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CURRENT APPROACHES TO CARBON MANAGEMENT FOR INCREASING ITS BUDGET IN SOILS

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Abstract

It is shown the average humus content in agricultural soils of different soil and climate zones of Ukraine. It is emphasized that today there is a positive trend in the humus content of soils in comparison with the data of previous years. The existing resources of organic raw materials for replenishment of organic carbon reserves in the soils of different zones of Ukraine have been analyzed. The characteristics of potential resources of organic raw materials of natural origin and organic waste from the standpoint of humus formation are given. Approaches to the management of organic materials to increase the efficiency of accumulation of humus in soils are proposed. In a model experiment, it is proved that humus of alluvial-meadow soils is easy to be mineralized in comparison with chernozem soils. Taking into account the peculiarities of meadow soil formation, approaches to carbon budget conservation in these environmentally sensitive soils are proposed.

Key words*: soil organic carbon, carbon budget conservation.*

INTRODUCTION

Soil organic carbon (SOC) is essential for soil fertility, for its ecosystem functions, especially for food production. SOC is one of the world's climate change factors because of excessive carbon dioxide emission from soils affected by imbalance of humification-mineralization processes of soil organic matter in favour of the last ones, which are due to current intensive and irrational soil use. This unqualified assertion is in the focus of fundamental and applied research both of national and foreign scientific experience (Kell, 2011; Xiao, 2015; Crowther et al., 2016).

According to the "World Soil Resources" edition (FAO, 2015), organic carbon budget of agricultural soils is 30 Gt in the USA, 26-28 Gt in China, 17-18 Gt in Russia and from 2-3 to 4-5 Gt in Ukraine (1 Gt is 1 bln tones). However, this huge SOC budget could be lost easily as a result of increased and unreasonable anthropogenic influence on natural equilibrium of soil-formation processes as well as a wide range of natural factors.

Indeed, during 1850-2005 years it was lost 74 ± 18 Pg of SOC due to erosion, 79-85% of which are on agricultural lands and pastures (Naipal et al, 2018). According to Regional soil change assessment in Europe and Eurasia (FAO, 2015), humus content is being lost on 23-70% of agricultural land areas and it was expectedly proved (Lal, 2010) that agricultural soils contain SOC by 25-75% less than their analogues but on natural ecosystems.

Total emissions of greenhouse gases released into the atmosphere on agricultural land in 2019 amounted to 10.7 billion tons of carbon dioxide equivalent (Gt CO_2 eq), a decrease of 2 percent, or 0.2 Gt CO_2 eq compared with 2000 (FAO, 2021).

Besides, according to the data of Maun-Loan laboratory, the concentration of carbon dioxide in earth's atmosphere went beyond 415 ppm grade at the date of the 11th of May, 2019 (Dockrill, 2019).

That is why soil carbon circle and sequestration management is a key link in solving such world's actual problems as combating soil degradation and climate change mitigation (FAO, 2017).

Development and implementation of methods for SOC sustainable management are extremely important for soil protection in Ukraine. Ukraine has joint the UNO Convention to Combat Desertification, where it adopted a voluntary national commitment to increase the organic carbon content in soils at least by 0.1 % by 2030. Increasing SOC budget will contribute to the improvement of soil ecological properties, including preservation and restoration of soil biota, optimization of nutrient and moisture regime thereby increasing the long-term resistance of arable soils to degradation under the influence of anthropogenic factors. Therefore, the relevance of the issues disclosed in this article does not raise any doubts.

MATERIALS AND METHODS

The research was conducted in certified laboratories: laboratory of organic fertilizers and humus (Certificate of compliance of the measurement system with the requirements of DSTU ISO 10012:2005, No. 01-0083/2020) and laboratory of instrumental soil research methods, standardization and metrology (Certificate of compliance of the measurement system with the requirements of DSTU ISO 10012:2005, No. 01-0083/2020) in accordance with current standards of Ukraine (DSTU).

During two tours of soil surveys (2006-2010 and 2011-2015), soil samples of different soil types were taken from the depth of 0-30 sm for laboratory analysis.

Organic carbon content in studied soils was determined by Tyurin method based on dichromate oxidation. Organic carbon content then was recalculated into humus using the mean coefficient (1.724). Humus composition was determined by Tyurin method according to Ponomareva - Plotnikova procedure (Ponomareva & Plotnikova, 1980) where different organic matter groups were separated into humic acids (HA) and fulvic acids (FA) with further calculation the HA/FA value.

All measurements were performed in triplicate. Statistical analysis of variance was performed using Statistica 10 software.

Generalization of main characteristics of available organic fertilizers and local raw materials of different origins was carried out on the basis of the assessment of statistical reports of the laboratory of organic fertilizers and humus.

Soil samples were also taken from the meadow soils (0-30 cm depth) on the middle part of floodplains of the Left-bank Forest-steppe zone of Ukraine for analysis and laboratory-model experiments.

A laboratory-model experiment was conducted for establishing the susceptibility of meadow soils humus to mineralization processes. For experiment, there were taken loess heavy loamy, chernozem podzolized heavy loamy, meadow heavy loamy soils from different floodplains and meadow residual saline light loamy soil. The experiment involved composting soil samples in glass vessels in the thermostat at a temperature of 20-22°C and humidity of 60% of the total moisture content.

Soil samples without composting were used for control. The mass of air-dry soil in each vessel was 500 g. The study was five times repeated. The experiment lasted 9 months. At the end of every three months period it was determined the amount of accumulated mineral nitrogen in composted soil samples (according to DSTU 4729:2007).

RESULTS AND DISCUSSIONS

Anthropogenic influence and interference into soil natural processes disrupts the process of humus accumulation, which leads to a ratio changes in synthesis and mineralization of organic matter in soil. Processes of dehumidification cause deterioration of agronomic properties of the soil and reducing its fertility, which may affect functioning of the biosphere as a whole.

According to the latest tour of lands agrochemical certification (2011-2015), agricultural soils of Ukraine are characterized mainly by high humus content (3.07%). This reflects the positive trend of soil humus content compared to the data of the previous tour of surveys (2006-2010), which revealed average humus content of 3.05%. This trend is due to the increase in the supplying of organic matter to the soil, mainly due to plant residues. For example, over the last five years, 2.5 to 4.8 t ha^{-1} of straw and 11.6 to 16.6 t ha^{-1} of green manure have been applied annually. In terms of soil and climatic zones, the most significant increase in humus content in soils was observed in the Polessye zone (4% compared to 2006-2010), the least was in the Forest-Steppe zone - 0.6 % and Steppe zone - 0.1 % (Figures 1-3).

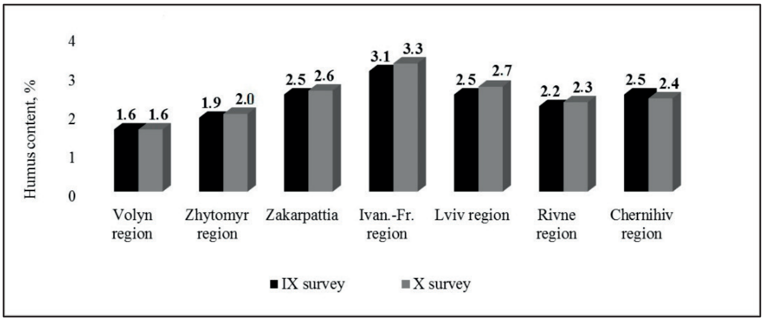


Figure 1. Humus content in soils of the Polessye zone of Ukraine [IX (2006-2010) and X (2011-2015) tour of the survey], %

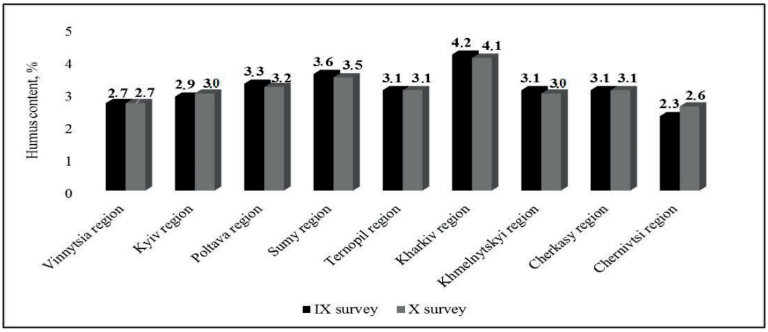


Figure 2. Humus content in soils of the Forest-Steppe zone of Ukraine [IX (2006-2010) and X (2011-2015) tour of the survey], %

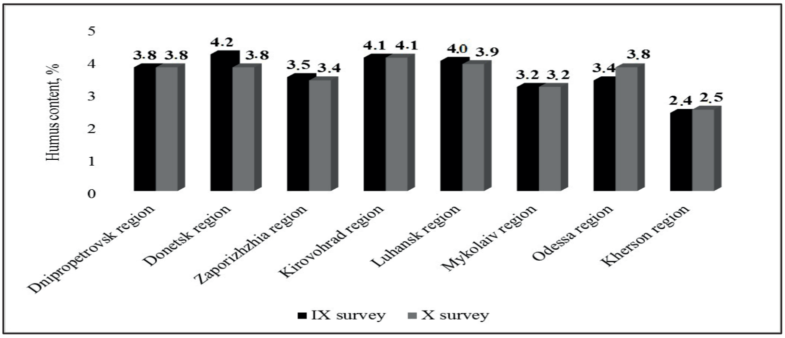


Figure 3. Humus content in soils of the Steppe zone of Ukraine [IX (2006-2010) and X (2011-2015) tour of the survey], %

Preventing soil degradation, reducing the risk of environmental disturbances during crops growth as well as stabilizing soil carbon stocks necessitates the use of organic raw materials, such as organic fertilizers, crop residues and local raw materials with maximum fertilizing and reclamation effect (Skrylnyk et al., 2019; 2020).

According to statistic data, the production and use of organic fertilizers have decreased almost 16 times during the last 30 years. Currently, the use of organic fertilizers ranges from 0.13 to 1.20 t ha^{-1} in different zones of Ukraine.

For the last five years the largest amount of organic fertilizers was applied in the Polessye zone (from 0.8 to 1.2 t ha^{-1}), the smallest - in the Steppe zone (from 0.13 to 0.25 t ha^{-1}). Organic fertilizers are mainly applied to fodder crops, the least - to cereals (except corn). As of 2020, only 1.9 % (0.8 million ha) of manure was applied.

The total annual output of manure in farms of all categories was 106.2 million tons in 2020. As for calculations of 2020, the use of all manure and poultry manure (in terms of a litter manure) provided fertilization of agricultural land with traditional organic fertilizers at a dose per dry matter in the Polessye region - 1.9 t ha^{-1}, in the Forest-Steppe zone - 1.5 t ha^{-1} and in the Steppe zone - 0.5 t ha^{-1}.

Currently, the measures that promote greater inflow of organic matter into the soil include the use of plant residues (Skrylnyk et al., 2019).

According to 2020, in case of plowing the by-products of the main agricultural crops, their application is possible in the Polessye zone at a dose of 4.9 t ha^{-1}, Forest-Steppe - 6.4 t ha^{-1}, in the Steppe zone - 3.4 t ha^{-1}, which in terms of litter manure is 2.8 t, 3.2 t and 1.9 t of dry matter per hectare of sown area in zones of Ukraine, respectively.

Thus, considering the available output of manure and by-products of the main crops in Ukraine, the estimated possible application of organic fertilizers, is 4.7 t of dry matter equivalent to litter manure per 1 ha of sown area for the Polessye zone, 5.9 t ha^{-1} for Forest-Steppe and 2.5 t ha^{-1} for the Steppe zone, while the norm for ensuring a deficit-free balance of humus, depending on the soil-climatic zone, should be from 8 to 14 t ha^{-1}.

The calculation of organic fertilizers doses is based on the indicator of the total nitrogen content. The greatest efficiency of organic fertilizers is provided when applying them in the recommended application norms. The increase in organic fertilizer rates causes, on the one hand, a significant decrease (by 1.5-2 times) in cost recovery and profitability, and, on the other hand, unwanted ecological consequences such as environmental pollution and deterioration of the ameliorating effect of organic fertilizers.

There is necessity to control the quantity and quality of carbon compounds entering the soil for regulation the humus state of arable soils.

Proving the role of organic fertilizers as humus-formers requires data of their chemical composition on total content of nutrients and the composition of their organic matter as well.

A specific feature of the chemical composition of most organic materials compared to plant residues and by-products is that they contain "finished" humic acids (Burdon, 2011; Skrylnyk et al., 2016; Drichko et al., 2013). The quantity of these compounds is different and depends, mainly, on their content in the organic filler, and on the intensity of humification processes during biocomposting of raw materials. In addition to humic acids, organic fertilizers contain various components that are easily and difficult to decompose. For example, manure on straw bedding contains a small amount of humic acids and an increased amount of carbohydrates and lignin.

During storage, the organic matter of manure changes significantly (Table 1). As an example, the content of carbon in mold is 5 and 3 times less than that of fresh and rotted manure, respectively.

Table 1. Organic matter composition of cattle manure of different storage period

Sample	C_{total}, %	Alkaline-pyrophosphate extract				Alkaline (NaOH) extract			
		C_{total}	C_{HA}	C_{FA}	C_{HA} of C_{total}	C_{total}	C_{HA}	C_{FA}	C_{HA} of C_{total}
		%							
Fresh	34.8	2.9	1.2	1.7	41.4	5.9	4.0	1.9	67.8
Half-rotted	28.3	1.9	1.3	0.6	68.4	5.2	3.4	1.8	65.4
Rotted	22.8	2.1	1.1	1.0	52.4	3.9	2.9	1.0	74.4
Mold	7.6	0.7	0.3	0.4	42.9	1.0	0.9	0.1	90.0

During the composting, the qualitative composition of organic matter of manure is being transformed as well, the content of humic and fulvic acids decreases.

Fresh manure consists mainly of fulvic acids (about 60% of the total carbon of the alkaline-pyrophosphate extract). At the half-rotted stage, the content of humic acids twice exceeds fulvic acids in the composition of humic compounds, i.e., alkaline-pyrophosphate solution extracts more than 68% of humic acids. At above mentioned stage of manure decomposition alkaline solution also extracts up to 65% of humic acids, and already at the stage of rotting - more than 74%.

Due to the shortage of traditional organic fertilizers, the role of attracting local raw materials of various origins to replenish organic carbon reserves is growing.
Natural raw materials (sapropel, peat, lignite, leonardite, biochar), organic wastes from processing industry and utilities (molasses, pulp, lignin, organic raw materials from biogas system, sewage sludge), livestock and poultry farming (solid and liquid manure, droppings), vegetable raw materials (green manure, by-products) are alternative sources of organic matter in soil and raw materials for production organic and organo-mineral fertilizers (Figure 4) (Brassard et al., 2019; Skrylnyk et al., 2020, 2021; Hetmanenko et al., 2021; Seadi et al., 2012).

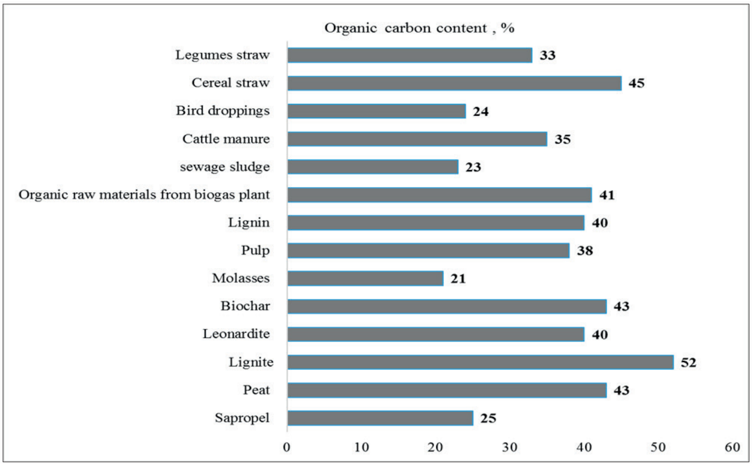
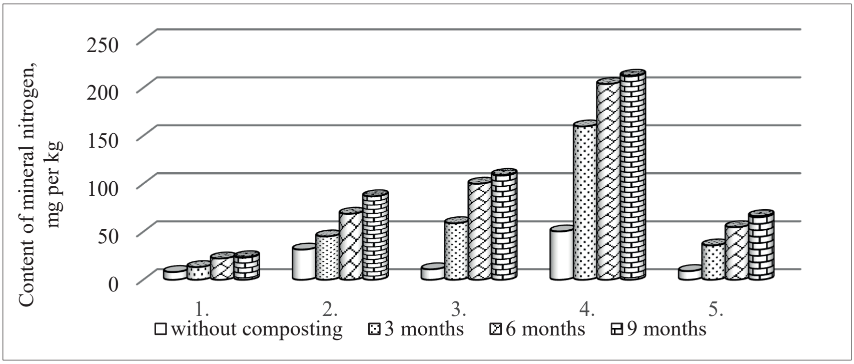


Figure 4. The average content of organic carbon in organic raw materials of various origins

Production of crop by-products in Ukraine exceeds 80 million tons per year. Predictably, the possible output of the crop by-products is for grain crops - 22.5 mln t (75% of the total output for fertilizer); corn per grain - 46.0 mln t; sunflower - 23.6 mln t; soy - 2.7 mln t; vegetables - 6.8 mln t. On average, up to 400 kg of carbon, 8.5 kg of nitrogen, 3.8 kg of phosphorus, 13 kg of potassium and microelements are added to the soil from 1 t of straw. During the decomposition of the cereal crops residues or their straw in the soil without the addition of nitrogen from mineral or organic fertilizers, the humification coefficient does not exceed 8-10%. The application rate of nitrogen fertilizers should be differentiated, depending on the type and amount of plant residues left after harvesting. This approach to fertilizing will not only improve the humus state of the soil, but also reduce the unproductive loss of nitrogen.
The importance of using crop residues as organic fertilizers is also justified from an economic side, because it requires minimal additional costs, since it is simultaneous with harvesting.
As for hydromorphic soils, they don't require additional management for increasing humus content, because naturally it is on a high level (at times up to 20%), but due to their natural ecological specificity it could be easy mineralized when these soils are overused. According to the results of model experiment with composting soil samples of various genesis, at the end of the experiment the content of nitrogen in hydromorphic meadow soils increased approximately 10 times, compared to variant without composting (Figure 5) and it was the highest amount among all variants of the experiment. On the other hand, after 9 months of composting the automorphic soil and loess, the content of mineral nitrogen increased only 3 times, compared to variant without composting. It shows that humus of automorphic soils is more stable to mineralization in contrast to hydromorphic soils.
Thus, overuse of hydromorphic soils may lead to the strengthening of mineralization processes, which can cause eutrophication of groundwater and nearest water sources with nitrates and

increase the emission of greenhouse gases from these soils.

In this regard, soil carbon management of hydromorphic soils should be mainly focused on preservation available soil carbon budget and prevention its further loses. Only implementtation of sustainable management on these soils will help to achieve above-mentioned aims.



1 - Loess heavy loamy.
2 - Chernozem podzolized heavy loamy.
3 - Meadow heavy loamy soil.
4 - Meadow heavy loamy soil.
5 - Meadow light loamy soil.

Figure 5. Content of mineral nitrogen in different soils after 9 months composting

Sustainable management of hydromorphic soils means keeping differentiated approach to the use of meadow soils, introduction of cultural hay and pasture areas with regulated regime of use, implementation of contour and phytoameliorative system (selection of meadow grasses mixes, most adapted to specific soil and hydrological conditions) and cultivation of energy crops (Khyzhniak, 2020).

The use of these soils as arable lands requires strict adherence to scientifically based recommendations, balanced actions and, above all, the use of soil-protecting agricultural methods and technologies.

CONCLUSIONS

There is a deficit of available manure and by-products of the main agricultural crops in various soil and climatic zones of Ukraine and even their maximum application into the soil does not ensure the recommended zonal norms. The possible dose of applying organic fertilizers, such as entire amount of manure, by-products of cereal and legume crops with addition the 40% of the annual amount of cereal straw, reaches on average only 2 t per ha in Ukraine (equivalent to the dry matter of litter manure per hectare of sown area).

Due to the shortage of traditional organic fertilizers, the role of raw resources of various origins (natural raw materials, organic waste from the processing industry and utilities, animal husbandry and poultry farming, plant raw materials, etc.) is significantly increasing for the replenishment of organic carbon reserves in the soils of Ukraine.

Organic waste is proposed to consider primarily as a source of carbon-containing compounds and plant nutrients after appropriate technological decisions have been made.

Systematic use of organic materials in agriculture will lead to reducing the imbalance of biogeochemical carbon cycles and increasing the stability of agrocenoses.

In order to conduct scientifically based optimization of the humus state of soils, it is necessary to control the quality of organic fertilizers, taking into account the characteristics of the organic component, which is an important factor influencing the processes of mineralization and humification of carbon in the soil.

A balanced zonal scientific and methodical approach to the management of organic raw materials in the context of increasing the carbon content in the soil will contribute to preserving the fertility of the soils of Ukraine, rational nature management and protection of environment.

For the preservation of huge budget of organic carbon in hydromorphic soils there should be justified, controlled and regulated agricultural activity with the implementation of sustainable management practices.

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