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RATIONAL USE OF AGRICULTURAL LANDS: MONITORING THE HUMUS BALANCE ACROSS CROP ROTATIONS

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Abstract. *Sustainable land use cannot be achieved without deliberate efforts to preserve and restore soil fertility, with the humus status serving as its key indicator. The challenge of maintaining a stable humus balance has become particularly pressing under the dominance of short-rotation crop sequences in the agricultural practice of the Southern Steppe of Ukraine. The absence of systematic monitoring of soil organic matter complicates the prediction of agroecosystem productivity and threatens the degradation of chernozems, the country's most valuable agricultural resource.*

This study aimed to assess the performance of different short-rotation crop rotations under conditions of complete fertilizer exclusion, to quantify their effects on the humus balance, and to identify the most suitable model for long-term land use. The methodological framework was based on humus balance calculations in a five-field rotation with winter rapeseed and sunflower, conducted during 2020–2024.

The results indicated that technical crops generated a negative humus balance (–0.28 t/ha and –0.77 t/ha, respectively), with the most severe deficit observed after bare fallow (–1.46 t/ha). In contrast, cereals contributed to partial restoration of humus reserves (up to +0.21 t/ha and +0.08 t/ha), while the highest positive effect was obtained from bare fallow (+1.14 t/ha). The overall balance per rotation amounted to –2.22 t/ha in the first sequence and +0.38 t/ha in the second.

These findings highlight the importance of incorporating bare fallow into crop rotations as a natural source of organic matter, essential for sustaining chernozem fertility and ensuring the resilience of agricultural production in the Southern Steppe of Ukraine.

Keywords: *southern chernozems, humus, biomass, balance, short-rotation crop rotation, cover crops.*

Problem Statement

Rational use of agricultural land requires a comprehensive approach to the preservation and reproduction of soil fertility, one of the key indicators of which is the humus status. Under conditions of intensified farming, reduced application of organic fertilizers, disruption of crop rotations, and increased agrochemical load, the risk of soil degradation, particularly humus loss, is significantly increasing [1,2].

The issue of maintaining a sustainable humus balance in short-rotation crop rotations, which currently prevail in farming practice, is especially urgent. The absence of systematic monitoring of organic matter dynamics in agroecosystems limits the possibilities of sound land-use planning and increases the threat of depletion of chernozems – the main resource of productive agriculture [3].

Therefore, there is a need for a scientifically grounded assessment of humus balance within different types of crop rotations in order to develop effective land-use models aimed at the long-term preservation of soil fertility.

Analysis of Recent Research and Publications

Rational use of agricultural land is one of the priority areas of modern land management and agroecological governance. Under conditions of increasing anthropogenic pressure, climate change, and intensive farming, the preservation of soil fertility, particularly its humus status, acquires strategic importance [4].

According to numerous studies, humus serves as the main indicator of soil fertility, influencing the water-physical, chemical, and biological properties of the arable layer. Maintaining a positive humus balance in soils is a necessary condition for sustainable agricultural production, ensuring ecological stability in agro-landscapes, and supporting effective land use [5,6,7].

One of the most effective mechanisms for regulating the humus balance is a rationally organized crop rotation,

which influences humus formation processes through the alternation of crops with different biological productivity, root system types, and capacities for symbiotic nitrogen fixation. Long-term field experiments indicate that the inclusion of legumes, green manure crops, catch crops, as well as the application of organic fertilizers, significantly improves the humus status of soils.

The issue of maintaining humus balance in agroecosystems holds a central place in modern scientific research. Results of long-term experiments demonstrate that the main source of humus replenishment in soils is plant residues and the non-commercial part of the harvest. In the absence of fertilization, row crops (such as sunflower and maize) generally form a negative balance, while cereals and crops with continuous sowing methods have greater potential to maintain a positive humus balance. The use of organic and mineral fertilizers, along with green manure crops, contributes to the enrichment of soils with organic matter and ensures their non-deficit condition [8,9].

Regional monitoring studies (Poltava, Kharkiv, and Kirovohrad regions) reveal significant differences in the formation of humus balance, determined both by crop rotation structure and fertilization levels. It has been established that, in most cases, the absence of fertilizers results in a humus deficit, with the greatest losses associated with the cultivation of industrial crops. Conversely, the inclusion of cereals and occupied fallows in crop rotation structures allows for partial or complete compensation of these losses [10,11,12].

Some scientific publications emphasize that the assessment of humus balance should be considered not only in the production aspect but also as an important component of the ecological and economic justification of sustainable land use. This approach makes it possible to form a system of indicators necessary for long-term land resource management and for preventing soil degradation [13].

As a result of long-term studies conducted by scientific institutions in various soil-climatic conditions of Ukraine, scientific approaches to optimizing crop rotation structure have been developed. In particular, the features of crop placement in rotations have been studied, taking into account their growing duration, biological compatibility, return period to the same field, as well as the requirements of modern intensive technologies.

Under current agricultural production conditions, traditional ten-field rotations, characteristic of collective farms in the past, are gradually being replaced by short-rotation crop rotations of various agro-industrial orientations. In this regard, both scientific and practical interest in studying the transformation of soil organic matter in land-use systems dominated by cereals and industrial crops is growing.

Research Aim. The aim of the study is to provide a comparative assessment of the efficiency of different short-rotation crop rotations on chernozems of the Southern Steppe of Ukraine in terms of humus balance formation under conditions of complete abandonment of fertilization, with subsequent identification of the optimal model for sustainable land use.

Materials and Methods

To evaluate the impact of short-rotation crop rotations on the humus status of chernozems in the Southern Steppe of Ukraine, we used the method of humus balance calculation in crop rota-

tions [14], which is based on the ratio between the input and mineralization of organic matter in the soil. The calculations took into account the mass of the main and by-product yields of agricultural crops, humification coefficients of plant residues, as well as the amount of humus losses caused by mineralization processes.

The object of the study was short-rotation crop rotations developed and recommended for the conditions of the southern region of Ukraine [15]. The subject of the study was a five-field crop rotation including winter rapeseed and sunflower, which was investigated during 2020-2024 under production conditions of the Southern Steppe.

The calculations were carried out according to the following indicators: organic matter input into the soil from root and post-harvest residues; the amount of humus formed as a result of the humification of plant residues; humus losses due to mineralization and erosion processes; and the integral humus balance per crop rotation cycle.

Results and Discussion

In recent years, the issue of soil humus balance has attracted increasing attention from researchers, given its key importance for sustainable land use and fertility preservation [8–12].

Our research, conducted under the conditions of the Southern Steppe of Ukraine (Odesa region), was aimed at assessing the efficiency of short-rotation crop rotations in humus balance formation. The analysis was carried out for two variants of crop rotations that differed in the type of preceding crop for winter wheat (bare fallow vs. occupied fallow). The crop rotation included cereal crops (winter wheat and spring barley) and industrial oilseed crops (winter rapeseed and sunflower).

We evaluated the two short-rotation crop rotations in terms of their ability to accumulate or lose humus. Considering the indicators of humus losses per equivalent area (Fig. 1a, 1b), it should be noted that the highest values were recorded under bare fallow (1.46 t/ha) and the row crop sunflower (1.01 t/ha). This allows us to conclude that the greatest humus losses occurred in the first crop rotation (4.43 t/ha), where the preceding crop for winter wheat was bare fallow. The lowest humus losses were observed in the second crop rotation (3.59 t/ha), where bare fallow was replaced by occupied fallow with white mustard as a green manure crop.

Indicators of biomass input into the soil for humus formation are also of great importance. Analyzing the data on biomass input into the soil (Fig. 2a, 2b), we observe that the total amount of by-products was higher in the second crop rotation (3.97 t/ha), which indicates its better potential capacity to replenish organic matter. The highest amount of by-products was observed after the occupied fallow (1.76 t/ha), confirming its significant role as a stabilizer of the humus balance. Cereal crops provide a considerably larger volume of organic residues (0.88…0.70 t/ha) compared to industrial (oilseed) crops (0.39…0.24 t/ha), which demonstrates their advantage in forming the soil's humus potential.

Calculations of the humus balance in short-rotation crop rotations (Table 1) showed that in both rotations, a humus deficit was observed after industrial (oilseed) crops (–0.28 t/ha and –0.77 t/ha, respectively), which is due to the low level of by-product input into the soil. The largest deficit was recorded in the first rotation after bare fallow (–1.46

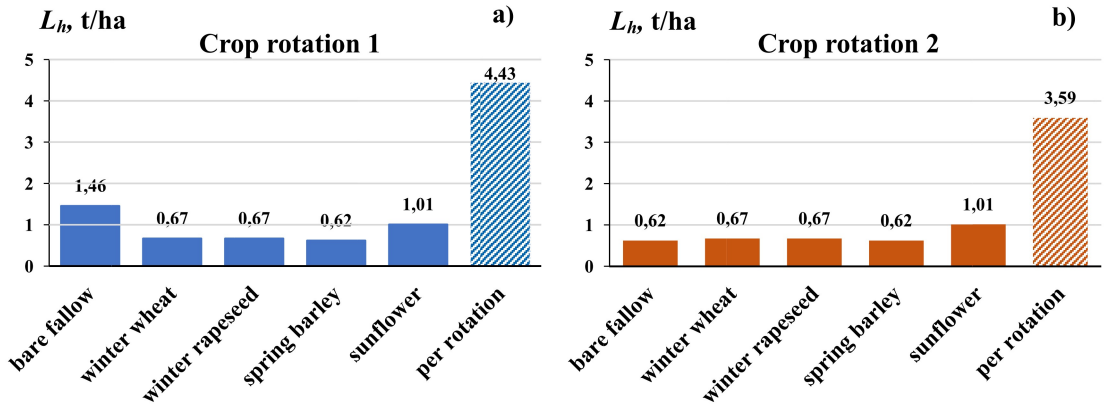

Fig. 1. Dynamics of humus losses in crop rotations. Southern Steppe.

Note: soil type – southern chernozem, heavy loam.

Source: compiled by the authors using the methodology for calculating humus balance in crop rotation [14].

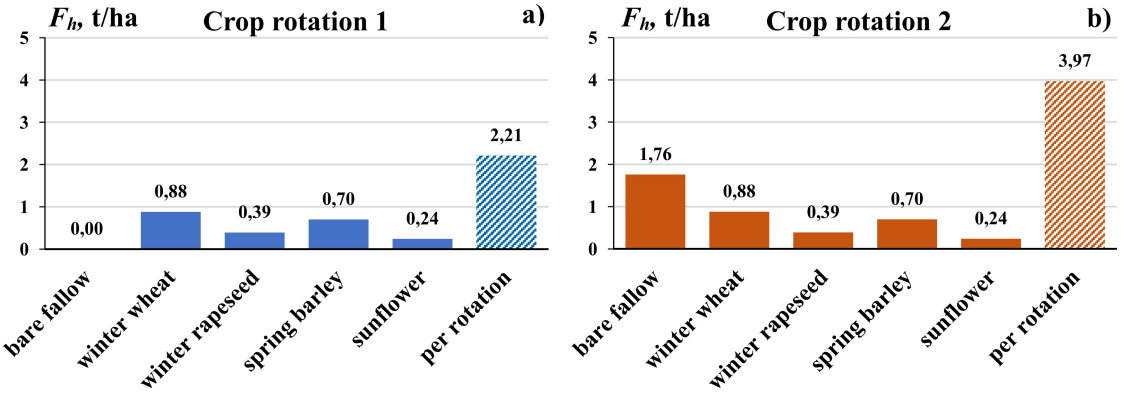

Fig. 1. Dynamics of humus formation in crop rotations. Southern Steppe.

Note: Calculations were made taking into account the yield of agricultural crops in 2020-2024 in the Odessa region.

Source: compiled by the authors using the methodology for calculating humus balance in crop rotation [14].

t/ha), confirming its negative impact on the humus status of the soil.

At the same time, after cereal crops a certain surplus of humus was observed (+0.21 t/ha after winter wheat and +0.08 t/ha after spring barley), which indicates their more favorable role in the humus formation process. Particularly significant is the indicator for the occupied fallow, where the surplus reached its maximum values (+1.14 t/ha), highlighting its effectiveness as a source of replenishing organic matter in the soil.

Summarizing the calculation results for the full rotation, it was established that the first crop rotation is characterized by a considerable humus deficit (–2.22 t/ha), which necessitates the application of organic fertilizers to eliminate soil degradation processes. In contrast, the second rotation showed a slight surplus (+0.38 t/ha), contributing to the stabilization of humus reserves. This indicates the expediency of includ-

Table 1. Balance of humus in short-rotational crop rotations in the Southern Steppe (2020-2024)

№ i/o	Culture	Crop rotation	Loss of humus (L_h), t	Formation of humus (F_h), t	Deficiency of humus (D_h), t
1	Bare fallow	The option 1	1,46	–	-1,46
2	Winter wheat		0,67	0,88	0,21
3	Winter rapeseed		0,67	0,39	- 0,28
4	Spring barley		0,62	0,70	0,08
5	Sunflower		1,01	0,24	-0,77
For the rotation			4,43	2,21	-2,22
1	Occupied fallow	The option 2	0,62	1,76	1,14
2	Winter wheat		0,67	0,88	0,21
3	Winter rapeseed		0,67	0,39	-0,28
4	Spring barley		0,62	0,70	0,08
5	Sunflower		1,01	0,24	-0,77
For the rotation			3,59	3,97	0,38

Note: Humus balance per 1 hectare of crop rotation area in the absence of fertilizer; green manure – white spring mustard.
Source: compiled by the authors using the methodology for calculating humus balance in crop rotation [14].

ing occupied fallow in the crop rotation structure, as it is capable of compensating for organic matter losses and maintaining the ecological balance of the agroecosystem.

Conclusions

The performed calculations of humus balance demonstrated that the cultivation of industrial (oilseed) crops in short-rotation crop rotations is accompanied by a persistent humus deficit (–0.28 to –0.77 t/ha), with the greatest losses recorded after bare fallow (–1.46 t/ha).

Cereal crops, by contrast, contribute to the formation of a certain surplus of humus (+0.08 to +0.21 t/ha), while the greatest positive effect was obtained after occupied fallow (+1.14 t/ha), confirming its expediency in the crop rotation structure.

Over the full rotation, the first crop rotation was characterized by a considerable humus deficit (–2.22 t/ha), indicating a potential threat to the fertility of southern chernozems. In contrast, the second rotation showed a slight surplus (+0.38 t/ha), pointing to its higher ecological and agronomic efficiency.

The obtained results confirm that optimizing the structure of short-rotation crop rotations, particularly by replacing bare fallow with occupied fallow using green manure crops, is an important prerequisite for preserving the humus status and enhancing the sustainability of agroecosystems in the Southern Steppe of Ukraine.

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РАЦІОНАЛЬНЕ ВИКОРИСТАННЯ ЗЕМЕЛЬ СІЛЬСЬКОГОСПОДАРСЬКОГО ПРИЗНАЧЕННЯ: МОНІТОРИНГ ГУМУСОВОГО БАЛАНСУ В МЕЖАХ СІВОЗМІН

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Анотація. *Раціональне землекористування неможливе без цілеспрямованого збереження та відновлення родючості ґрунтів, ключовим індикатором якої виступає рівень гумусового стану. Особливої актуальності набуває питання підтримання стабільного гумусового балансу в умовах поширеного застосування короткоротаційних сівозмін, що переважають у сільськогосподарській практиці Південного Степу України. Відсутність налагодженого моніторингу вмісту органічної речовини у ґрунті ускладнює прогнозування продуктивності агроекосистем та загрожує виснаженням чорноземів – найціннішого ресурсу вітчизняного землеробства.*

Метою дослідження було здійснити порівняльний аналіз ефективності різних короткоротаційних сівозмін за умов повної відмови від внесення добрив, визначити їх вплив на баланс гумусу та виокремити найбільш раціональну модель для довгострокового землекористування. Методичною основою стали розрахунки гумусового балансу у п'ятипільній польовій сівозміні з ріпаком озимим і соняшником, що вивчалася у 2020–2024 рр.

Результати показали, що після технічних (олійних) культур формується від'ємний баланс гумусу (–0,28 т/га і –0,77 т/га відповідно), а найсуттєвіший дефіцит зафіксовано після чистого пару (–1,46 т/га). Водночас зернові культури сприяють частковому відновленню запасів гумусу (до +0,21 т/га і +0,08 т/га), а найбільший позитивний ефект забезпечує зайнятий пар (+1,14 т/га). Сумарний баланс за ротацію становить –2,22 т/га у першій сівозміні та +0,38 т/га у другій.

Таким чином, наші дослідження підтверджують необхідність включення зайнятого пару до структури сівозмін як природного джерела органічної речовини, що дозволяє зберегти родючість чорноземів та забезпечити сталість агровиробництва у Південному Степу України.

Ключові слова: *чорноземи південні, гумус, біомаса, баланс, короткоротаційна сівозміна, сидерати.*