

PAPER • OPEN ACCESS

Physical properties as a key factor in the soil functioning in Chernevaya Taiga (Western Siberia)

To cite this article: E Abakumov *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **862** 012036

View the [article online](#) for updates and enhancements.

You may also like

- [Tunka Advanced Instrument for cosmic rays and Gamma Astronomy](#)
D Kostunin, I Astapov, P Bezyazeev et al.
- [Potential change in forest types and stand heights in central Siberia in a warming climate](#)
N M Tchepakova, E I Parfenova, M A Korets et al.
- [The TAIGA experiment: from cosmic ray to gamma-ray astronomy in the Tunka valley](#)
N Budnev, I Astapov, P Bezyazeev et al.

Physical properties as a key factor in the soil functioning in Chernevaya Taiga (Western Siberia)

E Abakumov^{1*}, S Loyko², G Istigechev² and A Lapidus^{1,3}

¹ Department of Applied Ecology, Faculty of Biology, Saint-Petersburg State University, 16 line of VO, 29, Saint-Petersburg 199178, Russian Federation

² Tomsk State University, 36, Lenin Ave, Tomsk 634050, Russian Federation

³ Center for Algorithmic Biotechnology, Saint-Petersburg State University, 6 line of VO 11/21, Saint-Petersburg 199004, Russian Federation

*E-mail: e_abakumov@mail.ru

Abstract. On the barrier-rain slopes of the low mountains of Western Siberia, there are tall-grass forests dominated by fir and aspen. Their regional name is Chernevaya taiga (from the word "chernyj" – black). Chernevaya taiga is a unique representative of the highly productive and fertile ecosystems of Western Siberia. The key features of the development of these ecosystems in the mountains of Southern Siberia are still poorly investigated. The soil physical properties play a crucial role in forming the functioning of the Chernevaya taiga ecosystem. The thermal regime, particle size distribution (profile differentiation and texture class) and hydrophysical constants of soils in Chernevaya taiga are studied. It is shown that the soil profiles of Chernevaya taiga are differentiated by the content of fine particles, which indicates the development of eluvial-illuvial hydrological and biogeochemical regimes. The favourable thermic regime is caused by a thick layer of snow existence during the winter period, when the soils of Chernevaya taiga are not frozen during the winter period. This is one of the key factors of high productivity of this ecosystem. Soils of Chernevaya taiga are characterized by increased values of key hydrological constants in comparison with sandy textured soils of oligotrophic environments.

1. Introduction

The extent areas in the mountains and foothills of the Altai-Sayan ecoregion (Western Siberia) included in the Global 200 list belong to the black (Chernevaya) taiga. These unique ecosystems have developed on the western, windward macro slopes of mountain ridges of Southern Siberia. Their sustainability is resulted from the ascent of moist western air masses in the foothills and mountains, resulting in a large amount of precipitation, which, together with a specific soil cover, provides favorable conditions for the vegetation and biogeochemical functioning of aspen-fir tall-grass taiga and the conservation of relict plant species preserved from the thermophilic vegetation of the Pliocene.

The largest areas of Chernevaya taiga are on Salair ridges, Kuznetsk Alatau, Gornaya Shoria and the foothills of Altai, and can also be found on East and West Sayan Jungar Alatau and on the northern slope of the Hamar Daban Range south of Baikal [1–4].

The climate of Chernevaya taiga is mainly affected by the influence of the Atlantic air masses. The prevailing western air flows in the regional circulation results in the dominance of precipitation over evaporation and the formation of a positive water balance with the possible formation of a vertical preferential flow. During winter, the invasion of dry and cold Arctic air masses causes a sharp drop in



temperatures. The same air masses are responsible for the early-autumn and late-spring temperature decrease. Warm and dry weather is brought by air masses coming from Central Asia and Kazakhstan. The area of Kuzneckiy Alatau mountain ridges, which has a submeridional extension, acts a barrier-transferring role on the path of air masses from the Atlantic, despite the small height of its northern part. The consequence of this is the climatic asymmetry in the precipitation distribution between the western and eastern macroecotones of the region.

The available climate data on black taiga were obtained on metostations of cities, which are located in valleys of rivers. In the valleys, however, the climate is colder and drier, and data on the watershed (mountain range) is not available. At the same time, these differences can be significant. Thus, Amelin [5] found that within the black taiga, the average monthly temperatures of the winter months and March in the watershed are 8–20 °C higher than in the valleys. In summer, the watershed ecosystems are usually warmer due to temperature inversions during the anti-cyclone type of weather. This has a significant impact on the vegetation state, so that on watershed and mountain slopes there is usually higher projective grass cover, and in the valleys there are more dense dark coniferous forests.

The main adaptation of black ecosystems to the humid climate conditions is the special structure of the soil profile and the fact that the topsoil humus horizons have increased filtration capacity and low density (0.5–0.8 g/cm³). The soils usually do not freeze during the winter. Therefore, liquid precipitates and melted surface waters are usually quickly absorbed into humus and eluvial porous soil horizons. The underlying horizon Bt (illuvial) acts as a biogeochemical and hydrological barrier [6].

The main feature of the thermal regime of Chernevaya taiga soils is the complete absence of seasonal freezing or weak freezing to a shallow depth, in comparison with the rather harsh Siberian winters, when the temperature in winter can decline to –40–45 °C. Weak soil freezing during cold winters is associated with the insulating role of the snow layer of greater thickness. Usually the snow thickness is 1 m. In the most humid areas of Gornaya Shoria, the snow thickness is 1.5–2 m. For the first time, the phenomenon of the presence of non-freezing soils in the continental conditions of Siberia for Kuznetsky Alatau was described by Petrov [7]. This thermal regime of the black taiga soils is associated with a significant share of solid precipitation (up to 30–40%) in their annual quantity. According to the observations of Khmelev and co-authors (1988), the maximum snow cover capacity in the northern part of the range is 85 cm. According to Kovalev et al. [6], up to a meter and slightly more [6]. According to Krylov [8], southwestern Altai values of snow thickness are up to 2 meters, and when the snow layer depth is more than 1 m, soil freezing is observed only in the topsoil layer.

In the northernmost part of the Chernevaya taiga area, shallow seasonal freezing is already observed everywhere. The depth of Albic Retisols freezing rarely reaches 40–60 cm even in the coldest winters, while the soil freezing processes are very slow and begin much later than the stabilization of the snow cover. At the same time, the soil thaws quite quickly, under the influence of surface water [6, 9]. Our measurements in the northern part of the area showed that Albic Retisols have a freezing depth of about 70 cm, with the temperature not declining below -1 °C, and in Luvic Stagnic Phaeozems with a high water content, the temperatures near zero were kept only in the 30 cm layer, becoming positive in deeper layers. At such temperatures in winter, there is an active movement of capillary moisture and surface water. In the conditions of humid climate, unfreezing conditions and over moistening of soils of Chernevaya taiga, there is a redistribution of fine fractions in the vertical scale of the soils profile [6]. Thus, the soil physical properties are considered as the most important in the formation of the Chernevaya taiga forest in boreal environments of southern Siberia.

The aim of this work was to clarify the specificity of the soil physical properties of Chernevaya taiga. The following objectives were established:

- (1) to conduct annual monitoring of soil temperature;
- (2) to determine the particle size distribution of the selected soils;
- (3) to estimate key soil hydrological constants.

2. Material and methods

2.1. Study sites and sampling

The field study was conducted during the summer season of 2019 on the territory of the Novosibirskaya, Tomskaya and Kemerovskaya oblast. Typical undisturbed ecosystems of Chernevaya taiga were selected as benchmark plots for detailed description and taxonomic diagnostics of soil profiles. The soil horizons types and soil diagnostics were performed according to the rules of the World Reference Base of Soil Resources [10]. A total of 15 soil pits were analysed in terms of soil morphology, and 6 of them were selected for further more detailed analyses of soil morphology and properties. Abbreviations of the soil profiles are N1, N2, N3 (Novosibirsk region, Altayskiy region) and T1, T2, T3 (Tomsk region, Kemerovo region). N1, N2 and T1, T2 sections are represented by the soils of Chernevaya taiga (Retisols of various parent loams and clays materials), while N3 and T3 soils are represented by soils of oligotrophic environments (Arenosols formed on sands of aeolian genesis outside the area of Chernevaya taiga, near its borders).

2.2. Field thermometry

Observations of the temperature regime of dark gray soil (section T1) were carried out using automatic monitoring of climatic parameters SAM-SM (Russia) in order to establish the specificity of the soil climate conditions from July 2019 till July 2020.

2.3. Laboratory methods

All laboratory analyses were performed with the use of fine earth material (fraction with a diameter of < 2 mm). In the laboratory, the soil hydrological constants were determined in soil columns. All hydrological parameters were determined on the base of the gravimetric method. Gravimetric values of hygroscopic water (HW), which serve as the index of the water amount contained in the air-dry soil, were identified [11]. The lowest water capacity was determined gravimetrically after soil saturation with steam of water on the surface of K_2SO_4 [11]. Full water capacity (FWC) was physically imitated in laboratory columns placed in the desiccator with water. After 24 hours, the column with soil and accumulated water was weighted. After what, the water was removed from the desiccator, the same columns with soil were released with free gravimetric water and field water capacity (FWC) was determined, gravimetrically.

The texture analysis was carried out according to the Kachinsky sedimentation method and consisted of two stages: 1 – dispersion of the soil mass using sodium pyrophosphate, 2 – analysis of the content of particles of different sizes with sedimentation and further application of the pipette method [11]. Statistical analysis of soil properties for soil profiles from both key plots was performed in the Statistica 10 software (one-way ANOVA for HW, LWC, TWS, FWC).

3. Results and discussion

3.1. Soil thermic regime

Our measurements of soil temperatures in the northern part of the Chernevaya taiga area showed that Albic Retisols have a freezing depth of about 60 cm and that the soil temperature never descends lower than $-1\text{ }^{\circ}\text{C}$. At the same time, in Luvic Stagnic Phaeozems, characterised by high levels of humidity, the freezing depth reaches only 30 cm (temperature in the range from 0 to $-0.2\text{ }^{\circ}\text{C}$), exhibiting temperatures of above $0\text{ }^{\circ}\text{C}$ in the deeper layers of the soil (figure 1). These thermal characteristics result in an active movement of capillary moisture and surface water saturation during the winter months. Melting of snow increases the moisture content of the soil even further.

The temperature in Luvic Stagnic Phaeozems during the period from July 2019 to July 2020 was identified. The measurements were carried out in Chernevaya taiga near Tomsk. The air temperature was measured at a height of 1.5 m, directly above the measuring logger.

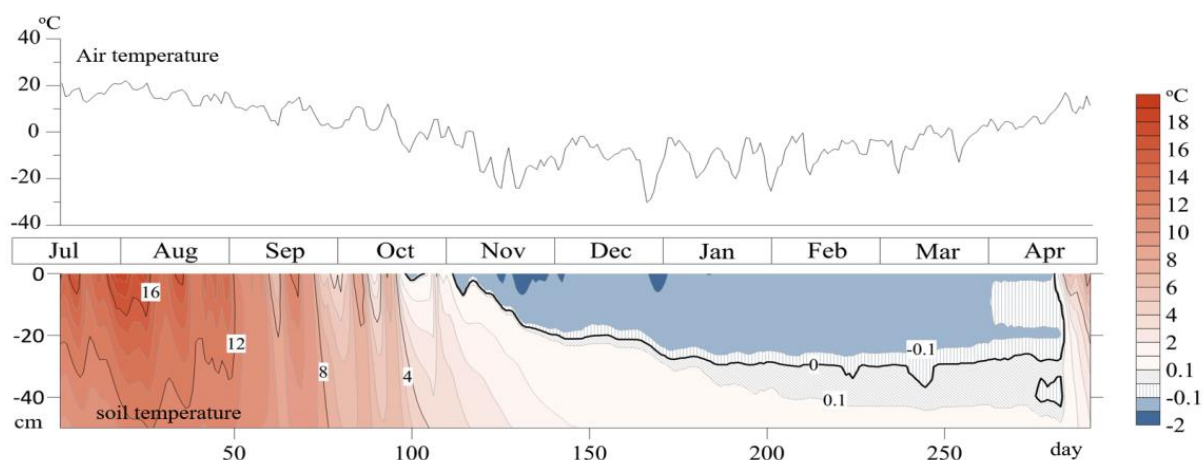


Figure 1. Albic Retisols temperature dynamics.

In particular snowy winters (like the winter of 2012–2013), open glades could be covered with snow from 1 to 1.5 meters thick. The combination of frequently present surface water with the presence of a hydrological barrier and a dense argic horizon often leads to windthrows [12].

The formation of Chernevaya taiga ecosystems is defined by climatic conditions and topographical position. Thus, low mountain ridges act as barriers to western air masses and concentrate humidity on the western slopes, as a result of which a high amount of precipitation, a humid climate, a high thickness of snow cover and the specific hydrological regime of the soil in these regions create a set of unique thermic conditions within the soil profile. It leads to either a low frost depth, or no frost at all throughout the winter months.

3.2. Particle size distribution whitening soil profiles

Vertical profile diagrams (curves) are given in figure 2. It is evident that the profile curves of all the investigated soils are not homogenous within the depth. This indicates the development of eluvial-illuvial differentiation of soils due to the dominance of the eluvial water regime in the humid environments of the investigated areas. At the same time, the degree of eluvial-illuvial differentiation is higher in the soil of Chernevaya taiga, which indicates a higher rate of soil formation. The Arenosols of N3 and T3 environments are less differentiated due to two reasons. First is that the sandy textured parent material contains less fine particles, and, thus, the lithological potential for soil texture differentiation is less than in the case of loams (parent materials of N1N2 and T1T2).

3.3. Soil texture classes

The visualisation of the soil texture class by the diagram of Fere is given in figures 3 and 4. The data shown in figure 3 demonstrates that the illuvial B horizons form the separate areas in the diagram. This is an evidence of the soil profiles differentiation by the eluvial-illuvial type. The representation of texture classes according to soil profiles (figure 4), demonstrates that N3 and T3 soils are less clay than soils of Chernevaya taiga.

3.4. Soil hydrological constants

Data on the soil hydrological constants are given in table 1. The hygroscopic water content was essentially higher in the soil of Chernevaya taiga in comparison with the soil of oligotrophous environments. These differences, as well as differences among other values of hydrological constants, were significant on the base of a One-Way Anova analyses. This can be directly related to the fact that the soils of Chernevaya taiga are enriched with fine fractions, especially clay fraction, then soils N3 and T3. Thus, the particle size distribution plays an important role in the formation of water retention capacity. The increased hydrological capacity is very important for the functioning of the soils of

Chernevaya taiga. Namely, to avoid the physiological drought that can appear in the low mountain ridges of the southern part of Western Siberia.

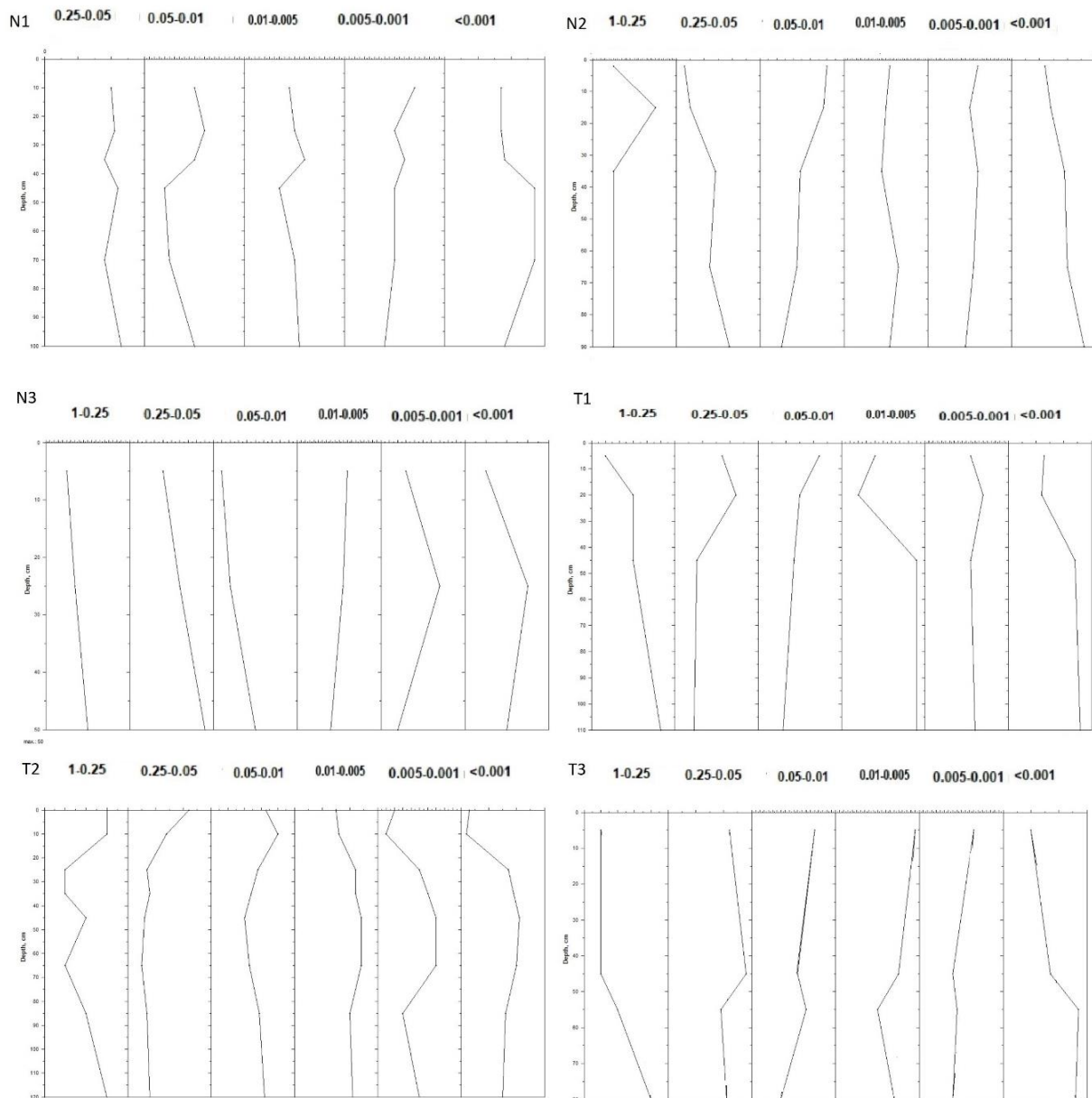


Figure 2. Particle size distribution within soil profiles.

An increase in the content of clay fraction in the middle part of soil profiles plays an important geochemical role. Atmospheric precipitation easily penetrates the humus horizon and accumulates over the dense clay horizon Bt. The relief in Chernevaya taiga is hilly, the soils are widespread on long slopes. Because of this, the water accumulated on the Bt horizon begins to slowly flow downward, feeding the foot of the slopes. High porosity leads to saturation of soil water with oxygen. Due to this, the vegetation of the middle and lower parts of the slopes has a good supply of water and nutrients. The plant roots do not experience strong anaerobic stress, despite the constant presence of shallow soil water on the Bt horizons.

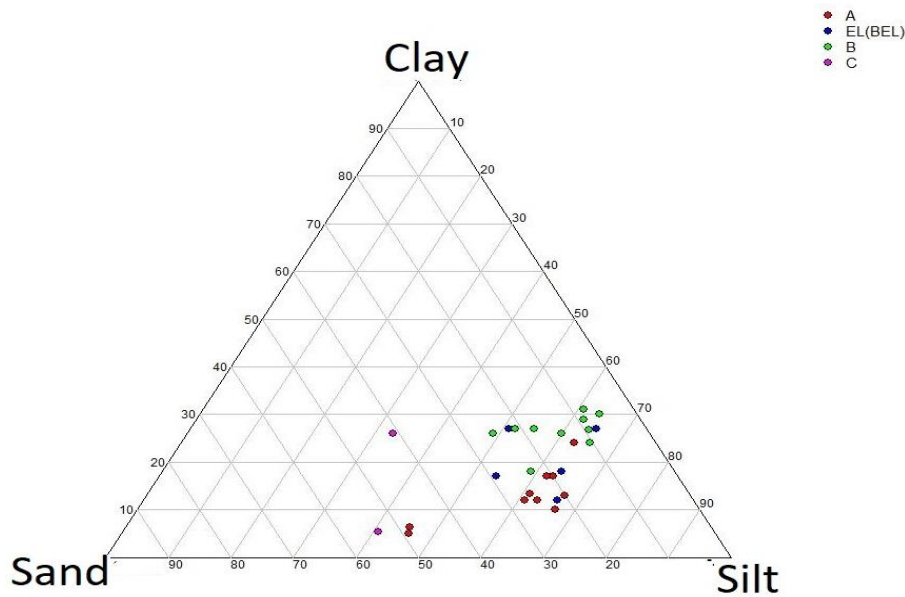


Figure 3. Soil texture diagram within various horizons.

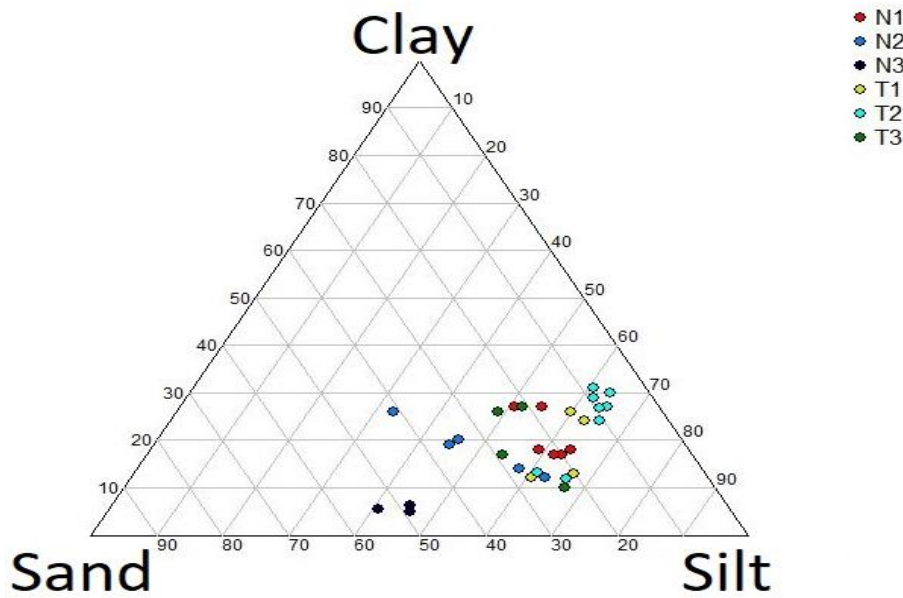


Figure 4. Soil texture diagram within various profiles.

Table 1. Soil hydrological constants.

	HW	LWC	FWC	TWC
T1	7±1	11±2	16±3	37±3
T2	6±1	9±3	23±2	41±4
T3	3±1	9±2	12±2	25±2
N1	5±1	10±2	19±2	35±3
N2	8±2	16±2	22±2	34±3
N3	1±0	1±0	16±2	32±2
One-Way Anova	p < 0.003	p < 0.004	p < 0.002	p < 0.005

4. Conclusions

The physical soil properties play an important role in the formation of the Chernevaya taiga ecosystem and its functioning. Few soils of Chernevaya taiga have been studied in terms of thermic regime, particle size distribution and texture class, as well as soil hydrophysical constants. It has been shown that the soils of Chernevaya taiga are differentiated on a vertical scale by the content of fine particles, which indicates the development of the eluvial-illuvial regime.

The soils of Chernevaya taiga do not freeze in winter, and this is one of the key factors for the high productivity of this ecosystem. The favorable thermic regime in the forest stands caused by a stable and thick layer of snow.

Soils of Chernevaya taiga are characterized by increased values of key hydrological constants in comparison with sandy textured soils of oligotrophic environments.

Acknowledgments

This work was supported by Russian Scientific Foundation (grant ID 19-16-00049).

References

- [1] Kuminova A V 1957 Teletsky refuge of the Tertiary vegetation *News East-Siberian Br. USSR Acad. Sci.* **2** 104–8 (in Russian)
- [2] Shumilova L V 1962 *Botanical geography of Siberia* (Tomsk) p 439 (in Russian)
- [3] Nazimova D I 1975 *Mountain dark-coniferous forests of West Sayan (case of ecologo-phytocoenological classification)* (Leningrad) p 118 (in Russian)
- [4] Lashchinskiy N N 2009 *Salair range vegetation* (Novosibirsk) p 263 (in Russian)
- [5] Amelin I 2017 Methodology of determination of near ground layer air temperature in hard-to-reach mountain areas (on the example of Shoriya mountains) *Interexpo GEO-Siberia-2017. XIII Int. Sci. Congr.* (Novosibirsk) **1** pp 42–6
- [6] Kovalev R V, Kovaleva S R, Korsunov V M and Taranov S A 1974 Specific features of Podzol formation in the soils of low and medium high mountains in the southeastern part of Western Siberia *Trans. Int. Congr. Soil Sci.* pp 142–8
- [7] Petrov B F 1939 Ancient crust of wind erosion and post-Tertiary sediments in the western part of Kuznetsk Alatau (mountainous Shoria) *Proc. Soil Inst. V. V. Dokuchaeva* **19(2)** 3–37 (in Russian)
- [8] Krylov A G 2014 Chernevaya taiga of South-Western Altai: coenoflora, age dynamics and productivity *Forestry Sci.* **(1)** 13–20
- [9] Dyukarev A G, Pologova N N and Dyukarev E A 2011 Temperature regime of the deep podzolic soils on the Tom'-Yaya interfluvium *Modern problems of the genesis, geography, and cartography of soils* (Tomsk) pp 35–8 (in Russian)
- [10] World reference base for soil resources 2014 2015 *International soil classification system for naming soils and creating legends for soil maps* (Rome: FAO) p 203
- [11] Rastvorova O G 1983 *Soil physics manual* (Leningrad) p 195 (in Russian)
- [12] Loiko S V, Bobrovskiy M V and Amelin I 2017 High-grass black taiga of Western Siberia: soil and paleoecological reasons for high productivity *Man and nature – interaction in specially protected natural areas* pp 81–96 (in Russian)