КРАТКИЕ СООБЩЕНИЯ И ОБМЕН ОПЫТОМ

УДК 574.36
DOI: 10.37482/0536-1036-2020-2-169-176

ORGANIC CARBON STOCKS IN THE FOREST SOILS OF NORTHERN MONGOLIA

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Soil organic carbon (SOC) stock and its variation on the regional and large spatial scales are critical for estimating the global SOC inventory and predicting further changes. This study was aimed at estimation of the SOC stock in the boreal forests of Northern Mongolia. The study was carried out in the forested areas of the Bulgan, Selenge and Tuv provinces using a completely randomized design. A total of 900 soil samples from 60 sampling points were collected for the laboratory analyses. At each point, a soil profile with a depth of more than 30 cm was laid out, and then soil samples were taken from three soil layers: 0–5, 5–15, and 15–30 cm of each profile. Therefore, the results of the assessment show a high difference of the SOC stock not only between the provinces, but also within each province. The higher SOC stocks were observed in the Selenge (123.5±14.85 t/ha), and lowest in the Tuv (51.23±7.8 t/ha) provinces. The estimated SOC stock in the studied regions was 93.77 t/ha on average. We found relatively less SOC stock in the boreal forests of Mongolia compared with the Asian part of Russia including Siberia and the Russian Far East. Such a less SOC stock may be caused by geographical distribution, where the Mongolian forests border the Central Asian dry steppe and frequent water deficit. However, we found that the accumulation of SOC stocks in the boreal forests of Mongolia is largely dependent on the mountain slopes and aspects combined with the distribution of precipitation across the country. Higher amount of SOC stocks were found in north-facing aspects and lower positions with low slopes of the mountains in lower altitude. Consequently, moisture supply basically determines the pattern of the SOC stock distribution in the northern boreal forests of Mongolia.
For citation: Tungalag M., Gerelbaatar S., Lobanov A.I. Organic Carbon Stocks in the Forest Soils of Northern Mongolia. *Lesnoy Zhurnal* [Russian Forestry Journal], 2020, no. 2, pp. 169–176. DOI: 10.37482/0536-1036-2020-2-169-176

Keywords: forest soil, organic carbon, SOC stock, aspect, Northern Mongolia.

Introduction

The mass of soil organic carbon (SOC) is not only the largest carbon stock in terrestrial ecosystem, but also the determinant factor of the concentration of atmospheric CO_2 [16, 23] and is greater than the combined biomass of carbon (C)

contained in the atmosphere and living biomass [9, 19]. Boreal forests cover about 22 % of terrestrial ecosystem [8] and accounts for 9 % of the vegetation carbon stock [7]. Therefore, most of C is accumulated in the soil, which is caused by limited low microbial decomposition rates in wetlands and permafrost soils due to the low availability of oxygen and low temperatures [17, 24, 28]. Zhu et al. [32] pointed out that the amount of C released as a consequence will strongly depend on simultaneous changes in topography, hydrology, vegetation, fire regimes, nutrient availability and SOC lability. However, in relation to rapidly rising temperatures, boreal forests are susceptible to insect invasions [6, 18], moisture stress [27, 30], frequent forest fires [25, 26], which all have the potential to alter C cycling. In Russia, the Regional Evaluation of Carbon Budget of Forests (RECBF) system developed by the Zamolodchikov et al. [3], and a significant part of regional and national assessments for Russian forests [1, 2, 10] with the respect to data generalization is an extrapolation of a limited number of field studies to larger areas, which is inconsistent with the IPCC approach. Mongolia has relatively limited forest resources, which is distributed along the transitional zone between the Siberian boreal forest and the Central Asian dry steppe [11, 20]. Forest cover represents roughly 7–8 % of the territory; the most recent National Forest Inventory [22] reported that boreal forest cover is nearly 9.1 mln ha. This transitional zone is characterized by a highly continental climate with a prolonged dry period. In addition, forests in Mongolia mainly grow on mountain slopes from 700 to 2500 m a.s.l. To assess the contribution of Mongolian forest ecosystems to mitigating the effects of global warming, there is a potential need for research related to the assessment of the forest SOC stocks. The research problems are to estimate the SOC stock in the boreal forests of Northern Mongolia, and to assess the influence of mountain slope aspect on the SOC stock.

Materials and methods

Soil samples were collected from the forested areas of the Bulgan, Selenge and Tuv provinces using completely randomized design. According to forest-vegetation zoning, the study area belongs to the South Baikal forest vegetation zone. SOC at 0–30 cm was surveyed at the center point of each sample plot of National Forest Inventory of Mongolia. At each point, the soil profile above 30 cm depth was made and then divided into three soil layers of 0–5, 5–15, and 15–30 cm, respectively. A total of 900 samples taken from 60 sample plots were used for laboratory analyses. The ratio of gravel area to the area of soil profile was recorded for each soil layer, and a volumetric sample and also a sample for analyzing C concentration were taken in accordance with Ugawa et al. [29]. The volumetric samples were oven dried at 105 °C for 24 h and then weighed. Soil particles in the sample were washed out through a sieve (2-mm) using water. The remaining gravels and plant roots were oven dried at 105 °C for 24 h and weighed.

Bulk density was calculated using equation:

$$\rho = \left(\frac{W_t + W_g + W_r}{V} \right) \cdot 100 , \quad (1)$$

where ρ – bulk density, mg/m^3; W_t – total weight of the volumetric sample, g; W_g – weight of gravels, g; W_r – weight of plant roots, g; V – spatial volume of the volumetric sample, cm^3.

Loss on ignition (LOI) method [4, 14] was used to determine the SOC concentration based on sequential heating of samples in a muffle furnace. After oven-drying the soil sample to a constant weight for 24 hours at 105 °C, the organic matter was combusted to ash and carbon dioxide at a temperature of 500 and 550 °C. The LOI is then calculated using equation:

$$LOI_{550} = \left(\frac{DW_{105} - DW_{550}}{DW_{105}} \right) \cdot 100, \quad (2)$$

where LOI_{550} – LOI at 550 °C, %; DW_{105} – dry weight of the sample before combustion, g; DW_{550} – dry weight of the sample after heating to 550 °C, g.

Results and discussion

Estimated values of the SOC stocks of the inventoried forests are gathered in Table 1. Results of the assessment indicated that there is a significant difference in the SOC stocks (*P* value > 0.002) in the forests of the provinces. The relatively higher accumulation of the SOC stocks was observed in the Selenge, and lower in the Tuv provinces.

Table 1

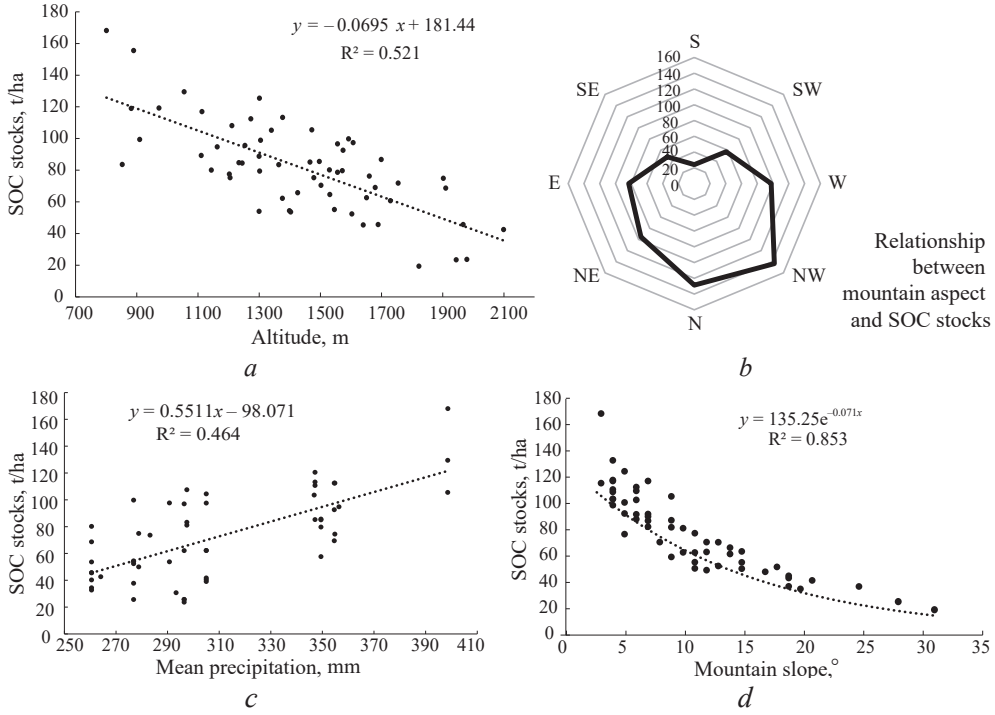
Statistical characteristics of the SOC stocks in the inventoried areas

Province	Number of plots	Mean temperature, °C	Average precipitation, mm	SOC stock, t/ha				P
				mean	min	max	SD	
Bulgan	21	0.2	333.3	91.50	17.20	129.50	9.01	0.001
Selege	23	1.1	273.8	12.50	23.70	168.20	14.85	0.000
Tuv	16	0.4	251.2	51.13	14.80	99.80	7.80	0.002

Hancock et al. [13] emphasized that plant biomass contributes significantly to the concentration of organic carbon in soil. In this regard, a well-developed river network and a slightly higher temperature in the mountains of Western Khentii, which are found in the territory of the Selenge province, can maintain a relatively higher productivity of forest vegetation. Mukhortova et al. [21], however, reported that about 81 % of the total SOC pool of Russian forests is distributed in the Asian part of Russia. Studies on the SOC stocks in temperate forests of the European and Asian parts of Russia reported that they averaged 162.1 t/ha and 154.7 t/ha [14], respectively. A number of researches have reported that various SOC stocks in the forests are the consequence of environmental factors such as air precipitation and temperature, altitude, mountain slope and aspect [8, 12, 15, 31]. Our study also confirmed this idea and found a rather strong relationship between the SOC stock and the above mentioned factors (see Fig.). Boreal forests in Mongolia are mainly distributed in mountainous area and grow basically on the north facing slopes. The effect of the mountain aspect and slope ($R^2 = 0.85$) on the SOC stock was clearly found in our study.

Our findings showed that increasing mountain slopes negatively affect the SOC stocks, and a relatively higher amount of the SOC stocks can be accumulated in the lower mountain slopes (Fig. *d*). In comparison, greater amount of the SOC stocks is distributed in the north-facing slopes of the mountains (Fig. *b*). The greatest SOC stocks were observed in the northwest and north mountain aspects (Fig. *b*). On the

one hand, mountain aspect can have a strong effect on the temperature and moisture regimes in connection with the angle of the sun rays [5]. Thus, humidity levels are relatively higher on the northern slope than on the southern slope and have a greater growth of woody plants and accumulation of organic matter [12]. The amount of precipitation in the study area becomes an important factor for accumulation of SOC ($R^2 = 0.46$) among other climate factors, and the highest SOC stocks were found in most humid areas (Fig. *c*). Simultaneously, there exists a negative correlation between the SOC stocks and altitude (Fig. *a*). Low temperatures often have a negative effect on the microbiological activity of the soil with increasing elevation from the point of view of decomposition of organic matter in forest soils.



Factors effecting the SOC stocks: *a* – altitude; *b* – mountain aspect; *c* – precipitation; *d* – mountain slope

Conclusion

The SOC stocks in the forests of Northern Mongolia are varied not only among provinces, but also at the province level. The estimated SOC stock in the studied regions was averaged 93.77±6.4 t/ha. We found relatively less SOC stock in the boreal forests of Mongolia compared with the Asian part of Russia including Siberia and the Russian Far East. Such a less SOC stock may be caused by geographical distribution, where the Mongolian forests border the Central Asian dry steppe, and frequent water deficit.

However, the accumulation of the SOC stocks in the boreal forests of Mongolia is largely dependent on the mountain slopes and aspects in combination with the distribution of precipitation throughout the country. Higher amount of the SOC stocks were found in the north-facing aspects and lower positions with low slopes of

the mountains in lower altitude. Consequently, water sufficiency basically determines the pattern SOC stock distribution in the northern boreal forests of Mongolia.

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ЗАПАСЫ ОРГАНИЧЕСКОГО УГЛЕРОДА В ЛЕСНЫХ ПОЧВАХ СЕВЕРНОЙ МОНГОЛИИ

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Запасы органического углерода в почве и их изменение в региональном и большем пространственном масштабе имеют решающее значение для оценки их глобальной инвертации в почвах и прогнозирования дальнейших изменений. Цель работы – оценить запасы органического углерода в почвах бореальных лесов Северной Монголии. Исследование проводилось в лесах Булган, Сэленгэ и Тув аймаков с использованием полностью рандомизированного метода отбора пробных площадей. Для лабораторных анализов было отобрано 900 почвенных образцов на 60 пробных площадях. На каждой пробной площади заложен почвенный профиль глубиной 30 см с взятием образцов из трех слоев почвы: 0...5, 5...15 и 15...30 см. Результаты исследования показали значительное отличие в запасах органического углерода в почвах не только между аймаками, но и внутри каждого аймака. Более высокие показатели отмечены в лесных почвах Сэленгийского аймака (123,5±14,85 т/га), самые низкие – в почвах Тув аймака (51,13±7,8 т/га). Обнаружено заметно меньше органического углерода в почвах бореальных лесов Монголии по сравнению с азиатской частью России, включая Сибирь и Дальний Восток, что может быть вызвано частым дефицитом воды и географическим расположением монгольских бореальных лесов, граничащих с засушливыми степями

Центральной Азии. Установлено, что накопление органического углерода в почвах бореальных лесов Монголии в значительной степени связано с их расположением на горных склонах и распределением осадков по территории. Более высокое количество органического углерода в почвах обнаружено на северных склонах, в более пониженных местах с малыми склонами и возвышенностью. Следовательно, влагообеспеченность в основном определяет характер распределения запасов органического углерода в почвах бореальных лесов Северной Монголии.

***Для цитирования**:* Tungalag M., Gerelbaatar S., Lobanov A.I. Organic Carbon Stocks in the Forest Soils of Northern Mongolia // Изв. вузов. Лесн. журн. 2020. № 2. С. 169–176. DOI: 10.37482/0536-1036-2020-2-169-176

Ключевые слова: почва лесной зоны, органический углерод, запас углерода, экспозиция склона, Северная Монголия.

Поступила 24.09.19 / Received on September 24, 2019