Typical features of short-profile soils in the Middle Urals

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Abstract. Data on short-profile mountainous soils of the Middle Urals are discussed. In the new Russian soil classification system, these soils belong to the orders of lithozems (Leptosols), petrozems (Lithic Leptosols), organo-accumulative (Skeletic Umbrisols), Al–Fe-humus (Entic Podzols, Albic Podzols), and gley (Gleysols) soils. Information-logical analysis of factual data attests to a close relationship between the thickness of soil profiles and the genetic types of soils. Thus, the degree of development of the profile can be a diagnostic indicator of the type of soil formation. Short-profile soils develop in all high-altitude landscapes. Lithozems are widespread in all vertical zones. Other short-profile soils are more definitely related to certain altitudes. Thus, organo-accumulative soils mainly develop in the subalpine zone at 650–750 m a.s.l. under tall-herb meadows, podburs are found in the mountainous tundra zone at 800–940 m a.s.l. on slightly sloping surfaces. Podzols tend to occur under elfin forest zone (740–850 m) and in the transitional zone between elfin forest and tundra on steep slopes. Gley soils are formed under woodlands on flat or slightly sloping terraces at the ecotone between the zones of mountainous taiga and park woodland.

1. Introduction
In Russia, mountain areas occupy 34% of the country. Many ideas about soil-forming processes and regularity of soil distribution in space in the mountains were based on the study of soils on neighboring plains. Meanwhile, in mountainous regions, soil cover patterns are undoubtedly more complex than on plains because of the sharp differences in the absolute height, diversity of landforms and diverse lithological and chemical composition of parent materials [1–5]. Mountain conditions determine specificity of the water and temperature regimes of weathering and soil formation [6–11]. Because of the activity of denudation processes, relatively young and not fully developed soils with short profiles are common. The demand for research on undisturbed soil cover in hard-to-reach areas has increased significantly due to the aggravation of environmental problems. The soil cover of mountains is being actively studied in many countries in order to predict the development of soils and environmental situations. In this regard, researchers are interested in facts about the relationship between the main profile-forming processes and the morphological characteristics of the soil profile.

For example, in the mountainous tropical forests of southern Mexico, an increase in the thickness of the eluvial-gley horizon was established depending on the degree of acid hydrolysis of fine fractions in the surface horizons of podzols [12].

For soils in Central Europe, the stratification of slope materials at 1,000–1,200 m a.s.l. (Sudeten Range, Poland) and its relation to the morphology and properties of podzols was determined, which
confirmed their polygenetic nature [13]. The result of stratification of slope sediments is the presence of lithological discontinuities that affect the lateral podzolization of soils. For podzols formed on the slopes of the Stolovy Mountains (Central Sudeten Range, Poland), a relationship was established between the thickness of the E horizon and its lower boundary and the lithological heterogeneity of parent materials [14]. The heterogeneity of soil profiles is manifested in a vertically differentiated sequence and is characterized by polygeneticity of podzols. In addition, the influence of relief-forming processes and lateral podzolization on the thickness of the E and Bh horizons and their properties has been found [14].

Thus, according to the morphogenetic characteristics of the soil catena, an altitude gradient was established: at higher positions, soils with a shorter profile and more intense humus illusion are formed; down the slope, the thickness of the horizons and soil profiles increases [1–9, 15–17].

Experimental data [1–11] in mountain landscapes confirm that the processes of migration of matter in soils are closely related to the meso- and micro-relief of the surface, as well as lateral and radial runoff, which proves the local specificity of the manifestation of soil-forming processes. The soils of individual vertical zones are characterized by their relationships between soil properties [12–19].

In Russia, one of the oldest mountain systems is the Ural Range. The Urals are of continental and world importance in terms of their ecological functions. However, the soil cover of this mountain system remains insufficiently studied, and its representation on small-scale maps [20, 21] is not entirely adequate. Until the middle of the twentieth century, it was believed that the Urals, as an old and heavily destroyed mountain system, did not show clearly the vertical soil zoning typical of young and high mountain systems such as the Caucasus. Active research of the mountain soils of the Urals began later than in other mountain systems. Soils of the Polar, Subpolar, Northern and Southern Urals were mainly studied [1, 3, 17, 22–24].

The soil cover of the Middle Urals has not been studied systematically. The first soil map of the Middle Urals on a scale of 1:1,000,000 was compiled based on the results of the Ural Expedition (1939–1945) [25]. According to this map, the Basegi Ridge is the area of mountainous podzolic and soddy-podzolic soils. In those years, it was believed that mountain-meadow and primitive-accumulative soils are only formed in middle and high mountains, and the Basegi Ridge was considered low mountains. Mountain brown forest soils in the Middle Urals were not identified at that time.

In the Perm Territory, local studies of the soils of the Middle Urals were carried out in the 30s – 60s of the last century in search of areas for haymaking and grazing [26–31]. Information on soils from sources of different years did not coincide due to changes in the classification and nomenclature of soils. For example, the soils of the mountain-taiga zone (300–600 m above sea level) had different names: soddy-mountain-meadow soil [28], mountain-meadow soil [29], mountain-forest acidic non-podzolized soil [28], mountain forest podzolic soil [32], mountain soddy podzolic soil [32], mountain soddy forest soil [32], brown unsaturated coarse humus soil [33], mountain taiga soil [34] and brown mountain forest soils [35–37].

Available literature data on soils of the Middle Urals does not give an idea of the specific features of the soil cover under particular local conditions. At present, there are more opportunities for research and systematization of soil data. Currently, there are more opportunities for research and systematization of soil data. The search for the meaningful characteristics of soils (as a manifestation of the main soil-forming process) and the identification of their relationship with high-altitude zones becomes urgent.

It is known that short-profile soils prevail in mountainous terrain [1, 13–17, 22–27]. We studied them from a geographic-genetic point of view trying to find the relationships between various soil processes and the thickness of the fine-earth strata. The results of this study in the western part of the Middle Urals are discussed below.

2. Objects and methods

2.1. Study area

Field studies were carried out on the Basegi Ridge in the western part of the Middle Urals, in the Perm region (figure 1). The Basegi State Reserve was organized in this area to protect natural mountainous
taiga ecosystems typical of the western part of the Middle Urals, on the interfluve between the Usva and Vilva rivers (58° 45’ – 59° 00’ N, 58° 15’ – 58° 38’ E) of the Volga–Kama basin.

2.2. Environmental conditions
Geologically, the territory is composed of the Late Proterozoic metamorphic rocks covered by a thin mantle of Quaternary sediments. The Basegi Ridge is composed of the resistant to weathering quartzite sandstones of the Oslyanskaya Formation – the most ancient (Riphean) rocks of the Middle Urals with quartz, mica-quartz, and feldspar-quartz varieties [38].

Tectonically, the Basegi Ridge belongs to the Visher-Chusovsky meridional uplift and consists of the Northern, Central, and Southern Basegi mounts of 951.9, 994.7, and 850 m a.s.l., respectively [39]. The length of the ridge is more than 20 km, and slope steepness varies from 2.5° to 10.0° or more (figure 2) [40].

Mountain peaks are separated by saddles at about 650 m a.s.l. The peaks have an asymmetric profile with gentle western and steeper eastern slopes. The Late Pleistocene glaciation did not reach the Basegi Ridge; long-term denudation processes have split the massif into isolated peaks. River valleys are poorly developed because of the hardness of the underlying rocks; intermontane depressions are significant in width [39]. Aeolian processes are active on the tops of the mountains.

The Basegi Reserve has a typical continental boreal climate with sharp temperature fluctuations. The mean annual temperature is –1.0° – 1.4°, the mean July temperature is +13.3°, and the mean January
temperature is $-17.9^\circ$. In the depressions, the mean July temperature reaches $+16.6^\circ$, and the mean January temperature is $-19.0^\circ$. The mean annual precipitation is about 800 mm with about 60% in the warm season [39]. On western slopes, precipitation is 25–130 mm higher than on eastern slopes. Snow cover lasts for about 180 days; its average depth is 115–120 cm on western slopes and 30 cm smaller on eastern slopes. In valleys, it reaches 1.5–2.0 m; on mountain tops, it is up to 50–70 cm.

According to the geobotanical zoning, the Basegi Ridge belongs to the subregion of fir-spruce and birch forests in the region of the mountainous fir taiga. The following vertical vegetation zones are expressed: mountain-forest, subalpine, and mountain-tundra (alpine). The subalpine zone is further subdivided into three subzones: park woodlands, elfin forests, and subalpine meadows [41].

2.3. Research methods

During field studies in 2009–2019, 52 soil profiles were described and sampled in typical biogeocenoses of different zones from the alpine tundra (940 m a.s.l.) to the mountainous taiga (315 m a.s.l.). Morphological characteristics of soils, symbols of soil horizons, and classification position of soils were determined according to the new Russian substantive-genetic soil classification system and the field guide to Russian soils [42] and the World Reference Base of Soil Resources (WRB) [43].

According to the total thickness of the organic and fine-earth mineral horizons, the soils were subdivided into several categories: very shallow soils (< 30 cm), shallow soils (30–50 cm), moderately deep soils (50–80 cm), deep soils (80–120 cm), and very deep soils (> 120 cm). Soils with the fine-earth layer of less than 30 cm belong to the order of lithozems (Leptosols), and soils with a weakly developed humus (W) or with a thin peaty litter (O) horizon overlying unaltered parent material are separated as the trunk of primary soil formation and department poorly developed soils (petrozems on hard rocks, psammozems on sands, and pelozems on loamy or clayey substrates) [42]. Soils with a thicker profile were classified within the orders of organo-accumulative, Al–Fe-humus, and gley soils.

Based on the previously identified relationships between soils and soil formation factors, geomodeling of the soil cover for the Basegi State Reserve was carried out [44]. The resulting soil map is presented in figure 3.

**Figure 3.** Soil map of the Basegi State Reserve (author's version).

Data on the depth of studied soil profiles and on the thickness of diagnostic soil horizons were analyzed by statistical methods using Microsoft Excel and STATISTICA 6.0 software to find their maximum, minimum, and average values in each of the separated soil groups. The results of statistical processing are reliable at $P = 0.95$. 

Soils:
1 – Brown soils (Cambisols).
2 – Brown gley soils (Gleyic Cambisols).
3 – Brown raw-humus soils (Folic Cambisols).
4 – Gray-humus soils (Skeletic Umbrisols).
5 – Petrozems protohumus (Lithic Leptosols Brunic), podburs raw-humus (Entic Podzols), podzols raw-humus (Albic Podzols).
6 – Lithozems dry peat (Folic Leptosols), raw-humus (Haplic Leptosols) and dark humus (Umbric Leptosols).
7 – Gley humus soils (Histic Gleysols).
8 – Gley soils (Haplic Gleysols).
9 – Peat oligotrophic gley soils (Ombric Histosols, Histic Gleysols).
10 – Alluvial humus gley soils (Humic Fluvisols Gleyic).
11 – The border of the Basegi State Reserve.
The use of only simple statistical methods limits the possibilities of research. The formation of soils is due to many factors, and for multifactorial phenomena, the use of information-logical analysis (ILA) is more promising [6, 40, 44–48]. Such an analysis was performed using the ALI program developed at the Altai State Agrarian University by L. M. Burlakova and D. I. Ivanichkin.

The method is based on the idea of measurability of information load on the studied phenomenon from the factors, and the assessment of the strength of connection between the features by comparing the prior probability (for the entire sample) with the conditional probabilities (for each of the factors). The degree of connection between the phenomenon and the factor is determined by the indicators: T (information content, bit), K (coefficient of efficiency of communication channels). Basic concepts of information theory: A – phenomenon (process), dependent value Y; B – factor (argument), independent variable X; H(A) – the uncertainty of the phenomenon under study (it reaches the maximum uncertainty with an equal probability of all its states, the unit of uncertainty is a bit); H(B) – factor uncertainty; T(A/B) – general informational content, i.e. the amount of information coming from factor B to phenomenon A (bit); K(A/B) – coefficient of efficiency of information transfer from factor B to phenomenon A. When analyzing relationships using information indicators, the thickness of the soil profile (< 20, 20–30, 31–40, 41–50, > 50 cm) and the genetic type of soil have been taken into account.

Ranking was performed and tables of the occurrence of combinations of the genetic type of soil and thickness of its profile were compiled. Next, a matrix of estimates of the probability of combinations of different states was calculated, on the basis of which the most probable thickness of the profile for each genetic type of soils was calculated. For lithozems as soils found in all vertical zones, the specificity of particular soil types was determined with due account for the absolute height of the terrain. Indicative connections were preliminarily established: absolute height-genetic type of soil. For absolute heights, the following grades were used: 300–500, 500–700, 700–900, > 900 m a.s.l. Genetic types of lithozems included gleyic, mucky-humus, gray-humus, ferruginous, eluviated, raw-humus, silty, peaty, and dry-peaty. On this basis, probability of the occurrence of particular combinations "soil type/terrain height" was estimated.

3. Results and discussion

In recent decades, new materials on soils of poorly studied and difficultly accessible territories have been obtained, and new concepts of soil genesis have been developed. Scientists from the Dokuchaev Soil Science Institute have initiated the work on refining the small-scale soil map of Russia (1988) on the basis of digital soil mapping technologies and the new classification system of Russian soils [49, 50]. It is expected that recently accumulated soil data will be included in the new map.

The Middle Urals on the Soil Map of the Russian Federation [20] is represented by mountainous soddy meadow and forest-meadow soils. On this map and its new version [21], the results of soil studies performed in the first half of the 20th century are reflected. In fact, they do not adequately characterize the real diversity and complexity of soil cover patterns in this region.

During field soil studies of the Basegi Ridge performed by the author in 2009–2019, the soils have been described and named according to the new classification system. The following diagnostic genetic horizons were most widespread in the studied soil profiles: AY (gray-humus), AO (raw-humus), BHF (Al–Fe-humus), E (podzolic), and G (gley).

The order of lithozems includes soils formed in a thin gravelly fine-earth strata underlain by hard bedrock at a depth of up to 30 cm. Lithozems with peaty litter (O), raw-humus (AO), mucky (H), or dry peat (TJ) surface organic horizons are formed in the mountainous tundra above 850 m a.s.l. Lithozems with gray-humus (AY) horizons are formed on rock outcrops in the mountainous taiga zone and on steep slopes near stone runs (kurums) in the subalpine zone under elfin forest vegetation.

Organo-accumulative soils are characterized by the presence of organic or humus horizons, which are gradually replaced by little-altered parent rock. The middle-profile horizon as an independent genetic formation is not expressed. The migration of suspensions, illuviation of Al–Fe-humus compounds, gleyzation, and other profile-differentiating processes are only manifested at the level of diagnostic soil features and do not form separate diagnostic horizons. These soils are mainly formed under herbaceous
plant communities. The total thickness of the loose strata exceeds 30 cm. Organo-accumulative soils are common in the subalpine meadow subzone at 650–750 m a.s.l.; raw-humified organo-accumulative soils occur in small areas within the mountainous tundra and taiga zones.

Al–Fe-humus soils are characterized by the illuvial accumulation of Al–Fe-humus compounds in the BHF horizon of brown or ochaceous-brown color. They are further separated into the types of podburs (with the BHF horizon) and podzols (with the E–BHF horizon sequence). Podburs tend to occur in the mountainous tundra zone at 800–950 m a.s.l., whereas podzols are common in the subzones of elfin forests and open woodlands and in the transitional zone to the mountainous tundra at 740–850 m a.s.l. The thickness of the soil profiles varies from 20 to 40 cm.

Gley soils (gleyzems) have a clearly expressed diagnostic gley horizon G of grayish blue color due to the reductive mobilization of iron oxide under periodically stagnant conditions. The gley horizon lies directly under the organic or humus horizon. Often, a thick (> 10 cm) raw-humus horizon is formed in gley soils in the mountainous tundra and park woodland zones at 350–500 m a.s.l. Gley soils with a humus horizon and raw-humus features (AYyo) are formed in the subzone of subalpine meadows at 515–640 m a.s.l. This height corresponds to the ancient leveling surface and represents a gently sloping plateau, where surface and subsurface runoff from the upper steep slopes is collected.

In the soil cover of the reserve, there are soils with a weakly developed humus (W) or peaty litter (O) horizons overlying hard rocks. These soils are classified as petrozems. The development of the soil profile is limited by the young age of the soil or by severe climatic conditions. Most often, petrozems are found in the mountainous tundra zone between bald mountains and stone fields; they also occur in the mountainous taiga zone in the areas of bedrock outcrops.

The thickness of major diagnostic horizons and entire soil profiles differs in the soils of different orders. The limits of variation in the thickness of the horizons vary within different limits (table 1).

**Table 1.** Limits of variation in the thickness of diagnostic soil horizons, (cm).

| Soil order (N) | Horizons\(^a\) | Profile depth |
|---------------|----------------|--------------|
| Lithozems (10) | O\(_1\), O\(_2\), AY, E, BHF, G | 7–29, 18, 34–50, 22–40, 31 |
| Organo–accumulative (18) | 2–13, 2–15, 5–20, 12, 6–34, 20 | 18, 42, 42 |
| Al–Fe-humus, including (18): | 2–10, 2–7, 9–18, 3–14, 9–30 | 22–40, 31 |
| Podburs (9) | 6–8, 6–13, 9–18, 3–14, 24, 20 | 35–40, 38, 20–40 |
| Podzols (9) | 2–10, 2–10, 3–14, 3–13 | 30 |
| Gleyzems (6) | 2–10, 2–10, 7–34, 9–8, 17–44 | 48–63 |

\(^a\) N. number of studied profiles.  
\(^b\) O\(_1\), first organic (superficial); O\(_2\), second organic; AY, gray-humus; E, podzolic; BHF, Al–Fe-humus; G, gley.

The thickness of surface organic horizons (O, H, T) varies within 2–13 cm with the average of 6–7 cm. The subsurface raw-humus horizon (AO) varies within a wider range (2–34 cm). The greatest thickness of this horizon is typical of gley soils (21 cm), and the minimum thickness is in lithozems (8 cm). The average thickness of the gray-humus AY horizon is maximal in the organo-accumulative soils (20 cm); the range of variation is great (6–34 cm). The BHF horizon thickness is highly variable (3–30 cm) and is generally thicker in podburs (17–30 cm with the average of 24 cm) than in podzols (3–13 cm with the average of 8 cm). It is interesting that the average thicknesses of podzolic (E) and Al–Fe-humus (BHF) horizons in podzols are approximately equal (9 and 8 cm, respectively). The thickness
of the gley (G) horizon in gleyzems averages 30 cm with the range from 17 to 44 cm. The thickness of the entire profile in the studied short-profile soils varies from 7 to 63 cm.

Information-logical analysis of data on the profile thickness and the genetic group (orders or types) of soils attests to their close relationship with a high general information content (T = 1.26) and a high transmission coefficient of communication channels (K = 0.63). The formation of a profile of less than 20 cm in thickness is most characteristic of lithozems. For organo-accumulative soils, the formation of soil profiles with a thickness of 31–40 cm and 41–50 cm is characteristic (table 2). The profile thickness of podburs is 41–50 cm; for podzols on steep slopes, it is usually about 20–30 cm. Gley soils are more developed and tend to have the profiles of more than 50 cm. The thickness of soil profiles depends on the manifestation of particular soil-forming processes shaping different diagnostic horizons and can serve as a diagnostic indicator of the soil nature.

Table 2. Profile thicknesses specific to soil types.

| Soil order                      | < 20 | 20–30 | 30–40 | 40–50 | > 50 |
|---------------------------------|------|-------|-------|-------|------|
| Lithozems                       | +++a | +     | –     | –     | –    |
| Organo-accumulative             | –    | –     | +++   | ++    | +    |
| Al–Fe-humus, including:         |      |       |       |       |      |
| Podburs                         | –    | –     | +     | +++   | –    |
| Podzols                         | –    | +++   | +     | –     | –    |
| Gleyzems                        | –    | –     | –     | +     | +++  |

*a Occurrence frequency: (+++) very often, (++) often, (+) rarely, and (–) never.

Studying short-profile soils, it turned out that genetic groups of soils (orders, types) are formed in certain vertical zones, where the manifestation of a diagnostic profile-forming process is possible. Only lithozems (Leptosols) are formed in all vertical zones in combination with soils of other orders: gley soils (Gleysols), petrozems (Lithic Leptosols), organj-accumulative soils (Skeletic Umbrisols), Al–Fe-humus soils (Entic Podzols, Albic Podzols), peat gley soils (Ombric Histosols, Histic Gleysols), and alluvial soils (Humic Fluviosols). This fact characterizes specificity of the soil cover patterns in mountainous conditions.

With the help of information-logical analysis, the patterns of formation of types (subtypes) of lithozems in space have been determined depending on the absolute height of the terrain. The overall information content of the relationship between landscape conditions and soil formation is 0.960 bits and is high. The coefficient of information transmission efficiency K shows a high closeness of the relationship between the height factor and the genetic groups of lithozems. The quantitative values of this relationship were determined, which made it possible to identify the topographic series of genetic groups of lithozems that regularly change in space (from bottom to top): raw-humus (mountain-forest zone, 300–500 m) – gleyic (meadow-bog zone, 500–700 m) – gray-humus, clay-illuviated (meadow glades, elfin forests, 700–900 m) – mucky-humus and dry peat (tundra zone, > 900 m).

4. Conclusion
On the territory of the Basegi State Reserve in the western part of the Middle Urals, conditions are created for the formation of short-profile soils belonging to different soil orders (five orders: lithozems, poorly developed soils, organo-accumulative, Al–Fe-humus and gley soils). Typical features of short-profile soils in the reserve are as follows:

– clear differentiation into mineral and organic horizons with the average thickness of the surface organic (peaty litter) horizons of about 6–7 cm;

– the thickness of the fine-earth strata of soil profiles depends on the manifestation of particular profile-forming processes (humus formation, gleyzation, Al–Fe–humus illuviation);
the processes of illuviation, ferruginization, humus accumulation and structure formation are characteristic of all studied soils;

- in all types of soils, there are raw-humus subtypes with dark-colored raw-humus horizons;
- in lithozems and organo-accumulative soils, the formation of the gray-humus horizon with a thickness of 5–20 and 6–34 cm, respectively, is mandatory;
- the profiles of lithozems and organo-accumulative soils are poorly differentiated into horizons by color;
- the profiles of Al–Fe–humus soils (podzols, podburs, soddy podzols, or soddy podburs) and gley soils are sharply differentiated into horizons by color.

A systematic list of short-profile soils in the study area has been compiled. The spatial heterogeneity of the soil cover and a variety of conditions for the formation of short-profile soils are revealed. Lithozems and petrozems are formed in all altitudinal zones. Organo-accumulative soils mainly develop in the subalpine zone under herbaceous meadows. In the harsh conditions of elfin forest and mountain tundra, Al–Fe-humus soils develop. Gleyzems are formed in park woodlands on flat, slightly sloping terraces in the mountainous taiga-park woodland ecotone.

References
[1] Dymov A A and Zhangurov E V 2011 Eurasian Soil Sci. 44(5) 471–9
[2] Samofalova I, Luzyanina O, Maulina E and Kulkova L 2012 Igdir Univ. J. Ins. Sci. Techn. 2 93–100
[3] Dymov A A, Zhangurov E V and Hagedorn F 2015 Catena 131 140–8
[4] Samofalova I 2015 Am. J. Env. Protect. 4(3–1) 148–56
[5] Samofalova I A, Rogova O B and Luzyanina O A 2016 Geogr. Nat. Res. 1 71–8
[6] Samofalova I A 2018 Geograph. Bull. 1 16–28 (in Russian)
[7] Kulizhskiy S P and Rodikova A V 2009 Tomsk State Univ. J. Biol. 3(7) 103–8
[8] Egli M, Norton K P and Dahms D E 2014 Geoderma 213 320–33
[9] Samofalova I A, Rogova O B, Luzyanina O A and Savichev A T 2016 Dokuchaev Soil Bull. 85 56–76 (in Russian)
[10] Senol H, Tuncay T and Dengiz O 2018 Indian J. Geo Marine Sci. 47(9) 1851–65
[11] Tyler G 2004 Geoderma 119 277–90
[12] Álvarez Arteaga G, Garcia Calderón N E, Krasilnikov P V, Sedov S N, Targulian V O and Velázquez R N 2008 Geoderma 144(3–4) 593–612
[13] Waroszewski J, Kalinski K, Malkiewicz M, Mazurek R, Kozlowski G and Kabala C 2013 Catena 104 161–73
[14] Waroszewski J, Malkiewicz M, Mazurek R, Labaz B, Jezierski P and Kabala C 2015 Catena 126 11–9
[15] Borisova I G 2012 Geo. Nat. Res. 4 126–36 (in Russian)
[16] Urusevskaya I S 2017 Eurasian Soil Sci. 50 765–79
[17] Dymov A A, Zhangurov E V and Startsev V V 2013 Eurasian Soil Sci. 46(5) 459–67
[18] Savieh V I, Kotenko M E, Belopukhov S L, Snaginsky M E, Mansurov B A and Gukalov V V 2017 Vestnik Techn. Univ. 20(7) 134–7 (in Russian)
[19] Sukhacheva E Yu and Revina Ya S 2020 Eurasian Soil Sci. (4) 389–97
[20] Fridland V M (ed) 1988 Soil map of the RSFSR Scale 1 : 2.5 million (Moscow: GUGK maps) (in Russian)
[21] Shoba S A (ed) 2011 National atlas of soils of the Russian Federation (Moscow: Astrel AST) p 632
[22] Startsev V V, Zhangurov E V and Dymov A A 2017 Tomsk State Univ. J. Biol. 38 6–27 (in Russian)
[23] Mukatanov A Kh 1982 Mountain forest soils of the Bashkir ASSR (Moscow: Nauka) p 148 (in Russian)
[24] Halitov R M, Abakumov E V, Suleymanov R R and Kotlugalyamova E Y 2011 Bull. Samara Sci.
Center Russian Academy Sci. 13(5–2) 128–30 (in Russian)
[25] Ivanova E N 1949 Mountain forest soils of the Middle Urals Proc. Soil Ins. USSR Academy Sci. 30 168–93 (in Russian)
[26] Bogatyrev K P 1947 Eurasian Soil Sci. 12 704–14
[27] Nogina N A 1948 Proc. Soil Ins. USSR Academy Sci. 28 124–90 (in Russian)
[28] Ovesnov A M 1952 Mountain meadows of the western Urals (Perm) p 130 (in Russian)
[29] Tiflov M A 1952 Soils of mountain meadows of the Western Urals PhD thesis abstract (St. Petersburg) p 18 (in Russian)
[30] Lyutin A A, Glavatskikh L K and Kamenskikh E M 1960 Proc. Perm department geographer society of the USSR I(2–4) 1–20 (in Russian)
[31] Firsova V P, Goryacheva T A and Prokopovich E V 1963 Eurasian Soil Sci. 5 16–25
[32] Kanisev G N 1964 Proc. problems of soil science and agrochemistry (Perm: Perm Agricultural Institute) 22 pp 175–88 (in Russian)
[33] Firsova V P 1968 Proc. Forest and soil (Krasnoyarsk) pp 200–3 (in Russian)
[34] Mikhailova R P and Gradusov B P 1969 Eurasian Soil Sci. 6 96–107 (in Russian)
[35] Snitko G P, Gai V V and Suslov S B 2016 State geological map of the Russian Federation scale 1:200,000 Perm series Sheet O–40–XI (Novovilvensky) p 164 (in Russian)
[36] Chronicle of nature reserve "Basegi" 1997 (Gremyachinsk) p 257 (in Russian)
[37] Samofalova I A and Shutov P S 2017 Bull. Altai State Agr. Univ. 1(147) 49–57 (in Russian)
[38] Gorchakovskiy P L 1975 Plant community of the highland Urals (Moscow: Science) pp 13–67 (in Russian)
[39] Field guide for Russian soils 2008 (Moscow: Soil Institute named after V V Dokuchaev) p 182 (in Russian)
[40] IUSS Working Group WRB 2015 World Reference Base for Soil Resources. International soil classification system for naming soil and creating legends for soil maps. World soil resources reports (Rome: FAO) 106 p 181
[41] Samofalova I A 2020 Geogr. Nat. Res. (1) 175–84 (in Russian)
[42] Daineko E K and Fridland V M 1969 Proc. soil cover patterns, soil combinations, their classification and methods of study (Moscow: Nauka) pp 56–7 (in Russian)
[43] Puzachenko Yu G, Karpachevsky L A and Vznuzdaeva N A 1970 Proc. patterns of spatial variation of soil properties and information-statistical methods of their study (Moscow: Nauka) p 220 (in Russian)
[44] Sorochkin V M 1977 Eurasian Soil Sci. 9 131–42
[45] Gribov S I 2012 Bull. Altai State Agr. Univ. 12(98) 50–3 (in Russian)
[46] Ananko T V, Gerasimova M I and Konyushkov D E 2018 Dokuchaev Soil Bull. 92 122–46 (in Russian)
[47] Ananko T V, Gerasimova M I and Konyushkov D E 2017 Eurasian Soil Sci. (12) 1411–20