

Carbon stocks in soils of dark coniferous forests of the Middle Urals, Russia

Victor Valdayskikh^{}, Olga Nekrasova^{}, and Tatiana Radchenko^{}

Department of Earth and Space Science, Ural Federal University, 48 Kuibysheva Str., 620043 Yekaterinburg, Russia. E-mails: v_vald@mail.ru (VV), o_nekr@mail.ru* (ON), tatiana.radchenko@urfu.ru (TR)

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Abstract

Challenges of our time require in-depth studies of the carbon cycle and, consequently, information about its stocks in soils. Soils play a leading role in the sequestration and emission of carbon. Boreal forests account for nearly 30 % of Earth's forests. Therefore, the purpose of this study was to establish the features of carbon accumulation in the soils of the southern taiga area within the territory of the supersite 'Ural-Carbon' in the Sverdlovsk Region, in the Urals. Geobotanical studies of a profile across the watershed and terrace showed that, despite the similarity in the floral composition and structure of forest communities, with a predominance of dark coniferous trees, there are more spruce trees in the upper site of the studied profile. Additionally, there is an increased proportion of tallgrass species. The soils exposed in 24 pits were classified as Luvisols with a high proportion of clay particles in the particle size distribution. The stocks of organic carbon in the supersite, determined based on the bulk density values obtained for each individual profile, were $9.06 \pm 3.86 \text{ t} \cdot \text{ha}^{-1}$ for the litter layer, $78.11 \pm 22.41 \text{ t} \cdot \text{ha}^{-1}$ for the upper 0–30 cm layer, $96.22 \pm 30.9 \text{ t} \cdot \text{ha}^{-1}$ for 0–50 cm layer, and $111.06 \pm 37.5 \text{ t} \cdot \text{ha}^{-1}$ for 0–100 cm layer. At the same time, soils in the lower site of the profile had significantly higher carbon content compared to those in the upper site, and the differences were statistically significant for the mineral horizons. Obtained data on carbon stocks indicate the heterogeneity of the soil cover and are generally consistent with the available estimates for soils in dark coniferous forests in other regions. These data can be used to create models of carbon stocks in old-growth southern taiga dark conifer forests that form in similar conditions, as well as for climate projects.

Key words: *Abies sibirica*, Luvisols, *Picea obovata*, relief position, soil organic carbon (SOC), southern taiga.

Introduction

New challenges require in-depth research related to the biogeochemical carbon cycle and, consequently, information about carbon stocks in soils, which play a lead-

ing role in its sequestration and emission. In the upper thirty centimetres of the Earth's soil alone, carbon stocks amount to 680 billion tons (FAO 2021), which exceeds the stocks of the planet's vegetation (560 billion tons) and is almost twice as

much as in the atmosphere. Almost one-third of the Earth's land area is occupied by forests, whose carbon sink is equivalent to almost half of fossil-fuel emissions ($7.8 \pm 0.4 \text{ Pg C} \cdot \text{yr}^{-1}$ in 1990–2019) (Pan et al. 2024). Approximately 30 % of these forests are boreal (FAO 2020), about 70 % of which are located in Eurasia (Gauthier et al. 2015), and they store about 2.5 times more carbon in soils than in tree biomass (De Vos et al. 2015). Therefore, special attention should be paid to the soils of taiga regions.

Obtaining new data allows for a better understanding of the actual stocks of carbon in forest soils (Pan et al. 2011). The data available in the literature on carbon stocks in the soils of forests in individual territories indicate their significant variation (Bradshaw and Warkentin 2015, Bakhmet 2018, Chernova et al. 2020, Ryzhova et al. 2022), ranging from three- to fourteen-fold across different soil groups (Osipov et al. 2021).

It is noted that the lack of data on soil bulk density makes it difficult to calculate organic carbon stocks in soils (Köchy et al. 2015, Tifafi et al. 2018, Sothe et al. 2022), and therefore some studies use a model for calculating bulk density proposed for mineral horizons of forest soils (Chestnykh and Zamolodchikov 2004).

Data on soil carbon stocks in the southern taiga of the Middle Urals are available only for a limited number of soil profiles (Firsova and Dergacheva 1972, Gafurov 2008), although this territory is characterised by a unique combination of mountainous and flat terrain and a variety of soil-forming rocks, which may influence the accumulation of carbon in soils.

Detailed information about local sites, based on all data necessary for calculating carbon stocks obtained for each profile, can provide more detailed under-

standing of the actual carbon stocks in taiga soils and will contribute to improving the modelling of this indicator, taking into account regional specifics.

The purpose of this work was to establish the features of organic carbon accumulation in the soils of the southern taiga on the territory of the supersite 'Ural-Carbon' in the Sverdlovsk Region, in the Urals. The carbon measurement supersite 'Ural-Carbon' was established to develop and test technologies for monitoring the balance of climatically active gases in natural ecosystems. The supersite territory is representative of the southern taiga of the Middle Urals in terms of topography, vegetation, and soil cover. It was hypothesised that soils formed on different relief elements within the supersite differ in their organic carbon stocks.

Materials and Methods

Geobotanical and soil studies were conducted on the territory of Kourovka, a part of the Ural-Carbon supersite (which, for convenience, will be referred to as the Kourovka supersite) in 2021–2024. The study area is located in the low mountains of the Middle Urals, underlain by limestones and covered by eluvial–deluvial deposits, and belongs to the southern taiga subzone (Fig. 1). The climate is temperate continental. The average annual air temperature is 2.0°C , and the annual precipitation amounts to 682 mm (Climate-Data.org 2025).

To study vegetation and soils, taking into account the main relief elements of the supersite, a profile was selected, on which two sites were identified: the first (upper, site 1) represents the flat peaks of the watershed and the gentle slopes adjacent to them (elevation of 290–305 m



Fig. 1. Location of Kourovka, a part of the Ural-Carbon supersite.

a.s.l.), and the second (lower, site 2) represents flat or slightly concave areas of the terrace in the Chusovaya River valley (elevation of 275–290 m a.s.l.).

Geobotanical descriptions were carried out at each site on four sample plots measuring 400 m² (a total of 8 plots were studied). The complete floral composition (considering all tiers), species abundance according to the Drude scale, the total projective vegetation cover, composition, structure and closeness of the stand, the renewal of tree and shrub species, composition and structure of the understorey, and the presence and projective cover of mosses and lichens were recorded for each sample plot.

At each study site of the Kourovka supersite, 12 soil pits were excavated in the inter-canopy space: 4 in sample plots for geobotanical studies and 8 additional ones at distances of 100–150 m from each other (a total of 24 pits). The sizes of the study sections were: 0.7 × 0.7 × 1.0 m. Morphological descriptions of the profiles were made, soil sampling was conducted

from each horizon, and in the case of thick horizons, several samples were taken every 10–15 cm in a continuous column (156 samples in total were collected).

Additionally, 108 samples were taken to determine the soil bulk density using steel cylinders with a volume of 100 cm³ from each mineral horizon or by cutting of 20×20 cm monolith from the litter layer.

The particle size distribution of soils was determined by the pipette method (Vadyunina and Korchagina 1986), the pH values were determined in aqueous and KCl suspension at a soil-to-water (salt) ratio of 1:2.5 using an Anion 4100 pH meter (Russia). Soil organic carbon (SOC) was determined by the Tyurin wet combustion method (with titrimetric termination); total nitrogen (TN) was determined by the Kjeldahl method using Velp equipment (Italy); exchangeable Ca²⁺ and Mg²⁺ were determined titrimetrically; mobile phosphorus (P₂O₅) was determined by the Kirsanov method using a UV Probe 1650 spectrophotometer (Japan); and mobile potassium (K₂O) was determined using a

PFA-378 flame photometer (Russia) (Ari-nushkina 1970, Vorobyova 2006).

Soil organic carbon stock (SOCS, t C·ha⁻¹) was calculated for each soil horizon using formula (1):

$$\text{SOCS} = \text{SOC} \cdot \text{BD} \cdot \text{H}, \quad (1)$$

where: SOC – soil organic carbon content, %; BD – bulk density, g·cm⁻³; H – thickness, cm.

To compare the carbon stocks in the soils of the dark coniferous forest of the Kourovka supersite with literature data, the total stocks were calculated for the organic layer, as well as for the 0–30, 0–50 and 0–100 cm layers (including the litter), by summing the SOC stocks in the corresponding horizons.

The choice of these layers is due to the fact that high amounts of organic carbon accumulate in the organic horizons of some forest (usually semi-hydromorphic) soils (Chernova et al. 2020). For the 0–30 cm layer, data are available from the GSOC-17 global map of soil organic carbon stocks; the 0–50 cm layer is considered the main root-inhabited layer and a number of datasets are available for it, and since organic matter in the 0–100 cm layer is actively involved in the modern carbon cycle (Orlov et al. 1996), data are also available for this depth.

Thus, used approach makes it possible to estimate the carbon stocks obtained for the soils of the southern taiga dark coniferous forest of the Middle Urals through comparison with available data for similar territories.

Statistical analysis was performed using the Statistica 8.0 package. Student's t-test was used to compare the data obtained at $p < 0.05$. The data in this article are presented as $\bar{X} \pm s$ (mean $\pm$ standard deviation).

Results

Characteristics of the Kourovka supersite forest communities

The vegetation cover of the Kourovka supersite is dominated by zonal maturing and mature forests of site quality class III. Dark coniferous tree species dominate in all sample plots (Fig. 2), and three distinct layers are clearly distinguished in the structure of the forest communities: arboreal, herbaceous or herbaceous-dwarf shrub, and moss.

The upper tree layer is dominated by *Abies sibirica* Ledeb. and *Picea obovata* Ledeb., with *Pinus sylvestris* L., *Larix sibirica* Ledeb., and *Betula pubescens* Ehrh., also present. Crown closure ranges from 0.5 to 0.7 (Table 1). Reliable regeneration of all tree and shrub species is represented by a variety of heights and ages.

The understorey is uneven, its projective cover averages no more than 10–15 %, and its height ranges from 0.6 to 3.0 m. It includes *Sorbus aucuparia* L., *Prunus padus* L., *Rosa acicularis* Lindl., *Lonicera xylosteum* L., *Sambucus sibirica* Nakai, among others.

In the herbaceous-dwarf shrub layer of the communities, 36 species of higher vascular plants were recorded, and the projective vegetation cover averages 60–70 %. The following species occur with high consistency: *Oxalis acetosella* L., *Linnaea borealis* L., *Gymnocarpium dryopteris* (L.) Newman, *Agrostis gigantea* Roth, *Carex macroura* Boott, *Dryopteris carthusiana* (Vill.) H.P. Fuchs, *Maianthemum bifolium* (L.) F.W. Schmidt, *Circaea alpina* L. and *Calamagrostis arundinacea* (L.) Roth.

The grass layer contains significant numbers of species typical of broadleaf



Fig. 2. Forest of the Kourovka supersite: a – site 1; b – site 2.

Table 1. Main characteristics of vegetation cover in the Kourovka supersite test plots.

Characteristic	Sample plots							
	Site 1				Site 2			
	1	2	3	4	5	6	7	8
Crown closure	0.6–0.7	0.7–0.8	0.7	0.6–0.7	0.7	0.5–0.6	0.7	0.6
Forest stand composition	5P4A 1B+Pin	4A4P 1Pin1B	5A4P 1Pin	5P4A1Pin +L+B	5A3P 1Pin1B	5A3P1Pin 1B +L	5A3P 1Pin1B	5A3P 1Pin1B
Average height of trees, m	24	23	25	22–23	24	23	26	23
Mean diameter at breast height (DBH), cm	28–30	26–28	30	30	28	26	30	29
Understorey cover, %	15	10	10	10	12	10	10	15
Herbaceous–dwarf shrub layer cover, %	65	45–55	70–80	60–70	65	70–75	60–75	75
Moss layer cover, %	70	30	60	50	65	40–50	60–65	60
Species richness (vascular plants), <i>n</i>	28	20	25	27	24	18	23	20
Dominant tree species	<i>Picea obovata</i> , <i>Abies sibirica</i> , <i>Betula pubescens</i> , <i>Pinus sylvestris</i> , <i>Larix sibirica</i> .				<i>Abies sibirica</i> , <i>Picea obovata</i> , <i>Pinus sylvestris</i> , <i>Betula pubescens</i> , <i>Larix sibirica</i> .			
Dominant shrub species	<i>Sorbus aucuparia</i> , <i>Lonicera xylosteum</i> , <i>Salix caprea</i> , <i>Rosa acicularis</i> , <i>Prunus padus</i> .				<i>Rosa acicularis</i> , <i>Sorbus aucuparia</i> , <i>Prunus padus</i> , <i>Lonicera xylosteum</i> , <i>Rubus idaeus</i> , <i>Sambucus sibirica</i> .			
Dominant herb-shrub species	<i>Oxalis acetosella</i> , <i>Gymnocarpium dryopteris</i> , <i>Carex macroura</i> , <i>Dryopteris carthusiana</i> .				<i>Calamagrostis arundinacea</i> , <i>Dryopteris carthusiana</i> , <i>Oxalis acetosella</i> , <i>Athyrium filix-femina</i> .			

Note: Numerals indicate the proportion of each tree species in tree density in tenths in the 'Forest stand composition' row. Species with minor participation (<1/10) are listed after the '+' sign. Species abbreviations are: A – *Abies sibirica*, P – *Picea obovata*, Pin – *Pinus sylvestris*, L – *Larix sibirica*, B – *Betula pubescens*.

forest: *Asarum europaeum* L., *Aegopodium podagraria* L., and *Stellaria holostea* L. Characteristic feature of the studied communities is a well-developed moss cover, 7–10 cm thick, with moss coverage reaching 60–70 %. The most abundant species are *Pleurozium schreberi* (Brid.) Mitt., *Ptilium crista-castrensis* (Hedw.) De Not., *Hylocomium splendens* (Hedw.) Schimp. and *Rhytidiadelphus triquetrus* (Hedw.) Warnst.

Despite the overall similarity in floristic composition and community structure, certain differences between the upper and lower sites of the profile were observed. The average share of *Picea obovata* was 4.5 and 3.0, and of *Abies sibirica* – 4.3 and 5.0, respectively. The upper part is characterised by a higher proportion of spruce (the differences are statistically significant), whereas fir is more abundant in the

lower part. In addition, a slight increase in the proportion of tallgrass species was recorded in the lower part of the profile.

Morphological and physico-chemical characteristics of the Kourovka supersite soils

The results of the morphological soil survey, conducted along the landscape profile of the Kourovka supersite (Fig. 3), showed that soils with O–Ah–E–Bt–C horizons were formed on clayey eluvial-deluvial deposits. According to the Russian soil classification system, these soils correspond to sod-podzolic soils (Egorov et al. 1977), while under the WRB system they are classified as Albic Luvisols (IUSS 2022).

The soils of site 2 differ from those of site 1 by a greater thickness of the humus



a



b

Fig. 3. Soil profiles of the Kourovka supersite: (a) site 1; (b) site 2.

horizon, which exhibits a more stable fine crumb structure, as well as a darker colouration of the Ah and E horizons. Particle size distribution analysis of the soils from both sites (Table 2) showed the predominance of silt particles with diameters of 0.005–0.001 mm and clay particles

<0.001 mm throughout the entire profile. The upper mineral horizons have a silty clay loam texture, while the Bt horizons are classified as clay or silty clay according to IUSS (2022).

Physico-chemical parameters provided for the main sections (Table 3) re-

Table 2. The particle size distribution of the Kouravka supersite soils.

Horizon	Loss from HCl, %	Particle diameter range, mm / Proportion, %						
		1.00–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	<0.01
Site 1								
Ah	5.5	6.7	6.2	25.5	13.6	16.8	25.7	56.1
E	4.5	4.7	1.1	25.0	12.9	20.9	30.9	64.7
Bt	7.0	5.4	0.6	16.6	3.9	13.7	52.8	70.4
Site 2								
Ah	5.7	2.4	4.4	31.6	9.9	20.4	25.6	55.9
E	3.8	3.7	2.2	36.6	12.8	19.0	21.9	53.7
Bt	5.0	1.7	2.4	22.4	10.7	22.2	35.6	68.5

Note: Particle-size fractions are defined as semi-open intervals; the lower boundary value is included in the fraction. Percentages represent the proportion of soil particles within each diameter range. Lower boundary values are included in the finer fraction.

Table 3. Physico-chemical characteristics of soils at the Kouravka supersite.

Horizon	Depth, cm	pH _{H2O}	pH _{KCl}	SOC	TN	Ca ²⁺	Mg ²⁺	Ca ²⁺ +Mg ²⁺	P ₂ O ₅	K ₂ O
				%		mg-eq per 100 g		mg per 100 g		
Site 1										
O	0–2	5.60	5.05	31.81	1.19	4.8	1.7	6.5	28.5	2.7
Ah	2–15	4.39	3.80	3.58	0.25	4.0	1.0	5.0	25.5	2.9
E	15–30	5.06	3.88	0.60	0.08	3.4	0.6	4.0	20.1	3.1
	30–40	5.08	3.83	0.51	0.06	7.1	1.7	8.8	32.0	4.0
Bt	40–50	5.27	4.00	0.45	0.07	9.0	1.7	10.7	25.6	3.7
	50–58	5.30	4.02	0.49	0.06	10.1	2.3	12.4	19.4	3.5
C	58–70	5.43	4.10	0.38	0.06	11.2	4.8	16.0	15.8	3.1
Site 2										
O	0–5	5.65	5.55	34.50	1.24	10.8	5.3	16.1	31.0	4.3
Ah	5–12	4.84	4.53	5.41	0.33	6.0	3.0	9.0	25.9	2.6
	12–22	5.25	4.85	2.41	0.20	4.0	2.8	6.8	20.2	2.9
E	22–37	5.62	4.94	2.10	0.11	5.0	2.9	7.9	26.5	3.4
Bt	37–50	5.68	4.87	0.46	0.07	17.3	1.0	18.3	28.1	3.1
	50–60	5.64	4.79	0.38	0.07	21.2	2.0	23.2	21.4	3.0
C	60–70	6.33	5.38	0.41	0.07	23.3	4.0	27.3	19.8	3.4

Note: Values are given for individual soil horizons; SOC – soil organic carbon, TN – total nitrogen; pH_{H2O} and pH_{KCl} – pH measured in water and 1M KCl suspension, respectively.

vealed that the soils of both studied sites are characterised by an acidic reaction of the medium – the pH_{H₂O} values range from 4.4 to 5.6 at the first site and from 4.8 to 6.3 at the second site. The pH_{KCl} values are on average lower by 1.0 and 0.6 units, respectively, due to the presence of exchangeable hydrogen and aluminium cations in the soil-absorbing complex.

The maximum amount of organic carbon is confined to the litter horizons (Table 3) and amounts to 32–35 %, in the humus horizon it is 2.4–5.4 %. Deeper along the profile, there is a further decrease in SOC content, which nevertheless remains at the level of 0.4–0.5 % in the lower horizons. The distribution of organic nitrogen in the soils of the supersite is similar to that of carbon.

In the profile of the studied soils, an eluvial-illuvial redistribution of exchangeable calcium and magnesium occurs, with a decrease in their content in the E horizon and an increase in the Bt horizon (Ta-

ble 3). The maximum amounts of Ca²⁺ and Mg²⁺ are confined to the C horizons. The content of exchangeable cations in the soil of the second site is higher in all horizons than in the first, reflecting the different enrichment of the soil-forming rocks.

In the soils of both sites, mobile forms of phosphorus are present in high amounts (16–32 mg per 100 g), whereas potassium occurs in low amounts (3–4 mg per 100 g).

Thus, the soils of the studied sites at the Kouravka supersite are similar in their content of mobile phosphorus and potassium but differ in pH and in the amounts of exchangeable Ca²⁺ and Mg²⁺ ions.

The stocks of organic carbon in the soils of the Kouravka supersite

The stocks of organic carbon in the soils of the Kouravka supersite are determined by the SOC content of each horizon, its thickness, and bulk density. Table 4 pres-

Table 4. Minimum, maximum, and mean values of horizon thickness, soil organic carbon content and bulk density in the soils of the Kouravka supersite.

Horizon	Depth, cm		SOC %		Bulk density, g·cm ⁻¹	
	Minimum–Maximum	X ±s	Minimum–Maximum	X ±s	Minimum–Maximum	X ±s
Site 1 (n=12)						
O	2–5	3.5±1.0a	25.56–41.90	35.4±4.50a	0.04–0.06	0.05±0.007a
Ah	6–10	7.5±2.4a	3.55–6.07	4.68±0.83a	0.83–1.20	0.99±0.11a
E	13–20	17.0±3.2a	0.21–0.74	0.63±0.09a	0.98–1.33	1.28±0.11a
Bt	18–29	26.3±3.0a	0.31–0.51	0.43±0.05a	1.31–1.44	1.40±0.06a
C	10–15	11.8±2.1a	0.24–0.44	0.38±0.06a	1.29–1.49	1.43±0.07a
Site 2 (n=12)						
O	3–5	4.0±0.9a	30.30–41.38	36.52±3.21a	0.04–0.07	0.06±0.008a
Ah	15–24	19.3±3.1b	2.96–5.12	3.87±0.66a	0.86–1.14	0.96±0.12a
E	10–15	12.3±2.0b	0.45–1.62	0.90±0.45a	1.01–1.37	1.25±0.12a
Bt	17–30	21.2±4.1b	0.38–0.98	0.64±0.21a	1.28–1.42	1.37±0.07a
C	10–15	11.3±2.3a	0.39–1.21	0.77±0.37b	1.29–1.39	1.35±0.06a

Note: For each soil horizon, values followed by the same letter are not significantly different at $p < 0.05$, whereas different letters indicate statistically significant differences.

ents the ranges and mean values of these indicators for the soils of the studied forest.

Soils at site 2 differ significantly from those at site 1, showing greater thickness of the humus horizon, lower thickness of the eluvial and textural horizons, and higher SOC content in the C horizon. The bulk density of corresponding soil horizons at the Kourovka supersite varies only slightly between sites, probably due to the similar soil texture.

The stocks of organic carbon in all soil layers at site 2 ($92\text{--}175\text{ t}\cdot\text{ha}^{-1}$) are higher than those at site 1 ($67\text{--}103\text{ t}\cdot\text{ha}^{-1}$) (Fig. 4), with statistically significant differences observed for all layers except the litter layer.

At site 1, SOC stocks in the organic (litter) horizon exhibit the highest coefficient of variation (59 %), while for other soil layers it ranges between 12 % and 14 % (Table 5). At site 2, coefficients of varia-

tion were generally slightly higher, ranging from 19 % to 24 % across all soil layers.

Thus, the litter horizon shows greatest variability in carbon stocks, and the lower site exhibits higher spatial heterogeneity.

Discussion

The study conducted in the dark coniferous forest, considering soil profiles across a watershed and terrace, showed that soils at lower relief positions have significantly thicker Au horizons and darker humus and eluvial horizons. This pattern is likely due to denudation processes involving downslope transport of fine soil particles from upper to lower landscape positions.

Despite these differences, soils at both sites are similar in terms of high mobile phosphorus (P_2O_5) content, low potassi-

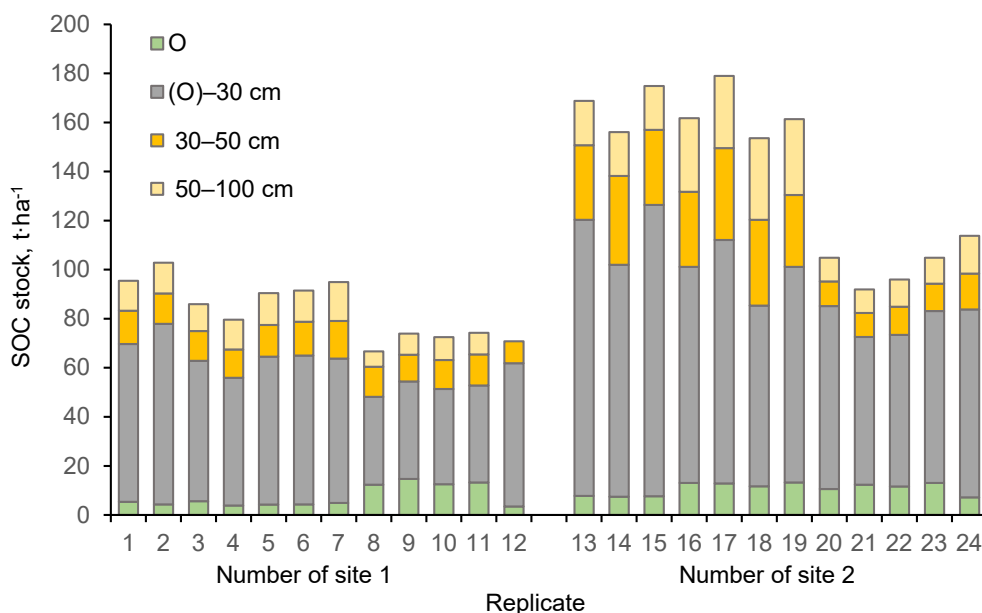


Fig. 4. Organic carbon stocks in litter and 0–30, 0–50, and 0–100 cm soil layers at the Kourovka supersite.

Table 5. Mean organic carbon stocks in soils of different sites of the Kourovka supersite (mean $\pm$ standard deviation).

Site	SOC stock in the layer, t·ha ⁻¹			
	Litter	0–30 cm	0–50 cm	0–100 cm
Site 1 (n=12)	7.40 $\pm$ 4.36a	60.69 $\pm$ 8.48a	73.03 $\pm$ 9.07a	83.23 $\pm$ 11.76a
Site 2 (n=12)	10.72 $\pm$ 2.48a	95.54 $\pm$ 17.76b	119.42 $\pm$ 27.22b	138.89 $\pm$ 33.47b
Both sites (n=24)	9.06 $\pm$ 3.86	78.11 $\pm$ 22.41	96.22 $\pm$ 30.90	111.06 $\pm$ 37.55

Note: Different letters (a, b) indicate statistically significant differences between sites at $p < 0.05$; same letters indicate no significant difference.

um (K₂O) content, and the accumulation maxima of exchangeable Ca²⁺ and Mg²⁺ in the lower horizons, indicating comparable parent material composition.

At the same time, soils at the lower site contain significantly higher amounts of exchangeable calcium and magnesium and consequently exhibit a less acidic soil reaction. This is most likely the result of downslope migration of Ca²⁺ and Mg²⁺ with surface and subsurface runoff. Humus horizons at both sites contain comparable concentrations of organic carbon, which further supports the role of denudation in redistributing soil material along the relief. As a result, higher SOC stocks in soils at the lower site are primarily driven by the greater thickness of the humus horizons.

The stocks of organic carbon in the entire soil profile also vary significantly within each studied site (Fig. 4). This heterogeneity in forest soils is caused by tree uprooting, variations in herbaceous layer composition, and differences in stand productivity. These factors, in turn, can affect the bulk density of the upper soil horizons, as well as the accumulation and redistribution of humus substances (Karpachevsky 1981).

At the Kourovka supersite, the organic soil layer contains on average 8–9 % of total SOC (Table 5). The 0–30 cm layer accumulates 69–73 % of total SOC, while the 0–50 cm layer contains 86–88 %. Thus, despite differences in total SOC be-

tween sites, the vertical distribution of carbon within the profiles is similar. Similarly, Jarman et al. (2023) reported that the upper third of a Luvisol profile contained 70 % of SOC.

The values of soil organic carbon stocks at the lower site of the Kourovka supersite are comparable to those reported for other spruce forests of the southern taiga in the Middle Urals, where average soil carbon stocks of about 126.4 t·ha⁻¹ have been documented (Chestnykh et al. 2020). Carbon stocks in the litter layer are also consistent with published data for this region (8.8–11.3 t·ha⁻¹) (Firsova and Pavlova 1983).

The soil SOC stocks obtained for the Kourovka supersite are generally consistent with values reported for comparable forest ecosystems in other regions. For example, average organic carbon stocks in the 0–30 cm mineral soil layer (excluding litter) reach about 114 t·ha⁻¹ in Bulgarian spruce forests (Kirova et al. 2025), while in Luvisols they average 52.3 t·ha⁻¹ (Stoeva and Kirova 2021). In similar coniferous forests in Sweden, soil organic carbon stocks in the 0–100 cm layer have been estimated at approximately 92 t·ha⁻¹ (Stendahl et al. 2010).

Nevertheless, SOC stocks obtained in this study are significantly lower than the average values reported for Middle Siberia (146 t·ha⁻¹; Osipov et al. 2023), southern taiga forests of Russia (167 t·ha⁻¹

¹; Schepaschenko et al. 2013) and the global average estimate for boreal forests ($195 \text{ t} \cdot \text{ha}^{-1}$; Bradshaw and Warkentin 2015). This discrepancy is likely attributable to the relatively shallow soil profiles typical of the mountainous conditions of the Middle Urals.

Calculations for the Kourovka supersite indicate that approximately 30 % of total soil organic carbon is stored below 30 cm depth. Therefore, global carbon stock maps (e.g., FAO, SoilGrids), which do not account for deeper soil layers, may underestimate soil carbon reserves, as also reported by other authors (Sothe et al. 2022).

Conclusions

The study has shown that the dark coniferous forest of the Kourovka supersite exhibits generally similar composition and structural characteristics across different relief positions. However, soils associated with vegetation within a local biogeochemical cycle may differ in their morphological structure and physico-chemical properties, which in turn affect the amount of organic carbon accumulated within the soil profile.

Denudation processes have led to the formation of a humus horizon of greater thickness in the soils of the lower site compared to the upper one. The stocks of organic carbon, determined considering the bulk density values for each profile, revealed statistically significantly higher values in the soils of the lower site ($138.9 \pm 33.5 \text{ t} \cdot \text{ha}^{-1}$) compared with the upper site ($83.2 \pm 11.8 \text{ t} \cdot \text{ha}^{-1}$).

The obtained data are generally consistent with available estimates for dark coniferous forest soils in this and other regions and indicate significant heteroge-

neity of the soil cover. These carbon accumulation data from 24 soil profiles can be valuable for climate projects and may also support the modelling of carbon stocks in dark coniferous boreal forests.

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