Abstract.

1 Introduction

Soil organic carbon (SOC) plays a key role in the carbon cycle as soils store about 1500 Gt of carbon at a depth of 1 m, which is the largest terrestrial carbon pool. Hence, carbon sequestration could potentially mitigate the effects of climate change [1, 2]. Soil is a multicomponent substance comprising organic and inorganic elements characterized by a variety of physical and chemical properties [3]. These properties can vary significantly from location to location, even within the same field [4, 5]. In this regard, quantitative and qualitative determination of soil components is a rather complex process and is of great interest for research [6, 7].

Optimizing monitoring and mapping capabilities requires consistent datasets that provide reliable information on SOC content. This requires methods that are accurate and cover large areas.

Methods for determining soil organic C content are divided into two blocks: invasive and non-destructive. Invasive methods involve the collection of soil samples and their subsequent wet or dry ashing. The wet ashing method of Walkley-Black (WB) is simple to perform but has a significant drawback of overestimating or underestimating organic carbon content depending on soil types [8, 9]. The Dumas dry combustion method has not only high accuracy in determining total carbon content but also cost [10]. Analyzing multiple samples increases the cost of analysis due to the increased time required to stabilize and calibrate them, as well as the increased number of standard runs for each operation. Comparison of different invasive methods for determining soil carbon content shows that high accuracy and low cost of analysis cannot be achieved using the same method [11]. Thus, the automated Dumas dry combustion analysis provides high accuracy while the Walkley-Black wet ashing method requires low cost. The cost of estimating soil carbon content can be reduced if the relationship between wet ashing and automated dry combustion is established for a particular soil type. However, it is rare to find a strong linear relationship between the two. In addition, wet ashing, the Walkley-Black method (REF), has large differences in percent recovery and does not show a strong correlation with Dumas automated dry combustion.

Non-destructive methods for carbon determination promise high accuracy without the time-consuming sample processing and subsequent analysis [12].

Non-destructive methods are mainly based on remote sensing and spectroscopic measurements in the field. Spectroscopic methods include near-infrared (NIR) and mid-infrared reflectance, laser-induced breakdown spectroscopy (LIBS) and inelastic neutron scattering (INS) [13, 14]. The potential of these techniques is calibrated to soil sampling and subsequent analysis using an automated dry combustion method. In remote sensing, the reflectance of different spectral bands are calculated and correlated with soil properties, including organic matter. Four wavelength bands are used to detect organic matter: visible (0.4-0.7 µm), reflectance infrared (0.7-3 µm), thermal infrared (8-14 µm), and (4) microwave
radiation (1 mm-1 m). The studies show that predictions of SOM content can be made based on light reflectance with linear or curvilinear dependence in the visual and infrared range, and they have high correlation with the results of the Dumas dry combustion method, indicating their accuracy.

Thus, the soil carbon estimation approach proposed by Valeeva et al [15], (2016) can serve as an effective tool for assessing its dynamics and spatial heterogeneity.

2 Material and method

2.1 Material

The assessment of spatial heterogeneity and dynamics of carbon in soil was carried out in the conditions of the field site of the Agroecological Station of the K.A. Timiryazev Russian State Agrarian University-MSHA with an area of about 2.2 ha, located in the Northern part of the Moscow metropolis.

Soils of the site are represented by sod-podzolic soils disturbed as a consequence of long-term anthropogenic load and irrigation works with high spatial heterogeneity of the main agroecological indicators, including acidity, organic matter content, available forms of nutrition elements and trace elements. The relief of the site is characterized by a small drop and weak slope up to 1°, microrelief is pronounced.

2.2 Method

2.2.1 Field methods

Field studies included marking a regular grid of one hundred points (Fig. 1) with precise coordinate reference by the Stonex S9 III GNSS system for subsequent soil sampling and aerial photography of the site surface in the visible range using a DJI Phantom 4 RTK quadrocopter. Sampling was carried out from the arable soil horizon with a depth of 0-10 cm using an Eidelman drill.

2.2.2 Lab methods

Laboratory studies included determination of carbon content in soil. Organic carbon content was determined by the Walkly-Black (Colorimetric) method using a leki SS2107UV spectrophotometer (Finland). Total carbon in soil was determined by the Dumas dry combustion method using a Vario El Cube (Germany). Acidity was determined in 1M KCl fume hood using Mettler Toledo SevenCompact S220 (Switzerland).

2.2.3 Data processing

Statistical processing of the data included checking the type of distribution, comparison of medians using the Kraskell-Wallis criterion, correlation and regression analyses. The software used was MS Excel spreadsheet processor and R statistical processing language.

QGIS and SAGA GIS software packages were used for mapping and spatial visualization using kriging and spline methods. Processing of aerial photographs and stitching was carried out using Agisoft Metashape.

3 Results and discussion

Evaluation of the terrain using a digital model revealed an elevation difference of up to 1.5 m, which for a total length of more than 200 m gives a slope of less than 1° steep (Fig. 2). Micro-relief expressed in the form of micro-slopes and elevations is noted.

Correlation-regression analysis of relationships between total soil carbon and altitude values (Fig. 3) shows a reliable direct relationship (r = 0.65, with a significant 0.195 for n = 100, p<0.05). At the same time, it is also observed the appearance of small amount of emissions with increasing values of altitudes.
Fig. 3. Relation of soil total carbon to elevation values.

Thus, the character of relief is one of the factors determining spatial heterogeneity in soil carbon distribution.

The study of pH variation within the site shows significant heterogeneity and scatter of values more than 2 units (Fig. 4). Variability corresponding to the influence of the adjacent highway was not observed. The south-western part of the site is characterized by close to neutral and neutral reaction of soil solution, which is consistent with the direction of runoff.

Analysis of the correlation between total carbon in soil and its acidity shows the presence of a reliable direct relationship ($r = 0.61$).

In conditions of increased spatial heterogeneity of carbon distribution in soil, in addition to relief, soil acidity acts as a significant factor. The increase of organic matter is associated with a decrease in acidity in some parts of the field.

Comparison of the content of total carbon in soil by the Dumas method (Fig. 6A) and its organic component by the Walkley-Black method (Fig. 6B) shows the presence of relationships only at the trend level ($r = 0.24$).

The next stage of the analysis was to assess the possibilities of using carbon calculation by values in the red channel (Valeeva method) in the conditions of the studied field agroecosystem. The result of correlation and regression analysis demonstrates the presence of statistically reliable inverse relationship ($r = -0.39$) of medium strength (Fig. 7).
Accurate prediction of carbon distribution using the obtained model is impossible, but it is quite applicable to describe the general trend in assessing the dynamics of this parameter.

Comparison of monthly average values of total carbon shows the presence of a reliable difference in July (Fig. 8) (Kruskell-Wallis criterion, \( p<0.01 \)).

This month is the peak of accumulation, after which the carbon content in the soil begins to decrease, which may be due to the end of vegetation of plants and a decrease in microbiological activity.

4 Conclusion

The high spatial variability of soil organic carbon and soil total carbon are observed. Elevation as a microrelief characteristic affects on total soil carbon distribution (\( R = 0.633 \) (significant \( R = 0.254, p <0.01, n = 100 \)); Soil acidity influences on total soil carbon distribution in condition of disturbed sod-podzolic soils as well (\( R = 0.606 \) (significant \( R = 0.254, p <0.01, n = 100 \)); The most content of soil total carbon in July observed (\( p < 0.01 \) by Kruskal-Wallis test).

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