

Review

Carbon Polygons and Carbon Offsets: Current State, Key Challenges and Pedological Aspects

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Abstract: Russia holds the largest store of carbon in soils, forests and permafrost grounds. Carbon, stored in a stabilized form, plays an important role in the balance of the global biogeochemical cycle and greenhouse gases. Thus, recalcitrance of soil organic matter to mineralization results in a decrease in current emissions of carbon dioxide into the atmosphere. At the same time, stabilization of organic matter in the form of humus due to organo–mineral interactions leads to the sequestration of carbon from the atmosphere into soils and biosediments. Thus, global carbon balance is essentially determined by soil cover state and stability. Currently, Russia is faced with a set of problems regarding carbon offsets and the carbon economy. One of the methods used to evaluate carbon stocks in ecosystems and verify offsets rates is carbon polygons, which are currently being organized, or are under organization, in various regions of Russia. This discussion addresses the current issues surrounding the methods and methodology of carbon polygons and their pedological organization and function.

Keywords: carbon polygons; carbon sequestration; climate change; carbon balance; soil organic matter



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1. Introduction

Soil organic carbon (SOC) is the main component of soil organic matter (SOM) [1,2]. SOC can be assumed as an indicator of soil health and plays a critical role in food production, climate change and sustainable human development [3,4]. In the face of climate change, SOC can be mineralized faster and become a significant source of greenhouse gases in the atmosphere [5,6]. However, the overall impact of climate change on SOC content differs depending on region and soil type [7–12]. Climate change can have catastrophic consequences for SOC and soils [2,4,9]. As a result, we can observe land degradation in various areas of the planet (the Arctic, desert and mountainous zones) [3,13–15]. Today, the world's soil contains up to 1500 Pg (1×10^{15} g) of soil organic carbon in the upper meter horizon [3,4,16]. The soil with the richest SOC levels (Histosol and Chernozem), as well as drylands with low carbon content, have the potential to make the greatest contribution to climate change [9]. The areas occupied by permafrost-affected soils make up more than 8.6 million km², roughly 27% of all land north of 50° N, meaning that up to 1024 Pg of soil organic carbon is stored within the upper 3 m of soil [1,17]. Thus, the management of these territories can enhance the sequestration of carbon in soils, contributing to the mitigation of climate change on our planet [2–4,9].

The soil cover of Russia holds the largest store of carbon in the whole world and is the most important area for carbon deposition in the northern hemisphere. Carbon stock in soils and biosediments have been evaluated by numerous investigators [4,7,9,12,14]. During the Postsoviet era, the sequestration rate of carbon in soil increased sharply due to abandoning of millions of hectares of arable lands and afforestation of former agricultural lands [18,19]. Thus, the abandoned agricultural lands were formed in various bioclimatic environments, and have recently been used for retrospective analyses of soil parameters by numerous researchers [20–24]. In this context, the forthcoming plans regarding the creation

of special monitoring plots state that carbon polygons should be considered and discussed in terms of pedological methodology with the aim of mutualizing carbon pool assessments with carbon offset risks in our national environmental economy and carbon market.

Carbon polygons are places where carbon dioxide emissions and accumulation are monitored under conditions of various types of relief and soil cover [4] (Figure 1).

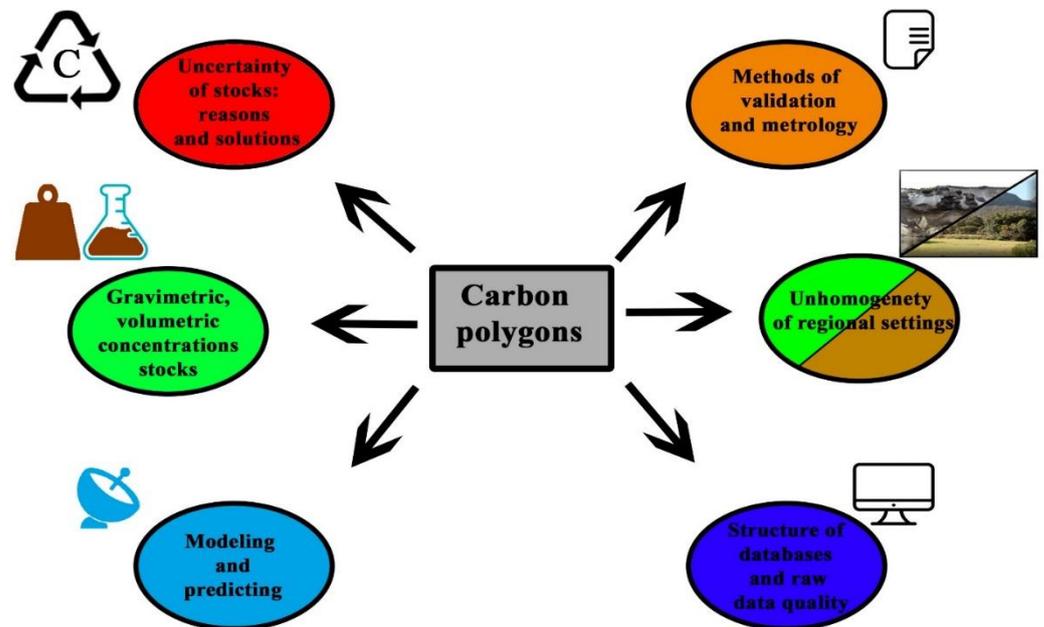


Figure 1. Responsibility tasks of carbon polygons.

Today, Russia has the only “Ugra” carbon polygon it located in the Kaluga region, which is a place for studying the global carbon balance and sequestration potential of the territory (Figure 2). It is planned to create polygons in Kaliningrad, Krasnodar, Sverdlovsk, Tyumen, Novosibirsk and Sakhalin regions as well as Chechen and Tatarstan republic up to 2022. Thus, the formation of carbon polygons in Russia will allow for the creation of a monitoring network that will study the processes of formation, accumulation, emission and deposit of priority greenhouse gases in various ecosystems of our country [25,26]. When forming carbon polygenes in natural zonal environments, industrial areas, large cities and anthropogenic ecosystems, it will create a reliable and productive monitoring network that will contribute to the study of the planetary carbon cycle and sequestration potential of the territory of the Russian Federation. This will allow to Russia to comply with the goals set out in the Sustainable Development Cooperation Framework of the UN and the Paris Climate Agreement [27,28].



Figure 2. First carbon polygon in Russia. National park “Ugra” (Source: ESRI: Geographic information system company (West Redlands, California, United States of America)).

2. Carbon Polygons: Current State and Key Challenges

2.1. Carbon Input and Emission

The input of carbon into soil is determined by two flows: aboveground and belowground. The first can be measured by a monthly quantification of litterfall in litter traps, which is quite useful when calculating carbon balance [29]. Below ground input is less costly in terms of time but more difficult to count the living-root biomass. As for the total emission of CO_2 , the classic method of closed field chambers [30] or the more advanced eddy covariance method are appropriate. The eddy covariance method is based on the measurement of net exchange of CO_2 over study area, as well as wind speed, to provide data regarding changes in SOC stocks [4]. The closed field chamber method is manual; therefore, portable CO_2 measurement units can be quickly transported and installed at the studied sites. This method is cheap and provides a simple analysis when investigating the carbon budget in an ecosystem, but it cannot cover a large area of investigation sites. Therefore, using the eddy covariance method is the most appropriate option for analyzing a carbon budget. The eddy covariance method allows dynamic data retrieval from a specific carbon landfill over a long period in any conditions (Arctic, Boreal, Tropical, etc.). For the placement of an eddy covariance tower, certain conditions must be observed, such as stable conditions for the polygons (wind, temperature, humidity and CO_2), homogeneity of the vegetation cover, as well as flat terrain [31]. It can cover an area of up to several hectares. However, this method is highly specialized and expensive. The use of this method depends on a number of local conditions: wind speed and direction, stable turbulent flow and the homogeneous distribution of the source and sink of CO_2 [4].

An important stage in this process is the task monitoring carbon dioxide and methane emissions in the Arctic sector of the Russian Federation. In the Russian Arctic, there are a number of monitoring stations (subordinated to the state monitoring network of Rosgidromet), which monitor greenhouse gas emissions, as well as the climatic parameters of remote territories. Such centers are located on the Svalbard Archipelago (Barentsburg), the Severnaya Zemlya Archipelago (Cape Baranov), a climate station in Tiksi (Yakutia), as well as a station on Samoilovsky Island (Yakutia). The soil of the circumpolar area (Histosols, Cryosols) is a potential hot spot for greenhouse gases. A significant amount of soil organic carbon is stored here, which can be further involved in the global carbon cycle and significantly contribute to climate change on the planet [1,32,33]. During the thawing of permafrost, greenhouse gases (CO_2 , CH_4) are emitted. One example is the Lena River Delta (Yakutia), where CO_2 emissions of up to $58.6 \text{ g CO}_2\text{-C kgC}^{-1}$ were observed in oxic conditions, while in anoxic areas, these figures were $17.5 \text{ g CO}_2\text{-C kgC}^{-1}$ and $10.7 \text{ g CH}_4\text{-C kgC}^{-1}$. Under the conditions of climate change, based on the current forecast, greenhouse gas emissions could increase to $113 \text{ g CO}_2\text{-C kgC}^{-1}$ in oxic conditions and up to $241 \text{ g CO}_2\text{-Ce (carbon equivalents) kgC}^{-1}$ in anoxic conditions by the year 2100 [34]. Thus, an important task is to monitor the most vulnerable ecosystems in order to calculate their possible contribution to climate change. We suggest that at least two carbon polygons should be located in the cryogenic ecosystems of Russia.

2.2. Carbon in the Fine Earth: Direct or Indirect

The most important area of study concerning carbon polygons is the problem of assessing the reserves and trends in the stability of organic matter in the soil of natural ecosystems. An adequate assessment of these stocks should be based on verified methods for determining the content of organic matter (direct and indirect methods and the problem of the correlation of results) and on unified ideas about the depth and regularity of sampling within soil profiles and monitoring sites. This problem is particularly relevant to the development of a spatial network of carbon polygons in the Russian Federation. Currently, two methods are used for the determination of gravimetric concentrations of soil organic carbon. The first is based on direct dry combustion of the carbon and an evaluation of the CO_2 emitted [35–38]. This method is very precise and accurate, but not every laboratory in Russia has the opportunity to work with these analyzers. Small laboratories cannot afford the purchase and maintenance of such equipment. In contrast, the indirect oxidation methods of Tyurin (Central and Eastern European countries) and Walkley–Black (Western world) [30,38], are based on the oxidation of carbon, halogens, Fe ions and can be easily implemented in any laboratory. These methods are also economically viable, with roughly 97 % of all data on soil and sediments carbon content being retrieved by these methods. However, these methods are inaccurate in many cases and do not work on salinized soils, soils with a high content of aliphatic chains in organic matter [38], and soils with a high iron content. Comparing this to previous data we have, these are indirect oxidation data [37,38]. In the context of the new contemporary polygons, it is necessary to decide, at the very beginning, which method we will use.

2.3. Gravimetric and Volumetric Concentration of Carbon

If gravimetric determination of carbon in fine earth is more or less clear, the conversion methods of gravimetric rates to volumetric concentrations or stocks are far from a complete resolution [1,39]. If soil density is usually considered, its rockiness is very rare, and the supply of organic substances greatly depends on this. Considering that the world's share of rocky and skeletal soils has reached 30%, this is an important methodological issue [3,4,40]. Therefore, an important task is the development of a unified system for determining the carbon content in soil and its stocks, depending on regional settings.

2.4. Humus Forms and Sampling of Soil Organic Profile

In Russia, different concepts are used regarding soil organic matter and humus compared to the EU and the USA. In the EU and USA, the SOM includes the following fractions: plant residues, particle decomposed plant materials, soil microbial biomass and humus [4]. In Russian pedology, humus is often understood as a colloidal organic substance that consists of humic acids and the precursors of humification (proteins, carbohydrates, lignin and aldehydes). Organic residues presented in the form of peat, sapropel, plant litter and organic fertilizers are not considered humus in the Russian School of Soil Science [41,42]. This is why, when determining carbon in fine earth, roots and detritus forms of organic matter are extracted, a process that is not always practiced in the EU and USA. Therefore, the concepts of humus, soil organic matter and total organic carbon, are not equivalent [43,44]. The concept of “carbon of organic compounds” also differs from them. Thus, we have to decide what we will use for monitoring and from which horizons we will gather regular samples, e.g., are we going to include a forest floor or all superficial undecomposed organic matter, which is an important part of stock [43,45–48] but not stabilized? The sequestration of organic carbon occurs at various levels of organization of organic matter, in forest litter, in peat and in the organo–mineral and mineral horizons. Due to various stabilization mechanisms (mechanical, chemical and molecular), SOM is transformed into a more stable form and can be stored in a soil for a long time [14,49]. Another important question is related to sampling depth: 0–20 (arable layers), 0–100 (the average depth of soil in Eurasia) or the horizontal approach (sampling from each soil genetic horizon). Thus, we have numerous key questions on sampling strategy that we must discuss and define at the very beginning of polygon creation.

2.5. Polygons in Space and Regional Settings

Currently, carbon polygons proposed by the Ministries of Education and Science in the Russian Federation [50] do not cover all natural zones. The proposed approach is based on the location of polygons in different areas of the Russian Federation. However, not all of the natural conditions, even at the biome level, will be covered by the proposed network of polygons, which will lead to distortions and inaccuracies even in approximate assessments. The planned network of carbon polygons does not yet include cryogenic soils found in of the circumpolar environments, in which huge reserves of organic matter are concentrated. It is necessary to pay special attention to the need to expand the network of carbon polygons to all natural zones of Russia. Russian boreal soil, polar soil and subsurface sediments possess the highest stock of carbon in the northern hemisphere; nevertheless, the stocks of organic matter in these environments are underestimated due to the complex heterogeneity of the territory and the presence of permafrost tables on soil [1]. Thus, the question of covering the country with the polygons is a keynote for the accurate assessment of carbon stocks, taking into account the unique phenomena of soils and environment zonality, which has been elaborated by V.V. Dokuchaev [41]. If Russia follows a zonal approach in the spatial distribution of polygons, it will become a standard for the whole world—all types of biomes will be covered, except for tropical ones. In this context, the previous experience of the International Biological Program should also be obtained [51,52]. The soils of Russia, taking into account the greatest pedodiversity, should be a standard in terms of humus state and carbon content metrology (Figure 3).

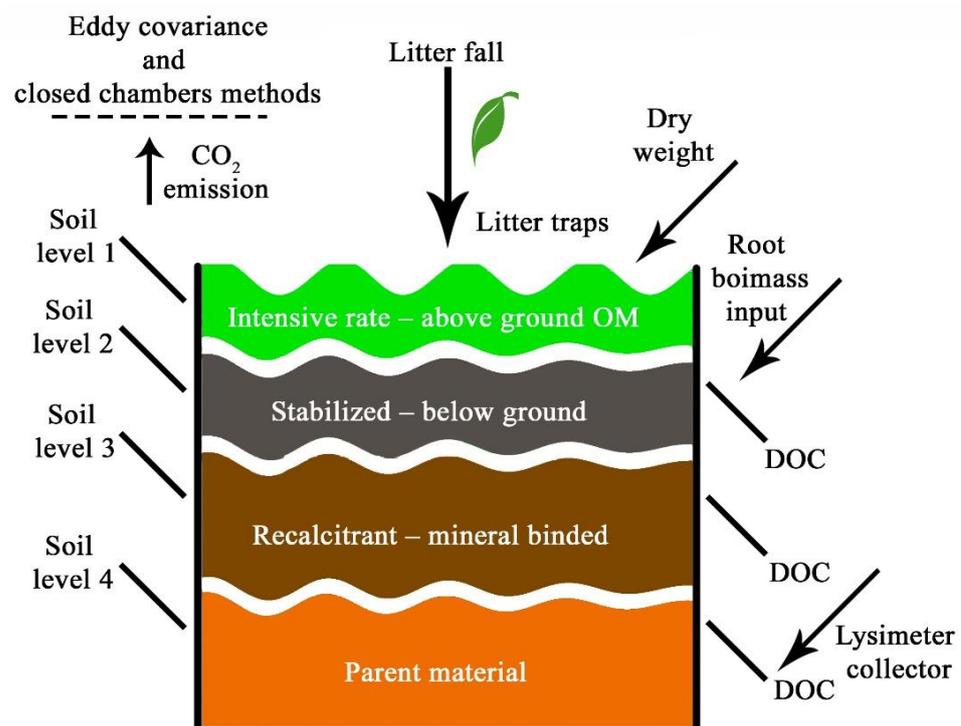


Figure 3. Schematic structure of carbon polygons functions and methods of carbon traps.

2.6. Modeling and Predicting

Modeling is a critical tool for predicting and analyzing large amounts of data, including carbon data. Modern mathematical simulation models (Romul, Efimod) allow one to process large amounts of soil–climatic and soil–chemical data to predict the dynamics of the content of various fractions of organic matter, from easily decomposable to highly stabilized [43,45,46,48]. Soil–climatic data are currently in deficit; therefore, a long-term temperature and water content logger should be inserted into the soil, at different depths to provide an automatic meteorostation on the soil’s surface. High-accuracy simulation modeling is not only important from the point of view of basic science; it is also important for the forecasting markets of carbon units and carbon offsets. Every type of carbon market should be targeted by a prediction system, such as a mathematical simulation model. This model should be verified using the input data derived from carbon polygons. The use of GIS systems is also crucial for the generalization of big raw data and the visualization of boundless information [51,52].

2.7. Carbon Offsets

“Stock or source?”—this is a key question concerning carbon polygons methodology. Can any natural zone of Russia represent the carbon sequestration—stock formation zone? Are any of these zones and environments critically important in terms of anthropogenically derived CO₂ emissions? How can we manage carbon fluxes to reduce emissions, increase sequestration and redistribute these components within the time and space available [53–55]? Another question—is decision making based on scientific data derived from polygons and environmental management practices in the fields of forestry, agronomy, mining and industry. Despite these questions, one of the most important tasks is understanding the rate at which organic carbon can be evaluated and assessed in terms of an ecosystem services evaluation. Here, both the stock (volumetric concentration), and the quality of organic matter (stabilization rate and resistance to mineralization) should play a crucial role [56,57]. The final inquiry of this discussion is “whether the carbon unit of humus of one quality is comparable to the carbon unit of humus of another quality?”. In other words, is 1 ton of Chernozemic carbon comparable to 1 ton of organic carbon derived from

Podzol? The above questions are not pedological, but relate to environmental economics and the monetization of ecosystem services (carbon units market), an area that is far from resolved [58,59]. As a result of increased anthropogenic activity in these natural ecosystems, the carbon balance within these territories becomes violated. The utilization of carbon polygons will make it possible to control Russia's carbon balance and monitor climate change in various geographic and climatic conditions within one country.

3. Conclusions

While creating the carbon polygon in any part of a country, we should discuss: (1) terminology—what we are determining, how and where, e.g., sampling strategy, laboratory processing, the transfer from a gravimetric to a volumetric concentration of carbon and related biogenic elements; (2) the spatial coverage of Russia by polygons and regional setting: we have to avoid the effects of data clusterization for better future spatial and temporal data interpolation; (3) vertical frequency and temporal regularity of sampling: data from different depths and different season are not comparable in terms of monitoring; (4) how to store/process raw data and how to generalize the great data massive? and, the last but nevertheless important question; (5) obviously, the carbon unit itself depends on how to measure it and how to calculate it, and whether the equivalent of the carbon currency will depend on our methodology and how we organize the network of carbon polygons.

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