40	0.30 8.00	0.19 5.07	1.33 35.47	0.57 15.20	0.39 10.40	0.75 20.00	0.27 7.20	0.98 52.80	0.44 11.73	0.67
BM1hi	50–60	2.15	0.48 22.32	0.09 4.19	0.06 2.79	0.63 29.30	0.58 26.98	0.09 4.19	0.28 13.02	0.12 5.58	1.07 49.77	0.45 20.93	0.59
BCbm	80–90	1.28	0.31 24.22	0.14 10.94	0.05 3.91	0.50 39.07	0.29 22.65	0.07 5.47	0.22 17.19	0.10 7.81	0.68 53.12	0.10 7.81	0.74
Burozem under hazelnut–lime post-pyrogenic forest, pit 13-04													
AUpir	15–25	8.09	1.94 23.98	0.32 3.95	0.30 3.71	2.56 31.64	0.22 2.72	0.42 5.19	0.97 11.99	0.62 7.66	2.23 27.56	3.30 40.80	1.15
BMhi,pir	35–45	5.85	1.42 24.27	0.08 1.37	0.21 3.59	1.71 29.23	0.20 3.42	0.13 2.22	0.71 12.14	0.53 9.06	1.57 26.84	2.57 43.93	1.09
BCbm	56–66	0.70	0.01 1.43	0.03 4.28	0.01 1.43	0.05 7.14	0.07 10.00	0.02 2.86	0.16 22.85	0.29 41.43	0.54 77.14	0.11 15.71	0.09

In the burozems under oak forests, the distribution of the first and second fractions of fulvic acids has an accumulative pattern. In the burozems under secondary herb–shrub cenoses, these fractions have their maximums in the illuvial horizon. In the burozems of post-pyrogenic areas, the first fraction of fulvic acids has its maximum in the upper humus horizons, whereas the second fraction of fulvic acids has its maximum in the illuvial horizon.

The contents and distribution of oxalate-extractable sesquioxides in the considered sequence of burozems are also important in terms of the specific morphology of these soils under different vegetation cenoses.

In the burozems under oak forests, the distribution of oxalate-extractable iron has a distinct eluvial–illuvial pattern; the maximum contents of oxalate-extractable sesquioxides are observed in the humus-illuvial horizons (Fe_2O_3 1.37–1.46%; R_2O_3 2.36–2.43%). The same horizons have the maximum content of the aggressive fraction (1a) of fulvic acids. Note that these horizons have a specific reddish brown color. In the burozems under herb–shrub associations, content of oxalate-extractable iron is relatively stable in the profile. In the soil of post-pyrogenic area, oxalate-extractable iron has a weak maximum in the humus-accumulative horizon. The humus-illuvial horizons are rich in fraction 1a of fulvic acids and in the second fraction of both humic and fulvic acids. Together with a relatively high content of organic carbon in this horizon, (C_{org} 3.75–5.85%), the high content of humic and fulvic acids of the second fraction is responsible for the dark color of the transitional horizons.

CONCLUSIONS

(1) The studied coastal region in the Far East of Russia is characterized by moderately warm and wet climatic conditions. The mean annual precipitation is 850 mm; in some years, it increases up to 1000–1200 mm. The mean annual temperature is 5.2°C in the coastal part and 3.5°C in the inland part. The frostless period is 55 to 60 days longer than that in the inland part. Thus, the climatic conditions favor differentiation of the products of weathering and pedogenesis in the soil profiles.

(2) Burozems of the coastal region are characterized by diverse morphologies that are tightly associated with vegetation successions. Under oak forests, the profile of burozems consists of the O–AY–BMf,hi–BCbm horizons. Under the secondary herb–shrub associations, burozems with the dark-humus (AU) horizon are developed: O–AU–BMhi1–BMhi2–BCbm. On the post-pyrogenic plots overgrown with secondary forests, the profiles of burozems have distinct pyrogenic features (charcoal): Opir–AUpir–BMhi,pir–BCbm.

(3) The physicochemical characteristics of the studied burozems (exchangeable and total acidity, base saturation, and humus content) are controlled by the character of vegetation and by the geomorphic position of the particular profiles on the windward or leeward slopes. Burozems developed under oak forests have somewhat higher total and exchangeable acidity, lower humus content and base saturation, and higher mobility of humus in comparison with burozems developed under herb–shrub associations and under secondary forests of post-pyrogenic plots. Burozems under oak forests on windward slopes are richer in the exchangeable calcium and magnesium in comparison with burozems on leeward slopes.

(4) The differentiation of the profile of burozems is due to the humus-accumulative and humus-illuvial processes. The latter is diagnosed by the presence of organomineral coatings and increased humus content in the humus-illuvial horizons. The differences between the soils developed under different vegetation communities are seen in the color of the humus-illuvial horizon. In the burozems under oak forests, this horizon has a cinnamonic-brown color; in the burozems, developed under secondary cenoses of anthropogenic successions, the humus-illuvial horizon has a dark gray color.

(5) Morphological specificity of burozems under different cenoses is largely controlled by the differences in the character of humification and humus migration processes. In the burozems of oak forests, humus of the humate–fulvate type is formed; the C_{ha}/C_{fa} ratio is about 0.8–0.77. In the burozems of herb–shrub associations and post-pyrogenic forests, humus of the fulvate–humate type ($C_{ha}/C_{fa} = 1.20–1.15$).

(6) The morphochromatic differentiation of burozems under different cenoses can be explained by the specificity of the fractional and group composition of humus. In the burozems under oak forests, the maximum content of the aggressive fraction of fulvic acids (FA-1a) in the humus-illuvial horizon is also accompanied by the maximum content of oxalate-extractable iron oxides. The abundance of these substances may explain the cinnamonic-brown (reddish brown) color of the humus-illuvial horizon in these soils. In the burozems developed under herb–shrub communities and under post-pyrogenic forests, the humus-illuvial horizon is richer in the second (Ca-bound) fractions of humic and fulvic acids that provide for the dark gray color of the humus-illuvial horizon.

REFERENCES

1. *Agroclimatic Resources of Primorskii Region* (Gidrometeoizdat, Leningrad, 1973) [in Russian].
2. *Agrochemical Methods of Soil Studies* (Nauka, Moscow, 1975) [in Russian].
3. V. S. Arzhanova and P. V. Elpat'evskii, *Geochemistry of Landscapes and Technogenesis* (Nauka, Moscow, 1990) [in Russian].
4. E. V. Arinushkina, *Handbook on the Chemical Analysis of Soils* (Moscow State University, Moscow, 1970) [in Russian].

5. R. G. Gracheva and V. O. Targulian, “Macro- and mesomorphological diagnostics of soils and simple soil-forming processes in the burozem–podbur soil sequence, " in *Soil Formation and Wind Erosion in Humid Landscape* (Nauka, Moscow, 1978), pp. 103–121.
6. A. P. Dobrynin, “Oak Forests of Russian Far East: Biology, Geography, and Origin,” Tr. Botanich. Sada, Dal’nevost. Otd., Ross. Akad. Nauk, 2000.
7. P. P. Zhudova, “Vegetation and flora of the Sudzukhins State Nature Reserve in Primorskii region,” Tr. Sikhote-Alin. Gos. Zapoved., No. 6, 5–249 (1967).
8. S. V. Zonn, “Peculiarities of allitic wind erosion and soil formation on the islands of Primorye and Far East,” in *Analysis and Exploration of Nature* (Nauka, Moscow, 1976), pp. 125–137.
9. S. V. Zonn, E. G. Nechaeva, and A. P. Sapozhnikov, “About the contrast of soil forming in southeastern part of the Far Eastern Primorye,” Tr. Inst. Ekol. Rast. Zhivotn., Ural. Nauchn. Tsentr, Akad. Nauk SSSR, No. 84, 135–145 (1972).
10. G. I. Ivanov, *Soil Formation in the Southern Far East* (Nauka, Moscow, 1976) [in Russian].
11. G. I. Ivanov, *Soils of Primorskii Region* (Dal’nevost. Knizhn. Izd., Vladivostok, 1964) [in Russian].
12. L. O. Karpachevskii, “Problems of forest soil science,” Eurasian Soil Sci. **32** (1), 133–140 (1999).
13. *Classification and Diagnostic System of Russian Soils* (Oikumena, Smolensk, 2004) [in Russian].
14. I. I. Kondrat’ev and G. I. Semykina, “Atmospheric precipitation,” in *Geosystems of the Russian Far East at the Turn of XX–XXI Centuries*, Vol. 1: *Natural Geosystems and Their Components* (Dal’nauka, Vladivostok, 2008), pp. 175–179.
15. T. G. Koval’, “Qualitative composition of soil humus on the Furugelma Island,” in *Genesis, Chemistry, and Biology of Soils in Primorye and Amur Region* (Far Eastern Branch, Academy of Sciences of USSR, Vladivostok, 1987), pp. 158–164.
16. *Lazovskii Nature Reserve* (Agropromizdat, Moscow, 1989) [in Russian].
17. R. A. Makarevich, “Composition of humus of some brown mountainous forest soils of Primorye,” Vestn. Mosk. Univ., Ser. 17: Pochvoved., No. 4, 22–28 (1977).
18. *World Reference Base for Soil Resources as the Basis for the International Classification and Correlation of Soils* (KMK, Moscow, 2007) [in Russian].
19. G. V. Motuzova, E. A. Karpova, and O. M. Savina, “Dark forest soils of Sikhote-Alin Nature Reserve,” Pochvovedenie, No. 8, 105–111 (1986).
20. L. N. Purtova and M. P. Zimina, “Variability of physicochemical characteristics of brown forest soils within the phytogenic fields of trees (the Southern Far East),” Eurasian Soil Sci. **40** (1), 26–31 (2007).
21. B. F. Pshenichnikov, “Specific structure and evolution of island brown soils of monsoon climate of the South Far East,” in *Proceedings of the II International Conference “The Plants Growing in Monsoon Climate”* (Far Eastern Branch, Russian Academy of Sciences, Vladivostok, 2003), pp. 124–129.
22. B. F. Pshenichnikov and N. F. Pshenichnikova, *Genesis and Evolution of Near Oceanic Brown Soils* (Far Eastern Federal University, Vladivostok, 2002) [in Russian].
23. B. F. Pshenichnikov and N. F. Pshenichnikova, “Geochemical influence of the Pacific Ocean on southern soils of the Far East,” in *Soil Sciences: History, Sociology, and Methodology* (Nauka, Moscow, 2005), pp. 291–295.
24. B. F. Pshenichnikov and N. F. Pshenichnikova, “Genesis and classification of oceanic brown soils of the Far East,” in *Proceedings of the III International Conference on Forest Soil Science “Productivity and Stability of the Forest Soils,” Petrozavodsk, September 7–11, 2009* (Petrozavodsk, 2009), pp. 94–95.
25. B. F. Pshenichnikov and N. F. Pshenichnikova, “Illuvial-humus brown soils of Primorye,” Nauchn. Dokl. Vyssh. Shk., Biol. Nauki, No. 8, 131–135 (1978).
26. B. F. Pshenichnikov and N. F. Pshenichnikova, “Soils of the islands and coasts,” in *Investigations of the Far Eastern Marine Biospheric Reserve* (Dal’nauka, Vladivostok, 2004), Vol. 1, pp. 251–283.
27. B. F. Pshenichnikov and N. F. Pshenichnikova, “A role of facial geochemistry of the landscapes in geography of brown soils in near-oceanic part of the southern Far East,” *Geochemistry of Landscapes and Geography of Soils. Reports of the All-Russia Conference Devoted to the Centennial Anniversary of the Birth of M.A. Glazovskaya* (Moscow, 2012), pp. 260–262.
28. B. F. Pshenichnikov and N. F. Pshenichnikova, “Specific formation of brown soils on the islands of the Peter the Great Bay (southern Far East),” Vestn. Dal’nevost. Otd., Ross. Akad. Nauk, No. 5, 87–96 (2013).
29. N. F. Pshenichnikova, B. F. Pshenichnikov, and L. A. Latysheva, “Brunisolic-type soils of the Reike Island,” Vestn. Tomsk. Gos. Univ., Suppl. No. 15, 61–62 (2005).
30. B. F. Pshenichnikov, N. F. Pshenichnikova, and L. A. Latysheva, “Influence of humification and humus accumulation on the morphogenetic features of coastal brown soils of southern Sikhote Alin,” in *Proceedings of the International Conference “Forest Ecosystems of Northeastern Asia and Their Dynamics”* (Dal’nauka, Vladivostok, 2006), pp. 72–78.
31. B. F. Pshenichnikov, N. F. Pshenichnikova, and L. A. Latysheva, “Role of humic acids in formation of morphological diversity of brown soils of the coastal zone in the southern Far East,” in *Transactions of the V All-Russia Conference “Humic Substances in the Biosphere”* (St. Petersburg State University, St. Petersburg, 2010), Part 2, pp. 623–629.
32. B. F. Pshenichnikov, E. V. Shein, E. Yu. Milanovskii, and N. F. Pshenichnikova, “Specific features of the formation and evolution of brown soils in the oceanic part of the southern Far East,” in *Proceedings of the V Conference “Evolution of Soil Cover: Development of the Concepts and Methods, Holocene Evolution, and Forecasts”* (Moscow, 2009), pp. 209–211.
33. *Soil Nomenclature and Correlation* (Karelian Scientific Center, Russian Academy of Sciences, Petrozavodsk, 1999) [in Russian].

34. V. A. Rozhkov and L. O. Karpachevskii, “The forest cover of Russia and soil conservation,” Eurasian Soil Sci. **39** (10), 1041–1048 (2006).
35. N. I. Surina, V. O. Targulian, and S. A. Shoba, “Morphogenetic analysis of the profile and chemical peculiarities of mountainous brown soils of the central Sikhote Alin,” Vestn. Mosk. Univ., Ser. 17: Pochvoved., No. 3, 10–19 (1984).
36. N. I. Surina, V. O. Targulian, and S. A. Shoba, “Morphology and chemistry of humus-accumulation and illuvial-humus process in brown soils of the Far East,” Pochvovedenie, No. 6, 33–48 (1985).
37. V. O. Targulian, “Mull-Al–Fe-humus soil formation in the mountains and on the plains of humid regions,” *The VI Delegate Congress of the All-Union Soil Science Society, Abstracts of Papers* (Tbilisi, 1981), pp. 9–10.
38. N. V. Khavkina, “Composition of humus in brown forest soils of the coastal zone of the eastern slopes of Sikhote Alin,” in *Soil-Forest Studies in the Far East* (Vladivostok, 1977), pp. 27–32.
39. A. S. Tsibart and A. N. Gennadiev, “The influence of fires on the properties of forest soils in the Amur River basin (the Norskii Reserve),” Eurasian Soil Sci. **41** (7), 686-693 (2008).
40. G. Almendros, F. J. Conzalez-Vila, and F. Martin, “Fire-induced transformation of soil organic matter from an oak forest: an experimental approach to the effects of fire on humic substances,” Soil Sci. **149**, 158–168 (1990).
41. I. Fernandez, A. Cabaneiro, and T. Carballas, “Thermal resistance to high temperatures of different organic fractions from soils under pine forest,” Geoderma **104** (3–4), 281–298 (2001).
42. J. A. Gonzalez-Perez, F. L. Gonzalez-Vila, G. Almendros, and H. Knicker, “The effect of fire on soil organic matter – a review,” Environ. Int. **30** (6), 855–870 (2004).

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