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Perspectives in Soil Organic Carbon Storage: From a Global Perspective to the Possibilities of Landscapes

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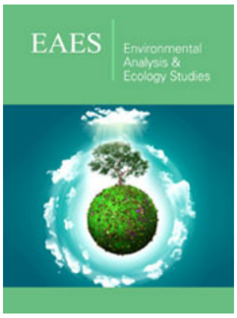

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Abstract

The features of the deposition of soil organic carbon on the national and regional scale in the context of global climate change are considered. Attention is drawn to the fact that low-humus soils in semiarid regions are characterized by high losses of soil organic carbon, including due to the influence of irrigation. Estimates of soil organic carbon storage during the accumulation of alluvium in river floodplains, deposition of pedosediments in negative landforms, and under conditions of soil renaturation on mining dumps are presented.

Keywords: Carbon sequestration; Carbon balance; Soil organic matter; Carbon landfill

Introduction

Soil is the largest carbon pool in terrestrial ecosystems, as it contains more than 70% of terrestrial organic carbon stocks, which is about three times the carbon stock in plants and twice the carbon stock in the atmospheric carbon pool [1]. Soil organic carbon (Corg) plays a critical role in ecosystems, controlling chemical and biophysical processes, but also performs a number of functions and services: shaping soil structure, retaining nutrients and water, maintaining soil biodiversity, and controlling greenhouse gas emissions [2]. Both under the conditions of self-development and in the course of the reaction of non-environmental influence, the quasi-stable state of Organic Matter (OM) leads to the sequestration of carbon from the atmosphere into soils and bio sediments, which determines the role of soil cover state and stability in the regulation of global carbon balance [3]. About 2344 Gt of Corg are deposited in the soil cover of the world, while its reserves reflect the balance between the decomposition of organic matter and the stabilization of assimilated carbon by soil microorganisms, and this balance can change depending on various biophysical conditions [4].

The soil and vegetation cover of the Russian Federation makes a global contribution to carbon sequestration due to the annual growth of new phyto mass, which makes it possible to remove carbon dioxide from the atmosphere, and to the deposition of Corg in soils. If the soil area of the country is about 12% of the soil fund of the entire globe, then the upper soil horizons accumulate at least 23% of the global reserves of soil organic matter [5]. The areas of Russian Chernozems are estimated at 52% of the world area of this soil type. Soils that can store the maximum amount of Corg in their natural state are typical Chernozems (130 and 410t ha^{-1} in layers of 0-20 and 0-100cm, respectively), as well as other subtypes of Chernozems (to the north or south of the distribution typical Chernozems) from 250 to 320t ha^{-1} in a layer of 0-100cm. In addition to the fact that, along with the process of humification, mineralization of organic matter also occurs in soils, the balance value of OM under certain bioclimatic conditions characterizes the potential of Corg deposition as a blocking mechanism for its return from the soil to the atmosphere. This study aims to show the main perspectives in the storage of soil organic carbon as one of the significant components in the regulation of carbon balance in bio spheric processes.

National and Regional Measurement of Depositing Soil Organic Carbon

At the 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC), the Paris Agreement and the 4p1000 initiative were proposed to increase soil organic carbon stocks. With a general understanding that the observed trend of global climate change can stimulate the mineralization of Soil Organic Matter (SOM), it is noted [3] that the regionalization factor (climate heterogeneity at the meso-level and soil diversity) will correct the rates and features of change on SOC content. In accordance with the Decree of the Government of the Russian Federation dated September 21, 2019 "On the adoption of the Paris Agreement" and the Presidential Decree dated November 4, 2020 "On the reduction of greenhouse gas emissions", the Russian Federation undertakes to reduce greenhouse gas emissions by 70% (against the 1990 figure) by 2030 and further achieve a carbon-neutral development path by 2060. In 2023, for the first time in Russia, it will be required to officially submit a report on greenhouse gas emissions. The reporting system for carbon dioxide emissions will be mandatory for companies whose emissions will be more than 150 thousand tons per year until 2024 and more than 50 thousand tons from 2024.

Today Russia is facing global challenges regarding climate change. The soil cover of the country can be considered as the largest reservoir of soil organic carbon, the transformation of which as a result of climate change can lead to landscape degradation. The formation of a network of carbon landfills will be able to create prerequisites for monitoring and accounting for the carbon budget in various natural zones of the country [3]. In February 2021, the Ministry of Science and Higher Education of the Russian Federation launched a pilot project to create carbon landfills in Russian regions to develop and test carbon balance control technologies. Carboniferous landfill-one or more areas of the earth's surface with a representative topography for the given territory, the structure of vegetation and soil cover, where a set of measures is being implemented aimed at developing scientific, human and infrastructural potentials in the development and testing of technologies for monitoring the balance of climatically active gases of natural ecosystems. Now the number of operating landfills is 14 on a total area of 39157 hectares.

The Republic of Tatarstan has become the eighth participant in the project of the Russian Ministry of Education and Science to create carbon landfills, which will allow, with the help of scientists from Kazan Federal University, to obtain more accurate data on the absorption capacity of the forests of Tatarstan. At Belgorod State National Research University in 2022, a carbon landfill was created on the basis of the Botanical Garden in order to monitor the fluxes of greenhouse gases (CO_2, CH_4, N_2O) in the atmospheric air and develop technologies for sequestering atmospheric carbon in plant biomass and soil organic matter. In addition to the botanical garden as the central site of the regional carbon balance monitoring system, in the future, a carbon landfill at the mining industry will become an integral part of this system. The NRU "BelSU" carbon landfill, as well as promising sites of the landfill at mining facilities and in agricultural landscapes, will become the basic elements of a regional carbon balance monitoring network with a database and a geoportal. The equipment of the landfill will be used in the activities of the Center for Validation and Verification of Carbon Units for experimental substantiation (validation) of companies' climate projects.

Carbon farms are prototypes of special atmospheric carbon sequestration facilities that could appear in carbon landfills. On these prototypes, special complexes of forestry and agricultural technologies, as well as other elements of the future sequestration industry, will be tested in the field. For the creation of carbon farms, mining enterprises have a territorial basis in the form of uncultivated lands.

Soil Organic Carbon Reserves and Losses: A Case Semiarid Regions

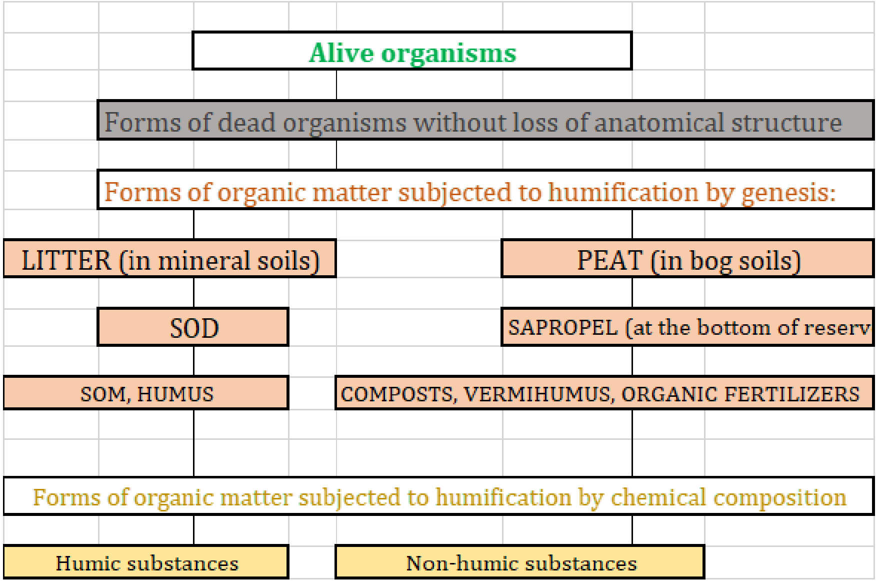

Figure 1: Forms of organic matter in the biosphere (by Alexandrova [7] with modification).

The biosphere contains various forms of organic matter (Figure 1), which, as products of the transformation and accumulation of OM, have some similarities with humus in certain characteristics, but differ in genesis. Thus, humus should be considered a purely soil term in relation to SOM, which necessarily passed the stage of humification with the formation of specific humic substances. Humus is only a part of SOM, since the system of organic particles and biomolecules of various sizes also includes plant residues, solid discrete particles of semi-decomposed organic material, dissolved substances, coals, and charred materials [6]. Organic substances that are part of plant residues that have not yet lost their anatomical structure, and as a chemically complex system, are the source from which humus is formed [7].

Virgin soils of the southern steppe, usually formed on loess, contain from 1.4 to 2.4% Corg in the humus-accumulative horizon. Moreover, one should take into account the significant participation of detritus in the structure of organic matter, which can reach 35% of the total content of OM in a layer of 0-20cm of Chernozem, determined by the method of oxidation of organic matter with a solution of potassium dichromate. According to Whittaker [8], the low biomass of grasslands is the result of the brevity of the life of the above-ground parts of plants adapted to fires. In studies of virgin areas of the northern Black Sea coast [9], it was shown that under the feather grass-fescue association, the proportion of mortmass (detritus) in the soil layer of 0-20cm is 27-32% of the total underground phytomass but increases to 45% after a fire. Thus, the pyrogenic factor increases root falls and the supply of soil organic carbon. But, on the other hand, the absence of rags and bedding in the burnt area favors a more intense transformation and mineralization of the newly formed litter.

It is important to note that the transition from steppe mat to the soil surface is gradual, since at this boundary, in addition to small (2-4mm) plant residues and detritus particles 0.9-0.05mm in diameter or less, which in total amount to about 10% by weight, there is a significant fragments of minerals and microaggregates attached to the litter take part. The soil mass of this transitional horizon is enriched in OM (the total content of Corg according to the method of oxidation of organic matter with a solution of potassium dichromic acid is 4.9%), and of this amount, the smallest fragments of plant residues and detritus account for 20% (in relative terms). The presence of a permanent reserve in the form of a pre-humus fraction gives the process of humus deposition in virgin soils a peculiar feature that distinguishes them from plowed land. All types of SOM are stratified according to hierarchical levels of soil structural organization, which is represented by aggregates of different sizes and granulometric fractions. Mega aggregates contain mostly plant remains, macro- and microaggregates contain semi-decomposed remains in the form of solid discrete particles (Particulate Organic Matter, POM), while humus proper, or rather Mineral Associated Organic Matter (MAOM) is concentrated in loam and silt fractions [6].

A study of the agrogenic sequence of soils in a region with a centuries-old agrarian history (since Antiquity) showed that, if we take the Corg content in the 0-23cm layer of virgin land as a basis (2.7%), then continuously ploughed land lost 51% Corg, modern-day ploughed land is 39%, and post-antique long-term fallow land is estimated at 27% loss [10]. Semiarid regions are distinguished not only by dehumification inherent in arable soils, but also by its more intense manifestation during soil reclamation with fresh water. Thus, in the typical region of the Ukraine Steppe zone, where the Corg content in the arable layer (0-20cm) does not exceed 2.2%, the Corg content decreased from 1.5 to 1.3% over three decades of irrigation [11].

Methodological Aspects of the Transition from SOM to Corg

A distinctive feature of SOM is the combination of plant residues, solid discrete particles, and dissolved organic matter in the structure, which does not allow identifying SOM with humus [6]. Due to the fact that the complex chemical structure of SOM is complex and not fully known [12], there is a need for consistency and comparability of the analytical procedures used for this. Traditionally in the region of Northern Eurasia, the mass fraction of Organic Matter (OM) is determined by the method of oxidation of organic matter with a solution of dichromic acid prepared with sulfuric acid, followed by the determination of trivalent chromium, equivalent to the content of organic matter, on a photo electro colorimeter (in Russia it is regulated by GOST 26213-91). At the same time, it is important to note that the efficiency of soil Corg oxidation depends on the conditions of the redox reaction (temperature, reagent concentration, oxidation time) and ranges from 70 to 95% [12]. In addition, the Corg content is calculated according to Tyurin's method by multiplying the OM content by 0.579. However, it should be noted that based on the assumption that carbon makes up about 58% of the OM content, a conversion factor from the carbon content (Corg) to the OM content of 1.724 is traditionally applied, although it has been shown that the value of this coefficient varies from 1.4 to 2.5 in soil type [13]. The new Standard operating procedure proposes to determine Corg by evaluating the amount of chromic ion (Cr^{3+}) formed which is determined by the spectrophotometric method [12].

Deposit Potentials of Soil Organic Carbon in Various Landscapes

Regions with a high degree of land development feel their shortage, including when searching for promising areas for the creation of carbon farms. In this regard, one can pay attention to landscapes that have been little transformed by humans, as well as to their anthropogenic modifications: river floodplains and bottoms of erosive landforms, the soils of which themselves act as carbon sequestration reservoirs, as well as non-reclaimed mining dumps. For soils from such landscapes, we present some estimates of the carbon-storage potential. The intensity of alluvium accumulation in river floodplains of the Central Russian Upland over the last millennium is estimated on average at rates up to 1mm yr^{-1} [14]. The reserves of Corg in the humus horizon of various subtypes of meadow soils on floodplains range from 170-200t ha^{-1}.

Deluvial soils are usually two-membered: the sediment layer is up to 2.3m thick, with a total thickness of up to 4.8m (taking into account the initial soil profile, which is buried under the sediment layer). In regions with high activity of agricultural development and erosion rates, such as in Moldova, in the profile of deluvial soils up to 1.5m, the Corg content is 1.9-2.0%, but from 2.2 to 3.2m there is a deposition peak with an average Corg content of 3.2% (with a maximum 3.5%), but below (to 4.8m) it gradually decreases to 0.9% [15]. The reserves of Corg in the 0-20cm layer in deluvial soils are 79-80t ha^{-1}, and in general, in the alluvial layer 2.3m thick, the reserves are 593t ha^{-1}. The author's studies in the conditions of the forest-steppe zone (precipitation 550mm per year) showed that at the bottom of the moat, which was created for the purpose of fortification 3.5 centuries ago, there was an accumulation of pedo sediments with a total thickness of 950mm at an average accumulation rate of 2.58mm yr^{-1}. In this case, Corg reserves in the 0-95cm layer amounted to 214t ha^{-1} [16].

The soils of technogenic landscapes and their formation after the cessation of human-transformed activities are largely determined by organic matter accumulations (humus, litter, and peat) [17]. Young soils in mining landscapes, as well as in other types of anthropogenic landscapes with a dated zero-moment [18], serve as informative natural models for studying the features of the carbon sequestration process at individual stages of pedogenesis under specific zonal-climatic conditions. The author's research on the dumps of iron ore mining showed that over the first three decades of the formation of embryonic soils, on average, their potential for deposition of Corg can be estimated at an average of 9.4t ha^{-1}, however, if optimal conditions are formed in terms of the substrate and phytocenosis, this indicator can reach 15.4t ha^{-1}. This gap reveals the prospect of controlling the carbon sequestration efficiency of pedogenesis, if the spontaneous process of formation of successions of vegetation and soils is replaced by renaturation technologies that can ensure the maintenance of complementary trajectories of the reproduction of soil and vegetation cover on mining dumps with control actions.

Conclusion and Future Perspectives

Summarizing the information of this review, we note that at the moment, with the great activity of researchers in developing approaches to assess the carbon sequestration efficiency of soil and vegetation cover, there remains a significant range of issues that relate to practical soil science, to the release of its data into the environmental economy and the field of monetization of ecosystem services (the market for Carbon credits), and there are also a number of methodological scientific problems that need to be solved at the stage preceding the formation of national networks of carbon landfills. Thus, such tasks include the need to determine the amount of organic carbon of various qualitative composition, subject to assessment in terms of ecosystem services; supplementing data on stocks (volume concentration) with data on the quality of organic matter (stabilization rate) and others.

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