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Qualitative composition of humus and physical and chemical properties of typical chernozem depending on the fertiliser system

Abstract. The soil-forming process is closely related to the accumulation and circulation of organic substances, which are a source of nutrients for plants released during the mineralisation of humus, so research on determining the qualitative composition of humus is relevant. In this regard, the purpose of this paper is to determine humic and fulvic acids in typical chernozem, depending on the fertiliser system. The leading approaches to solving this problem are conducting field and laboratory studies to determine the quality indicators of humus and dispersion methods to establish the

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accuracy and reliability of experimental data. Based on the conducted studies, it was observed that the application of an organo-mineral fertiliser system leads to an increase in the content of humic acids, while the insoluble residue shows an increase in carbon content. The utilisation of organo-mineral fertilisers resulted in a reduction in the excessive accumulation of non-humified organic substances. Additionally, the soils in these areas exhibited a higher level of organic substance humification. The combination of organic matter at a rate of 11.5 tonnes per hectare (8 tonnes of manure and 3.5 tonnes of by-products) and mineral fertilizer $N_{27}P_{38}K_{45}$ in a crop rotation resulted in an increasing trend of the buffering capacity of typical chernozem soil. In this scenario, there was an increase in absorption capacity at the end of the second rotation for grain-legume crop rotation by 6.05 mg/equiv per 100 g, specialised grain-legume rotation by 3.9 mg/equiv per 100 g, and legume rotation by 3.06 mg/equiv per 100 g of soil compared to the beginning of the first rotation. The use of organo-mineral fertilisers increases the third fraction of fulvic acids in specialised grain-legume rotation, which affects the ratio of humic acids to fulvic acids in favour of the humic type of humus formation. The ratio of humic acids to fulvic acids in the grain-planting crop rotation in the organo-mineral system was 2.84 at the end of the second rotation, and 2.24 at the beginning of the first rotation. The research materials are of practical importance for farmers when analysing the fractional-group composition of typical chernozem humus

Keywords: humic acids; fulvic acids; humic content; fractional composition; fertiliser system

INTRODUCTION

The organic matter of the soil is a key factor that reflects the level of potential soil fertility, and is of great importance in controlling biological and physico-chemical processes in the soil, and in providing plants with the necessary nutrients (Lin *et al.*, 2019; Tsyuk *et al.*, 2022). In chernozem soils, organic matter is mainly represented by humus, and its content and reserves depend on the plant cultivation technologies used. Changes in the content and reserves of humus will be determined by the relationship between the processes of humification (formation of humus) and mineralisation (decomposition of organic matter into mineral components) in the context of applied technologies. The amount of organic fertilisers and plant residues that enter the soil has the greatest impact on this relationship (Tsyuk *et al.*, 2018). One of the important factors for promoting humification processes is the application of mineral fertilisers at optimal standards, in particular nitrogen. The optimal ratio of carbon to nitrogen is 25-30:1. Humus mineralisation occurs during the cultivation of agricultural crops, and the intensity of this process depends on the biological characteristics of plants. The main strategies for preserving and restoring organic matter, as well as soil fertility, are the biologisation of fertiliser systems and the use of biological methods (Volkohon *et al.*, 2019; Tanchyk *et al.*, 2021).

Given the versatility of generalisations, the issues related to studies of the influence of fertiliser systems in various crop rotations on the quality of humus and the physical and chemical properties of typical chernozem are quite relevant. The group composition of humus is a consequence of direct processes of transformation of organic mass, which is related to the fertiliser system of agricultural crops (Tkachenko & Hryhora, 2013; Tsvei *et al.*, 2016).

As noted by E.S. Hasanova *et al.* (2010), humic acids exhibit the maximum ability for ion exchange interaction, which is due to their high molecular weight and more complex chemical structure compared to fulvic acids.Therewith, the authors indicate that exclusively mineral fertilisation of agricultural crops leads to the intensive destruction of all high-molecular fractions of humic acids.

Humic acids, which are formed during the synthesis of humus in the soil, are considered essential components of the soil according to numerous studies. They have a special nature and characteristics that distinguish them from other soil components (Tsentilo, 2019; Marenych *et al.*, 2020).

Y. Kravchenko *et al.* (2022) concluded that long-term use of organic fertilisers leads to an increase in humic acids in the composition of humus, which leads to a broader HA: FA ratio. Formation of organic compounds mainly of the fulvic acid type under the influence of mineral fertilisers (Lin *et al.*, 2019; Demydenko *et al.*, 2021). This claim is supported in other studies (Hospodarenko *et al.*, 2022).

The author states that introducing solely mineral fertilisers increases the fulvic acid level of the humus. Moreover, the systematic application of organic-mineral and organic fertilisation systems leads to a certain increase in the humification of humus.

Long-term application of manure and mineral fertilisers on chernozem soils provided an increase in the content of humic acids and a decrease in the amount of fulvic acids and non-hydrolysed residue compared to the option without fertilisers (Degtyarev *et al.*, 2020; Degtyarev & Chekar, 2020; Lin *et al.*, 2021).

The purpose of the study is to investigate changes in the quality indicators of humus in typical deep chernozem depending on the fertiliser system in short-rotation crop rotations.

MATERIALS AND METHODS

The research on qualitative changes in humus was conducted as part of a long-term study at Bila Tserkva National Agrarian University from 2012 to 2021.

The experimental soil area is a typical deep low-humus medium-loamy chernozem with a humus content in the upper soil layer (0-30 cm) in accordance with DSTU 4289:2004 (2005) – Soil quality. Methods for determining organic matter – in the range of 3.7-3.94%. The level of hydrolysed nitrogen is 110 mg/kg of soil according to DSTU 7863:2015 (2016) – Soil quality. Determination of easily hydrolysed nitrogen by the Cornfield method. According to DSTU 4114-2002 (2003) Soils, the content of available phosphorus and exchangeable potassium is 120 mg/kg and 110 mg/kg of soil, respectively. Available phosphorus and potassium compounds were determined using the modified Machigin method. The water-physical properties of the soil of the experimental site are favourable. The density of the treated soil layer varies between 1.16-1.25 g cm^3, and the total crevice is 52-55%. The area of the sown plot is 171 m^2, and the accounting plot is 112 m^2, with repetition 3 times. Agricultural techniques for growing crops are generally accepted for this zone.

The short-rotation crop rotations included the following crops: for the grain-legume rotation, grains accounted for 60% and legume rotation for 40% (soybeans – winter wheat – sunflower – barley – corn for grain); for the specialised grain-legume rotation, grains accounted for 40%, legumes for 40%, and cereals for 20% (buckwheat – winter wheat – corn for grain – sunflower – barley – sunflower); for the legume rotation, grains and grain legumes accounted for 40% and legumes for 60% (peas – winter wheat – sunflower – corn for grain – sunflower).

Gradations of fertiliser systems. Zero level – no fertilisers. Organo-mineral – to restore soil fertility, priority is given to the use of organic fertilisers, such as applying 8 tonnes of manure per hectare of crop rotation area and 3.5 tonnes of biomass from cover crops, non-productive crop residues. Additionally, 110 kg of mineral fertilisers ($N_{27}P_{38}K_{45}$) are applied. The fertilisers applied included semi-rotted manure from large cattle on straw bedding, ammonium nitrate, regular granulated superphosphate, and potassium salt.

In all variants, the remaining wheat straw was crushed after harvesting and driven into the soil with a disc harrow. After harvesting wheat, the soil was prepared for sowing white mustard as a cover crop. In late September and early October, post-harvest mustard crops in all variants were planted in the soil.

Soil samples were collected from a depth of 0-25 cm in three replications. To form a mixed soil sample, 5 individual samples were taken using a grid sampling method. Soil sampling and preparation for analysis were conducted in accordance with the requirements of DSTU 4287:2007 (2005). The analysis of soil samples was performed in accordance with the current regulatory and methodological documents: pretreatment of the sample according to DSTU ISO 11464:2007 (2012); determination of the total carbon content by the Tyurin method according to DSTU 4289:2004 (2005); establishment of the group and fractional composition of humus by the Tyurin method modified by Ponomarev and Plotnikov according to DSTU 7828:2015 (2015).

A notable difference between the variants was determined by the LSD criterion at a 95% probability level by the method of variance and correlation analysis according to B.O. Dospekhov (1985) using the Excel software package.

RESULTS AND DISCUSSION

Over the past twenty years, the application of mineral fertilisers in crop rotations on typical chernozems has notably altered the fractional composition of humus (Polevoy, 2007). The amount of humic acids (fraction 1) decreased by 0.03% in the variant without fertilisers in the grain-legume and specialised grain-legume crop rotations. A similar pattern occurred in the organo-mineral fertiliser system, and a decrease in the content of humic acids was observed (Table 1). The effectiveness of fertilisers influences the activation of humic acids, which are accompanied by the decomposition of high-molecular-weight fractions into low-molecular-weight ones. This can be explained by the fact that organic and mineral fertilizers contain oxidisers that contribute to the breakdown and peptisation of humic acids.

There is also a decrease in the second fraction of humic acids in the presence of both the organic-mineral fertiliser system and the absence of fertilisers. This decrease is influenced by the inclusion of sunflower in the crop rotation as well as the presence of leguminous crops.

A considerable decrease occurred in the grain crop rotation, where the proportion of humic acids of the second fraction decreased by 23.2%, which amounted to -0.86% for the organo-mineral fertilisation system.

Notably, regarding the content of humic acids (fraction 3), which are associated with stable semioxidants and clay minerals, an increase in their content occurs in the grain-legume crop rotation until the beginning of the first rotation, in areas without the application of fertilisers and in the organo-mineral fertilisation system, while in the legume rotation, there was a decrease. In the grain-legume crop rotation, the application of mineral and organic fertilisers resulted in a 30% increase in their quantity (in relative terms), while in the specialised grain-legume rotation, it only stabilised and increased by 11%. In the legume rotation, it increased to 23% (Table 1).

Table 1. The group and fractional composition of typical chernozem humus, %

Soil fertilisation system	$C_{general}$, %	Humic acids, %			HA, %	Fulvic acids, %			FA, %	HA: FA	Insoluble residue
		1	2	3		1	2	3			
Grain-legume crop rotation											
WF	2.51	0.06	0.92	0.22	1.20	0.10	0.15	0.17	0.42	2.85	0.89
	2.49	0.03	0.89	0.31	1.23	0.13	0.09	0.20	0.42	2.92	0.84
OM	2.56	0.09	0.83	0.20	1.12	0.10	0.20	0.21	0.50	2.24	0.94
	2.55	0.04	0.81	0.26	1.11	0.10	0.10	0.19	0.39	2.84	1.05
Specialised grain-legume rotation											
WF	2.42	0.06	0.98	0.19	1.23	0.11	0.34	0.14	0.59	2.08	0.60
	2.20	0.03	0.78	0.24	1.05	0.10	0.18	0.20	0.48	2.18	0.67
OM	2.46	0.09	0.99	0.18	1.25	0.11	0.29	0.20	0.60	2.10	0.61
	2.59	0.03	0.76	0.20	0.99	0.07	0.09	0.25	0.41	2.41	1.19
Legume rotation											
WF	2.41	0.05	1.05	0.13	1.23	0.14	0.44	0.16	0.74	1.66	0.44
	2.41	0.03	0.82	0.26	1.11	0.12	0.22	0.26	0.60	1.85	0.70
OM	2.54	0.05	0.93	0.16	1.14	0.13	0.45	0.20	0.78	1.46	0.62
	2.53	0.03	0.83	0.23	1.09	0.15	0.06	0.22	0.43	2.53	1.01

Note: WF – without fertilisers; OM – organo-mineral fertiliser system; numerator – beginning of the first rotation in 2012; denominator – end of the second rotation in 2021
Source: developed based on the conducted research

Under the influence of crop rotations, the fractions of fulvic acids also change. The amount of fraction 1 fulvic acids, associated with fraction 1 humic acids, decreased by 0.04% during grain-row crop rotation without fertilisers compared to row crop rotation. The use of mineral and organic fertilisers increased the amount of fulvic acids 1 during legume rotation by 0.08-0.12% compared to fraction 1 of humic acids. Fulvic acids of fraction 2, which are bound to fraction 2 of humic acids, decreased in all crop rotations both with the use of fertilisers and without them. The fraction of 3 fulvic acids, which is associated with the fraction of 3 humic acids, not only stabilised, their number increased by 0.03% compared to the beginning of the rotation.

A potential source of humus replenishment is the non-hydrolysed residue, which grew the most in grain-legume crop rotation by 0.11%. At the end of the second rotation, the non-hydrolysed balance increased by 25.0% compared to the beginning of the first rotation. The humus content of typical chernozem in crop rotations increases considerably due to an increase in the amount of non-hydrolysed residue. The ratio of humic acids to fulvic acids in grain-planting crop rotation in the organo-mineral fertiliser system increased by 26.7% during grain-legume crop rotation compared to the beginning of the first rotation. In the specialised grain-legume rotation and the legume rotation, the ratio of humic acids increased by 10.5% and 36.7% respectively compared to the variant without fertilisers, corresponding to the humate type of humus formation in all crop rotations.

The content of humic acids of the second and first fractions decreased, while the third fraction increased. The content of fulvic acids decreased, and the ratio between humic and fulvic acids increased, indicating a humate type of humus formation in the deep typical chernozem soil with low organic matter content.

Studies have shown that under the organo-mineral system, the soil buffering capacity increased in the grain crop rotation from 7.1 to 7.3, in the specialised grain crop rotation from 7.0 to 7.4, and in the legume rotation from 7.1 to 7.2 (Table 2, 3). It is explained by the fact that with the application of $N_{27}P_{38}K_{45}$ and manure, the content of Ca, Mg, and Na in the soil increased, and the effect of nitrogen and potash fertilisers reduced due to the activity of these cations. Increased pH absorption capacity under the influence of fertilisers and crop rotations. Under organo-mineral fertilisation, there was an increase in cation exchange capacity in the grain crop rotation, with a value of 6.05 mg/eq per 100 g in the tillage layer. In the specialised grain crop rotation, the value was 3.9 mg/eq per 100 g, and in the legume, it was 3.06 mg/eq per 100 g of soil compared to the beginning of the first crop rotation. This can be explained by the replenishment of exchangeable cations in the soil-absorbing complex.

Table 2. Changes in the physical and chemical parameters of typical chernozems depending on fertiliser systems in the 0-25 soil layer at the beginning of crop rotation

Soil fertilisation system	Salt pH	S, mg/eq per 100 g of soil	Mg/eq per 100 g of soil	Ca, mg/eq per 100 g of soil
Grain-legume crop rotation				
Without fertilisers	7.0	44.19	1.61	16.70
Organo-mineral	7.1	44.1	1.90	17.7
Specialised grain-legume rotation				
Without fertilisers	7.0	44.56	1.55	16.90
Organo-mineral	7.0	44.30	1.73	17.4
Legume rotation				
Without fertilisers	7.0	43.80	1.55	16.60
Organo-mineral	7.1	45.35	1.75	17.30
LSD_{05}	0.20	2.54	0.45	0.18

Source: developed based on the conducted research

The Ca content in areas without fertilisers decreased most for specialised grain-legume rotation by 1.80 mg/eq per 100 g of soil, legume – by 1.10 mg/eq per 100 g of soil, and for grain-legume crop rotation, slightly increased by 0.45 mg/eq per 100 g of soil.

There was a slight decrease in the content of Mg by the crops in the crop rotation. The amount of exchange Ca for the organo-mineral fertiliser system in grain-legume crop rotation increased by 2.1 mg/eq per 100 g of soil, in specialised grain-legume rotation and legume rotation – 3.28 and 2.51 mg/eq per 100 g of soil (Table 3).

At the end of the second crop rotation, the calcium content increased considerably compared to the beginning of the first grain-legume crop rotation – 8.7%, specialised grain-legume rotation – 9.8%, and in legume rotation by 4.1%, due to the presence of calcium in fertilisers and the rise of carbonates in the upper layers due to the humidification regime.

Several studies (Yashchuk *et al*., 2016; Skrylynyk *et al*., 2019) found that the application of manure twice during crop rotation in the amount of 40 tonnes per hectare contributed to an increase in humus content by 7.2%, and the use of an organo-mineral fertiliser system – by 11.4% compared to the control group. According to the classification of soils by humus content, its level is assessed as high or even very high. The type of humus is defined as humate and the degree of humification is characterised as high. The nitrogen content of humus is estimated as average.

Table 3. Changes in the physical and chemical parameters of typical chernozems depending on fertiliser systems in the 0-25 soil layer at the end of the second crop rotation

Soil fertilisation system	Salt pH	S, mg/eq per 100 g of soil	Mg/eq per 100 g of soil	Ca, mg/eq per 100 g of soil
Grain-legume crop rotation				
Without fertilisers	7.1	48.02	1.53	17.15
Organo-mineral	7.2	50.15	2.30	19.25
Specialised grain-legume rotation				
Without fertilisers	7.2	48.02	1.42	15.82
Organo-mineral	7.1	48.23	2.20	19.10
Legume rotation				
Without fertilisers	7.1	48.28	1.35	15.50
Organo-mineral	7.2	48.41	2.52	18.01
LSD_{05}	0.17	2.61	0.51	0.19

Source: developed based on the conducted research

Humins are the most stable compounds of soil organic matter, which gradually transform into carbon-rich compounds over time. It has been established that the organo-mineral fertiliser system creates favourable conditions for the accumulation of stable and decomposition-resistant organic matter compounds in the soil (Skrylnik *et al.*, 2020).

Under the influence of fertilisation systems and crop rotation, changes occur in the fractional composition of both fulvic and humic acids. The use of fertilisation systems leads to an increase in the third fraction of fulvic acids in grain-legume specialised crop rotation, which affects the HA: FA ratio in favour of the humic type of humus formation.

The transformation of typical deep low-humus chernozem depends on the saturation of row and grain crops in crop rotation and fertiliser systems. The organo-mineral fertiliser system helps to increase the humus content in typical deep chernozem. In all crop rotations, the qualitative composition of humus is transformed towards the redistribution of fractions.

Humus directly or indirectly affects soil fertility and has a considerable impact on the physico-chemical and agrochemical characteristics of typical chernozems, in particular on the overall metabolic acidity, cationic exchange capacity, soil buffering, and nitrogen and phosphorus content. Due to the strong direct correlation between them, an increase in humus content is always perceived as an improvement in these characteristics and overall soil fertility. (Yevtushenko & Tonkha 2017). According to the authors, under the influence of fertilisation, the physico-chemical characteristics of typical chernozem improve. Although the incorporation of straw, cover crops, and mineral fertilizers leads to a slight increase in hydrolytic acidity, it is not considered critical. Intermediate products of straw and cover crop decomposition have an acidic nature, which also contributes to soil acidification. Increasing the input of fresh organic matter into deeper soil layers promotes the intensive accumulation of semi-decomposed products due to limited oxygen availability for further transformations.

Similar research results were published by Degtyarov *et al*. (2018). It was established that under the control option (without fertilisers) and options with the use of mineral fertilisers ($N_{73}P_{81}K_{84}$) and organic fertilisers (12 tonnes of manure), a high degree of humification of organic substances is observed. Under an organo-mineral fertiliser system (single and one and a half), there is a more intensive accumulation of non-calculated organic substances, as a result of which the soils of these sites have an average degree of humification of organic substances.

H. Hospodarenko *et al*. (2018) found that the fraction-group composition of humus in an opdyzolised chernozem soil, after long-term (50 years) application of different fertiliser rates and fertilisation systems in crop rotation, is characterised by a predominance of humic acids over fulvic acids. This leads to an expansion of Ch to Cf ratio, indicating a humic type of soil. The proportion of humic acids bound to calcium (HA 2) is 18.1-25.4% of total carbon and prevails in the humic acid fraction. The fraction of fulvic acids bound to HA2 (FA2) is 6.1-7.4% of the total carbon and prevails in the fraction of fulvic acids. This indicates that the leached chernozem soil, after long-term and systematic fertiliser application, had a high optical density of humic acids, which is characteristic of soils of the chernozem type.

The proportion of fulvic acids, depending on the experiment variant, was in the range of 13.8-17.2% of the total carbon content in the soil. Under the mineral fertilisation system, the quantity of fulvic acids decreased by 23%, under the organic system by 21%, and under the organo-mineral system by 10-20% compared to unfertilised plots. This indicates that organic fertilisers, both alone and in combination with mineral fertilisers, are an important factor in increasing the total humus content in the soil, including humic acid groups (Paterson *et al*., 2016; Baskaran *et al*., 2017).

The use of mineral fertilisers and acid precipitation leads to the oxidation of organic substances in the soil and causes the decalcification of typical chernozem, which has a genetically neutral reaction. Applying 100 kilogrammes of mineral fertilisers per hectare on a leached chernozem soil reduces the pHKCL level by 0.007 and increases the acidity by 0.42 moles per kilogramme of soil (Smishna-Starinska, 2016). Long-term use of mineral fertilisers has a considerable effect on the acidification of the soil solution (Balaev *et al*., 2020).

Without the use of land reclamation agents and fertilisers, the use of chernozem soils leads to a decrease in the degree of soil saturation with bases to 85.7%, a decrease in pH, and an increase in hydrolytic acidity. Total calcium and magnesium losses depend on fertiliser doses and soil granulometric composition (Mazur, 2008).

CONCLUSIONS

The increase in the content of qualitative indicators of typical chernozem humus is most positively affected by the organo-mineral fertiliser system, which causes an increase in the proportion of humic acids. At the same time, the carbon fraction of the insoluble residue increases. Chernozem of the control option (without fertilisers) had a sufficient degree of humification of organic substances. Under the condition of using an organo-mineral fertiliser system, there is a less intensive accumulation of non-humified organic substances, as a result of which the soils of these sites have a high degree of humification of organic substances.

The combination of organic matter at a rate of 11.5 tonnes per hectare (8 tonnes of manure and 3.5 tons of by-products) and mineral fertilisers $N_{27}P_{38}K_{45}$ per hectare resulted in an observed tendency towards an increase in the buffering capacity of the typical chernozem soil type within the crop rotation area.

Crop rotation and the organic-mineral fertilisation system resulted in humus formation of the humic type, with HA:FA ratios of 2.84, 2.41, and 2.53 in the grain-legume, specialised grain-legume, and legume rotations, respectively. Humus of all research variants has a humane-fulvate type. It is characterised by a high content of free humic acids. Humus of the control options without the use of fertilisers has a low content of humic acids, which are bound to calcium, while the option of the organo-mineral fertiliser system has a high content.

Indicators of physical and chemical properties under the influence of fertiliser improve, although the combined application of mineral and organic fertilisers contributed to an increase in the amount of absorbent bases. The calcium content increased at the end of the second rotation compared to the beginning of the first rotation of crop rotations. The amount of calcium increased in the organo-mineral fertiliser system in specialised grain-legume rotation and legume rotation. Magnesium considerably increased with the combined application of mineral and organic fertilisers compared to the non-fertilised version. A promising area for further research is the qualitative changes in humus during repeated crop rotations within a short-rotation system.

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CONFLICT OF INTERESTS

None.

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Якісний склад гумусу та фізико-хімічні властивості чорнозему типового залежно від системи удобрення

Анотація. Ґрунтотворний процес тісно пов'язаний з накопиченням і колообігом органічних речовин, які є джерелом елементів живлення для рослин, що вивільняються в процесі мінералізації гумусу, тому актуальним є дослідження щодо визначення показників якісного складу гумусу. У зв'язку з цим метою даного дослідження є визначення гумінових і фульвокислот в чорноземі типовому залежно від системи удобрення. Провідними підходами до вирішення цієї проблеми є проведення польових і лабораторних досліджень для визначення якісних показників гумусу та дисперсійні методи, для визначення точності та достовірності експериментальних даних. В результаті проведених досліджень, встановлено, що за органо-мінеральної системи удобрення збільшується кількість гумінових кислот, проте зростає кількість вуглецю нерозчинного залишку. Застосування органо-мінерального удобрення, відмічено зменшення інтенсивного накопичення негуміфікованих органічних речовин, ґрунти даних ділянок мають підвищений ступінь гуміфікації органічних речовин. Поєднання органічних в нормі 11,5 т (8 т гною і побічна продукція 3,5 т) і мінеральних $N_{27}P_{38}K_{45}$ на гектар сівозмінної площі спостерігалася тенденція до зростання буферності чорнозему типового, цьому варіанті відбулось зростання ємкості поглинання у кінці другої ротації за зернопросапної сівозміни – на 6,05 мг/екв на 100 г, зернопросапної спеціалізованої – на 3,9 і просапної – на 3,06 мг/екв на 100 г грунту порівняно із початком першої ротації сівозмін. За органо-мінерального удобрення зростає третя фракція фульвокислот у зернопросапній спеціалізованій сівозміні, що впливає на співвідношення ГК:ФК у бік гуманного типу гумусоутворення. Співвідношення гумінових кислот до фульвокислот у зернопросапній сівозміні за органо-мінеральної системи становило 2,84 в кінці другої ротації, на початку першої ротації – 2,24. Матеріали дослідження мають практичне значення для аграріїв при аналізі фракційно-групового складу гумусу чорнозему типового

Ключові слова: гумінові кислоти; фульвокислоти; гумусованість; фракційний склад; система удобрення