Soil organic matter in temperate forest-grassland systems: a case study from the Southern Cis-Ural, Russia

Azamat Suleymanov[1*], *Iren* Tuktarova[1], *Larisa* Belan[1], *Ruslan* Suleymanov[1], and *Anastasia* Vittsenko[1]

[1]Ufa State Petroleum Technological University, Ufa, 450064, Russia

Abstract. Understanding the dynamics of SOM in different land use types is critical for effective land management and climate mitigation strategies. In this study, we investigated the differences in soil organic matter (SOM) content between forest and grassland landscapes in the mountainous zone of Republic of Bashkortostan, Russia. We collected soil samples from multiple locations under both land use types and analysed them for SOM content using standard laboratory techniques. The results showed that the SOM content varied from 2.2 to 15.3% under forest landscape with an average of 6.7% and was characterized by high variability (51.8%). The SOM concentrations under grassland ranged from 2.1 to 6.5% with an average of 3.2%, while the coefficient of variation was 31.8%. According to the classification, the average SOM value in forest soils was classified as "high", while in grassland soils it was classified as "low". Overall, the variability in SOM content within forested landscapes can be influenced by a range of factors, including topography, erosion, and redeposition of soil. These factors contributed to the complex patterns of SOM accumulation and decomposition observed in forest soils, and should be considered when evaluating the potential impacts of land use change on SOM. Our study highlights the importance of understanding the factors that influence SOM content in soils, and the need for careful management of land use systems to maintain or enhance soil fertility and productivity.

1 Introduction

Soil organic matter (SOM) is a crucial component of soil health and plays a critical role in regulating important ecosystem functions [1]. SOM consists of dead plant and animal material in various stages of decomposition, as well as living microorganisms that important in nutrient cycling and carbon sequestration. The amount and quality of SOM in soils can vary widely depending on land use type, with forest and grassland systems exhibiting different patterns of SOM accumulation and turnover [2-4]. Forests are known to have high SOM content due to the accumulation of dead plant material and the presence of diverse microbial communities [5]. Forest ecosystems generally have a greater capacity to store carbon in the soil due to slower rates of decomposition, lower rates of soil erosion,

* Corresponding author: filpip@yandex.ru

and fewer disturbances that can lead to carbon loss. However, different forest types can exhibit distinct patterns of SOM accumulation and turnover.

Grassland ecosystems also play an important role in SOM dynamics, as they are known for their high rates of belowground carbon allocation and rapid SOM turnover [6]. Grassland soils can accumulate large amounts of SOM through the deposition of belowground biomass, and the high activity of soil microbes can lead to rapid decomposition and nutrient cycling. However, intense grazing or land use change can lead to a decline in SOM content and loss of carbon from the soil. Earlier, Fiener et al. [7] analyzed 112 soil cores were in a small catchment in the tropical south of India and demonstrated that the highest soil organic carbon contents and stocks were observed under arable ecosystems, followed by forest/shrubland and grassland landscapes.

Thus, the preservation of forest and grassland ecosystems can help to maintain the capacity of soils to sequester carbon and support sustainable agricultural practices. By improving our understanding of the factors that regulate SOM dynamics in different land use types, we can develop more effective strategies for managing soils and mitigating the impacts of climate change. Thus, the primary objectives of the present study are: (1) to examine SOM concentrations of forest and grassland soils in the mountainous zone of Republic of Bashkortostan, Russia, and (2) to compare its content between the two types of land use.

2 Materials and methods

This study was carried out in the foothills of the Ural Mountains near the Pavlovka village (55.4221°, 56.5593°) in the Nurimanovsky district, Republic of Bashkortostan, Russia (Figure 1). The district has a continental climate, characterized by cold winters and warm summers. According to recently studies, the average annual rainfall is 535 mm/year and the average annual temperature is around 8.5°C in this region, with the warmest month being July and the coldest month being January [8]. The district is situated on the eastern slopes of the Ural Mountains, which influence the local climate and vegetation patterns. The study plot with forest vegetation is situated in a hilly area, with an altitude of 190 to 280 meters, while grassland landscape is flat area with an altitude of 260 m above sea level. Forest species are represented by conifers or mixed coniferous broad-leaved.

In the study area 32 plots were selected, of which 16 were located under forest and 16 under grassland landscape. In each plot, topsoil samples were collected in July 2022 to a depth of 20 cm. Then, the samples were prepared in a standard way (dried, sieved, etc.) and were used for the subsequent laboratory analyses.

SOM content was determined via a wet-combustion method (Tyurin method) in Nikitin's modification with spectrophotometric termination according to Orlov and Grindel [9, 10]. The gradation of SOM on categories was carry out according to the scale [11], where SOM content > 10% is classified as "very high", 6–10 – "high", 4–6 – "average", 2–4 – "low" and < 2 – "very low". Soils in the study area are classified as Lithic Leptosols according to the WRB classification.

In this study, we calculated the Normalized Difference Vegetation Index (NDVI) to estimate the spectral characteristics of landscapes. The remote sensing data were obtained from Sentinel-2A satellite, with cloud cover less than 10%. The Sentinel-2A satellite has 13 spectral bands, including 4 bands of a 10 m resolution and 6 bands of a 20 m resolution. The NDVI is computed as the difference between near-infrared (NIR) and red (RED) reflectance divided by their sum. This spectral index is widely used in environmental studies and serves as the best indicator of vegetation growth [12-14].

Fig. 1. Location of the study area.

3 Results and Discussion

Descriptive statistics of the SOM content under different land use types are show in Table 1. We revealed a minimum value of 2.2% and a maximum value of 15.3% in forest soils, while the corresponding values for grassland soils were 2.1% and 6.5%, respectively. The mean SOM content was 6.7% in forest soils and 3.2% in grassland soils, with a standard deviation of 3.4 and 1, respectively. Thus, according to the scale, the mean values of SOM under forest and grassland were characterized as "high" and "low", respectively. The coefficient of variation for SOM content was higher in forest soils (51.8%) compared to grassland soils (31.8%), indicating greater variability in SOM content among forest samples.

Table 1. Descriptive statistics of soil organic matter under different land use type.

Land use	Min	Max	Mean	Median	SD	CV, %
n=16						
Forest	2.2	15.3	6.7	5.4	3.5	51.8
n=16						
Grassland	2.1	6.5	3.2	3.1	1	31.8

n – number of samples; SD – standard deviation; CV – coefficient of variation

The coefficient of variation (CV) is a measure of relative variability, calculated as the ratio of the standard deviation to the mean. A high coefficient of variation indicates a large degree of variability relative to the mean value. In the context of SOM content, a high coefficient of variation suggests that there is a large degree of variability in SOM content across different samples. There are several factors that can contribute to the high coefficient of variation of SOM content. SOM content can vary greatly over small spatial scales due to differences in soil type, vegetation cover, topography, and management practices. This can lead to high variability in SOM content across different soil samples or locations, even within the same land use type.

Figure 2 shows the histograms of SOM content under different land use types. According to the histograms, the SOM values under the forest predominantly ranged from 2 to 8%, while the SOM concentrations under the grassland ranged from 2 to 4%. However, the peak values were found on both types of land use.

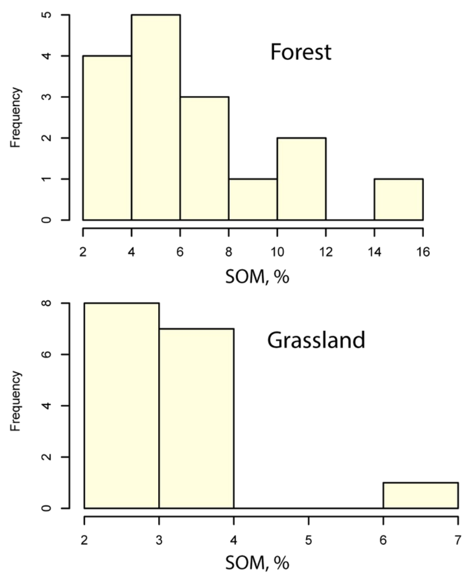

Fig. 2. Histograms of SOM content under different land-use type.

Several factors could explain the higher SOM content in forest soils compared to grassland soils. One potential explanation is the greater input of organic matter from tree litter and root exudates in forest ecosystems [15-16]. Trees produce a large amount of biomass, which falls to the forest floor and decomposes slowly due to the cool and moist conditions in the forest understory. This process contributes to the accumulation of SOM over time. In contrast, grasses have much lower biomass compared to trees and their roots tend to decompose more rapidly, leading to lower SOM content in grassland soils.

In our study, the forest plot was located on a slope. Thus, it is important to note that the variability and SOM content in forest soils can also be influenced by other factors such as topography and erosion. Complex topography can affect soil moisture, temperature, and nutrient availability, which in turn can influence SOM accumulation and decomposition rates. This could be due to the greater accumulation of litter and organic matter on slopes, as well as the slower rate of decomposition due to cooler and moister conditions. For example, we observed the maximum SOM content at the bottom of the slopes due to the effects of erosion and redeposition of soil. Erosion can lead to the loss of topsoil, which typically has higher SOM content, while the redeposition of eroded material can introduce new sources of organic matter and nutrients [17-19]. Due to the influence of the above processes, the SOM variation in the forest samples was much greater than in the flat grassland.

The carbon content under different types of land use varies due to different soil formation conditions. For instance, Solomon et al. [20] showed that the mean carbon stocks in the dense forests, open forests, grasslands, cultivated lands and bare lands were estimated at 181.78 ± 27.06, 104.83 ± 12.35, 108.77 ± 6.77, 76.54 ± 7.84 and 83.11 ± 8.53 MgC ha^{-1}, respectively in northern Ethiopia. Previous research in the Republic of Bashkortostan has shown that the SOM content under arable land was lower than on pristine counterparts [21]. It is can be also related with management practices such as tillage, fertilization, and crop rotation. For example, in agricultural systems, the use of tillage and monoculture cropping can lead to the loss of SOM through increased decomposition rates and erosion, while the use of cover crops and conservation tillage can help to maintain or increase SOM content in soils. Similarly, the study in Pakistan showed that soils under forest had significantly higher values of soil organic carbon (59.35 Mg ha^{-1}) than pasture (42.48 Mg ha^{-1}) and arable land (23.63 Mg ha^{-1}) [22].

Figure 3 shows the NDVI and the natural-color satellite images, capturing forest and grassland landscapes. According to the analysis, the NDVI values for the forest ranged from 0.33 to 0.52, while in the grassland area these values were from 0.24 to 0.31. Thus, spectral vegetation indices can also be useful in the spatial prediction of SOM content in different ecosystems [23-25]. For example, Kunkel et al. [26] used NDVI and the Enhanced Vegetation Index (EVI) obtained from the MODIS sensor (Terra/Aqua) and Landsat series satellites for spatial assessment of soil organic carbon in eastern Australia and found, that the above indices can reliably predict soil organic carbon content. Similarly, NDVI time series data were used for digital mapping of soil organic carbon in Hubei Province, China [27].

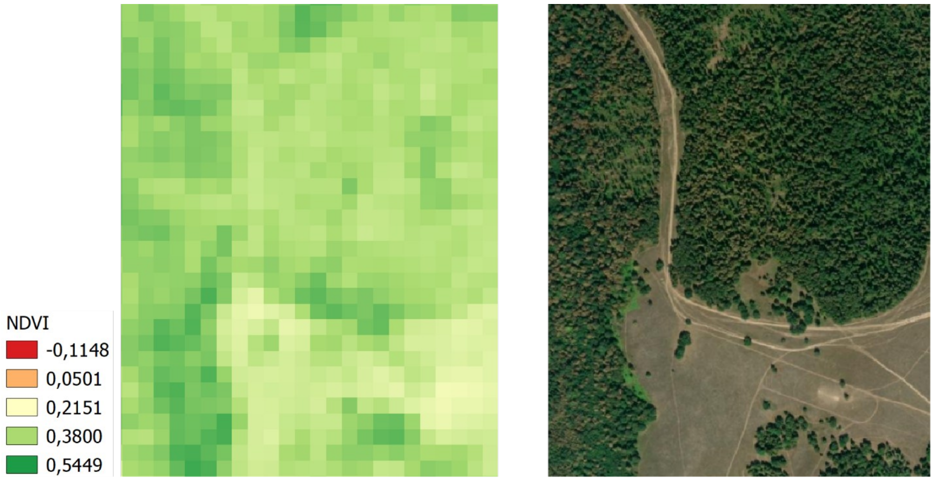

Fig. 3. Vegetation analysis using the NDVI index.

4 Conclusion

SOM has a significant impact on the quality of land resources, as well as on climate change through greenhouse gas emissions and carbon sequestration. The purpose of this study was to quantify the SOM content of forest and grassland soils at a site in the foothills of the Ural Mountains of the Republic of Bashkortostan, Russia. Our study found that SOM concentrations were significantly higher in forest soils compared to grassland soils. This difference can be attributed to a range of factors, including the greater input of organic matter from tree litter and root exudates in forest ecosystems. In addition, it is also important to note that the highest variability in SOM content within forested landscapes can be influenced by a range of factors, including erosion and redeposition of soil. These factors can contribute to the complex patterns of SOM accumulation and decomposition observed in forest soils, and should be considered when evaluating the potential impacts of land use change on soil organic matter. Our results have important implications for land management and conservation efforts. Preserving or restoring forest ecosystems can help to maintain or increase SOM content in soils, which in turn can promote soil fertility and productivity. Moreover, the higher SOM content in forest soils may provide greater resilience to environmental stresses, such as drought or nutrient depletion.

Acknowledgments

This research was performed within the state assignment framework of the Ministry of Science and Higher Education of the Russian Federation "Program for the creation and functioning of a carbon polygons on the territory Bashkortostan Republic "Eurasian carbon polygon" for 2022–2023 (Publication number: FEUR-2022–0001).

References

1. N. Batjes, European Journal of Soil Science, **47**, **2** (1996)
2. S.I.C. Akpa, I.O.A. Odeh, T.F.A. Bishop, A.E. Hartemink, I.Y. Amapu, Geoderma, **271,** 202–215 (2016)
3. K.R. Tate, A. Parshotam, D.J. Ross, Journal of Biogeography, **22**, **4/5** (1995)
4. G. Yellajosula, L. Cihacek, T. Faller, C. Schauer, Soil Systems, **4**, **3** (2020)
5. A.A. Dymov, I.D. Grodnitskaya, E.V. Yakovleva, Y.A. Dubrovskiy, I.N. Kutyavin, V.V. Startsev, E.Y. Milanovsky, A.S. Prokushkin, Forests, **13**, **11** (2022)
6. M. Wiesmeier, F. Barthold, B. Blank, I. Kögel-Knabner, Plant and soil, **340**, **1–2** (2011)
7. P. Fiener, T. Gottfried, M. Sommer, K. Steger, Geoderma Regional, **2–3** (2014)
8. E. Bogdan, R. Kamalova, A. Suleymanov, L. Belan, I. Tuktarova, SOCAR Proceedings (2022)
9. E.V. Arinushkina: A Handbook of Chemical Analysis of Soils. Moscow, Moscow State University (1970)
10. D.S. Orlov, N.M. Grindel, Eurasian Soil Sci, **1** (1967)
11. L.A. Grishina, D.S. Orlov System of indicators of humus state of soils. In Soil Science Issues (Nauka, Moscow, 1978)
12. S. Huang, L. Tang, J.P. Hupy, Y. Wang, G. Shao, A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing J For Res, **32**, **1** (2021)
13. R. Suleymanov, M. Yakimov, P. Liebelt, P. Shirokikh, A. Suleymanov, E. Abakumov, I. Adelmurzina, E. Bakieva, I. Asylbaev, Eurasian journal of soil sci (EJSS), **10** (2021)
14. A. Zaitunah, Samsuri, A.G. Ahmad, R.A. Safitri, IOP Conf Ser: Earth Environ Sci, **126**, **1** (2018)
15. P. Panchal, C. Preece, J. Peñuelas, J. Giri, Trends in Plant Science, **27**, **8** (2022)
16. K.I. Paul, J.R. England, S.H. Roxburgh, Forest Ecology and Management, **521** (2022)
17. A. Subhatu, T. Lemann, K. Hurni, B. Portner, T. Kassawmar, G. Zeleke, H. Hurni, International Soil and Water Conservation Research, **5**, **3** (2017)
18. A. Suleymanov, I. Gabbasova, R. Suleymanov, E. Abakumov, V. Polyakov, P. Liebelt, Hungarian Geographical Bulletin, **70** (2021)
19. B. Takoutsing, J.C. Weber, J.A. Rodríguez Martín, K. Shepherd, E. Aynekulu, A. Sila, Land Degradation & Development, **29**, **8** (2018)
20. N. Solomon, O. Pabi, T. Annang, I.K. Asante, E. Birhane, Carbon Balance and Management, **13**, **1** (2018)

21. I.M. Gabbasova, R.R. Suleimanov, I.K. Khabirov, M.A. Komissarov, M. Fruehauf, P. Liebelt, T.T. Garipov, L.V. Sidorova, F.Kh. Khaziev, Eurasian Soil Sc, **49**, **10** (2016)
22. S. Ali, F. Begum, R. Hayat, B.J.M. Bohannan, Acta Agriculturae Scandinavica, Section B — Soil & Plant Science, **67**, **6** (2017)
23. G.S. Bhunia, P. Kumar Shit, H.R. Pourghasemi, Geocarto international, **34**, **2** (2019)
24. P. Kumar, H. Sajjad, B.R. Tripathy, R. Ahmed, V.P. Mandal, Natural Hazards: Journal of the International Society for the Prevention and Mitigation of Natural Hazards, **90**, **2** (2018)
25. F. Stumpf, M.K. Schneider, A. Keller, A. Mayr, T. Rentschler, R.G. Meuli, M. Schaepman, F. Liebisch, Ecological Indicators, **113** (2020)
26. V.R. Kunkel, T. Wells, G.R. Hancock, Science of The Total Environment, **817** (2022)
27. Y. Zhang, L. Guo, Y. Chen, T. Shi, M. Luo, Q. Ju, H. Zhang, S. Wang, Remote Sensing, **11**, **14** (2019)