



INFLUENCE OF FERTILIZING AND TILLAGE SYSTEMS ON HUMUS CONTENT OF TYPICAL CHERNOZEM

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ABSTRACT. The study aimed to measure the effect of tillage and fertilizing systems in short crop rotation on the content, and composition of humus's substances in soil's type as typical chernozem of the zone Forest-Steppe of Ukraine. The highest humus content was determined in the variant with the application of 11.5 t ha⁻¹ of organic fertilizers + N₂₇P₃₈K₄₅ kg ha⁻¹. The humus content in the 0–10 cm layer against the background of shallow tillage without a moldboard was 4.25%, with moldboard-subsurface tillage – 4.23%. These tillage systems have the most favourable effect on the formation and humus matter (t ha⁻¹). The humus storage in the variant of shallow subsurface tillage was 41.4 t ha⁻¹, i.e. 1.3 t less than in differentiated tillage. The use of soil without fertilizing led to significant humus losses and deterioration of the compound of humus substances due to mineralization processes that prevail over immobilization processes. When applying 11.5 t of organic fertilizers and (N₂₇P₃₈K₄₅) mineral fertilizers per hectare of crop rotation area, the number of humic substances increased significantly and the amount of fulvic acids in the top layer decreased. The ratio of HA (Humic acids) to FA (Fulvic acids) is 2.48. The type of humus formation is humus-fulvatic.

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Introduction

The soil humus content is the main indicator of the potential soil fertility. Therefore, preservation, maintenance and restoration of humus are the main tasks of agriculture. The direction of organic matter transformation processes in the soil characterizes the degree of quantitative changes in humus (Hospodarenko *et al.*, 2018).

Traditional agricultural practices, such as tillage and excessive use of fertilizers, have led to degradation and reduced fertility of Typical Chernozems (Lal, 2008). The negative effect of deep tillage on organic matter is well known (Franzluebbbers, 2010). Intensive tillage usually causes more rapid mineralization of organic matter,

breaking down protective soil macroaggregates and increasing aeration, which provides more nitrogen (N) for the growing crop, and can also degrade soil quality. In areas of unstable moisture, a decrease in the organic matter content is the main cause of soil erosion, crust formation and the loss of aggregate stability, which in turn led to the loss of soil functionality for crop production (Blanco-Canqui *et al.*, 2004; Fernández-Ugalde *et al.*, 2010; Saygin *et al.*, 2017; Tsyuk *et al.*, 2022).

Among soil conservation methods, the use of manure and by-products increases the supply of organic matter to agroecosystems, and this is often associated with an increase in soil organic matter (Maillard, Angers, 2014; Lin *et al.*, 2019). Although priming effects may occur, generally more soil organic matter is added than lost



(Liang *et al.*, 2018; Hryhoriv *et al.*, 2022a). The use of organic fertilizers helps to solve problems related to by-products: it provides nutrients to crops, improves soil structure and moisture-holding capacity, and can contribute to mitigating the effects of climate change through carbon sequestration (Adeli, 2008; Diacono, Montemurro, 2012; Hijbeek *et al.*, 2017; Demydenko *et al.*, 2021). Several problems can arise from excessive or incorrect application or timing of organic fertilizers, such as greenhouse gas emissions, ammonia volatilization, phosphorus runoff from manure, heavy metals accumulation, leading to diffuse pollution and environmental problems (Cabrera *et al.*, 2009; Quemada, Gabriel 2016; Kravchenko *et al.*, 2022; Hryhoriv *et al.*, 2022b).

Minimum tillage and fertilizer application have been widely studied, but how agrotechnical measures to preserve fertility interact with the application of organic fertilizers has not been sufficiently studied. Soil structure can affect the degree of soil organic matter accumulation (Litvinova *et al.*, 2023). Chivenge *et al.* (2007) found that organic matter additions were more important for organic carbon accumulation on light soils than tillage. Whereas on heavy clay soils, tillage was more influential than organic matter application.

The use of various crop rotations and manure additions can change system efficiency by changing the degree of application and the type of material entering the soil (Govaerts *et al.*, 2009).

The purpose of the research is to study the influence of fertilizing and tillage systems of chernozem in a crop rotation on the content, reserves and qualitative composition of humus.

Materials and Methods

The experimental work was done on typical deep low-humus soils with medium-loam chernozem type during 2012–2021 in a 5-field crop rotation. The investigations were done in the experimental field of the Bila Tserkva National Agrarian University. This region is located in continental climate. The average annual air temperature during the years of research ranged from 8.5 to 12.3 °C. The average temperature in January in this zone is –7–8 °C, with absolute minimum –20 °C. The sum of active temperatures is over 3000°C. The annual rainfall is 400–550 mm but it is irregular. Most of them become from April to September (Havryliuk, 2022a, b; Ivanova *et al.*, 2022).

Long-term field investigations were done to study the influence of different tillage and fertilizing systems in crop rotation on the humus status of Typical Chernozem. Crop rotation had the following sequence: alfalfa – winter wheat+white mustard, green manure – sugar beets, sunflower – buckwheat - barley+alfalfa. The replication quantity in the experiment was 3, the placement of variants is systematic. Areas for the study of tillage systems are placed in 1 tier. The research was carried out in winter wheat agrocenosis. The sown area of elementary plots is 171.0 m², accounting – 112.0 m².

The first factor (A) was gradations of the main tillage systems

Differentiated (control) – moaldboard soil cultivation in the fields of sugar beets and sunflowers. For winter wheat, one shallow tillage, as well as buckwheat and one chisel tillage for the barley. The moaldboard-subsurface tillage – 1 time of variable-depth plowing for row crops. For winter wheat and buckwheat was done the 2 shallow tillages. And for the barley was done 1 chisel tillage per crop rotation. Shallow tillage means that soil cultivation was done with disc tools to a depth of 10–12 cm for all crop rotation. The main tillage measures were done with the following tools: 3-general purpose bottom (plow “Lemken Opal” 110; chisel deep loosener “AGC – 4.2”; disc harrow named “AG-2.1-20”.

The second factor (B) was gradations of fertilizing systems

Zero level – without fertilizers; organic – application of 8 t and 3.0 t of non-marketable part of the crop per hectare, mass of harvest green manure per hectare of crop rotation area. The rate of organic fertilizers was determined by the need for a positive balance of humus. Organo-mineral – to restore soil fertility, the priority use of organic fertilizers, application of 8 t ha⁻¹ of manure and 3.5 t ha⁻¹ of post-harvest green manure, non-marketable part of the crop, application of 110 kg (N₂₇P₃₈K₄₅) of mineral fertilizers. Mineral – to restore soil fertility, apply 8 tons of manure and 222 kg (N₆₈P₇₂K₈₂) of mineral fertilizers to 1 ha of crop rotation area. The following hybrids and varieties in the study were used: alfalfa – ‘Lidiia’, winter wheat – ‘Svitylo’, sunflower – ‘Kondi NK’, sugar beet – ‘Vapiti’, spring barley – ‘Helios’, buckwheat – ‘Dykul’. The main tillage measures were carried out with the following tools: 3-general purpose bottom (plow “Lemken Opal” 110); chisel deep loosener “AGC-4.2”; disk harrow AG-2.1-20, “Europak” combined unit, cultivator wides 4.2 m.

In all investigation’s variants, the remains of wheat straw were crushed and ploughed into the soil with a disc harrow. After wheat harvesting, the soil was prepared for sowing white mustard on the seed mass. In late September and part of October, post-harvest mustard remains were ploughed into the soil. Annually, after harvesting winter wheat in autumn, the manure was applied with the quantity rate of 40 t ha⁻¹. In October a field experiment was done by the options and repetitions.

Soil measurements and sampling

Soil samples were taken from the depth of 0–30 cm of the soil layer in three replications. To form a mixed soil sample, 5 individual samples were taken using the “envelope” method. The analysis of soil samples was carried out in accordance with the current regulatory and methodological documents: pre-treatment of the sample in accordance with DSTU ISO 11464; humus content was determined by Tyurin’s method, and the fractional-group composition of humus was determined

according to Tyurin's scheme as modified by Ponomaryova and Plotnikova (DSTU ISO 10694-2001; DSTU 4289:2004).

Analysis of humus fractional-group composition allows dividing it (A) into three fractions of humic acids (HA): fraction 1 – directly soluble in 0.1 N NaOH from a separate measurement, free and bound to mobile sesquioxides; fraction 2 – soluble in 0.1 N NaOH after preliminary decalcification of the soil, mainly associated with calcium, and fraction 3 – soluble in 0.02 N NaOH during 6-hour heating in a water bath, associated with clay minerals and immobile forms of sesquioxides; (B) into three fractions of fulvic acids (FA) fraction 1 – soluble in 0.1 N NaOH from non-decalcified soil and bound in the soil to fraction 1 of humic acids; fraction 2 – soluble in 0.1 N NaOH after preliminary decalcification and bound to fraction 2 of humic acids; fraction 3 – soluble in 0.02 N NaOH during 6-hour heating in a water bath and associated with fraction 3 of humic acids and (C) into humin, which is an insoluble soil residue that characterizes the strength of humic substances fixation with a clay fraction or a weak degree of organic substances humification.

Statistical analysis

Our indicators were analyzed statistically according to the analysis of variance (ANOVA) for R.C.B.D, with split plot arrangement using the least significant difference test (LSD) to compare arithmetic means of treatment at a level of probability (5%). The relationship between applied organic fertilizers in crop rotation (X) and the content of humus in the soil (Y) was studied with the method of simple linear regression. The correlation coefficient (r) was used as an indicator of the accordance of the equation to the indicators.

Results and Discussion

Humus content (%) and stocks (t ha⁻¹)

Organic matter in the soil is under the influence of oppositely directed processes, the process of humus synthesis and mineralization processes. This is due to different humus content, as well as anthropogenic load (Marenych *et al.*, 2020; Tsyuk *et al.*, 2021). It was established that during the winter wheat cultivation, in the soil the processes of organic substances mineralization prevail (Tables 1–3). The lowest content of humus in the soil layer of 20–30 cm is observed in the variant without the use of fertilizers (3.06%). This indicates a decrease in soil humus reserves involved in intensive agricultural use. With the application of fertilizers in all variants, a reliable preservation of a higher humus content was observed compared to areas without fertilizers.

The highest content of humus in the 0–10 cm layer was observed in the variant with an organic-mineral fertilizing system, against the background of shallow subsurface tillage – 4.25%, moaldboard-subsurface tillage – 4.23%, which have a positive effect on humus preservation.

The application of moaldboard-subsurface tillage against the background of the organic-mineral fertilizing system, the humus content in the 0–10 cm layer increased by 13.4%, while at the depth of 10–20 cm and in the 20–30 cm layer, on the contrary, it decreased by 8.8% compared to differentiated variant. Humus content in these variants did not change and amounted to 50.3 t ha⁻¹. In the variant of shallow subsurface tillage, the humus content in the 20–30 cm layer decreased by 3.6% compared to the control variant.

Table 1. Content (%) and humus stock (t ha⁻¹) in the 0–10 cm soil layer in the case of winter wheat cultivation

Fertilizing system	Without fertilizers			Organic system			Organo-mineral system			Mineral system		
	1	2	3	1	2	3	1	2	3	1	2	3
Tillage												
Humus % at the beginning of experiment	3.22	3.60	3.64	3.79	3.89	3.90	3.70	4.19	4.20	3.75	3.85	3.86
Humus % after wheat cultivation	3.20	3.58	3.60	3.79	3.90	3.91	3.73	4.23	4.25	3.72	3.83	3.85
Humus stock, t ha ⁻¹	37.7	44.6	45.9	44.7	46.4	47.7	44.0	50.3	51.8	43.8	45.5	46.9

1 – Differentiated tillage; 2 – Moaldboard-subsurface tillage; 3 – Shallow subsurface tillage; LSD₀₅ fertilizing system – 0.06; LSD₀₅ tillage – 0.11.

Table 2. Content (%) and humus stock (t ha⁻¹) in the 10–20 cm soil layer in the case of winter wheat cultivation

Fertilizing system	Without fertilizers			Organic system			Organic-mineral system			Mineral system		
	1	2	3	1	2	3	1	2	3	1	2	3
Tillage												
Humus % at the beginning of experiment	3.66	3.67	3.74	3.76	3.71	3.70	3.92	3.77	3.75	3.72	3.71	3.73
Humus % after wheat cultivation	3.63	3.65	3.69	3.76	3.73	3.70	3.96	3.81	3.78	3.70	3.70	3.73
Humus stock, t ha ⁻¹	44.2	44.1	46.1	45.8	45.1	44.0	48.3	45.3	44.9	45.1	44.7	46.6

1 – Differentiated tillage; 2 – Moaldboard-subsurface tillage; 3 – Shallow subsurface tillage; LSD₀₅ fertilizing system – 0.08; LSD₀₅ tillage – 0.10.

Table 3. Content (%) and humus stock (t ha⁻¹) in the 20–30 cm soil layer in the case of winter wheat cultivation

Fertilizing system	Without fertilizers			Organic system			Organic-mineral system			Mineral system		
	1	2	3	1	2	3	1	2	3	1	2	3
Tillage												
Humus % at the beginning of experiment	3.07	3.07	3.12	3.18	3.11	3.11	3.27	3.27	3.14	3.15	3.10	3.09
Humus % after wheat cultivation	3.06	3.07	3.10	3.18	3.09	3.11	3.26	3.26	3.14	3.11	3.08	3.09
Humus stock, t ha ⁻¹	38.9	39.0	39.4	40.4	39.2	39.5	41.4	41.4	39.9	39.5	39.1	39.2

1 – Differentiated tillage; 2 – Moaldboard-subsurface tillage; 3 – Shallow subsurface tillage; LSD₀₅ fertilizing system – 0.04; LSD₀₅ tillage – 0.15.

Scientific literature shows that only mineral fertilizers can stabilize the content of organic carbon in the soil, and can also prevent a decrease or even an increase in its content (Gonet, Wegner, 1990). In this study, the significant effect of joint application of organic fertilizers with mineral fertilizers was proven. In most experiments, an increase in total organic carbon content was recorded in soils fertilized with manure in combination with nitrogen fertilizers (Mockeviciene *et al.*, 2022). In the presented studies, the effect of fertilization had a greater influence on the accumulation of humus in the soil than the use of it tillage. In a number of works, it was noted that the joint application of manure and mineral fertilizers enhances the process of humus mineralization (Pikuta, Ciotucha, 2022). It is believed that mineral nitrogen has an effect on humus stabilization (Cambardella *et al.*, 2001). Our results are consistent with the common knowledge that soil humus changes slowly in response to various agricultural practices such as mineral fertilizers or manure (Kaiser, Kalbitzb, 2012).

Humus stock in the variant of shallow subsurface tillage is 39.9 t ha⁻¹, which is by 1.5 tons less than the control variant. The biggest difference in the humus content, depending on soil cultivation, is observed with the organic-mineral fertilizing system. Humus content increased in the 0–10 cm layer under moaldboard-sub-surface and shallow subsurface tillage by 13.0–13.4% compared to the control variant. In the layer of 10–20 cm, the differentiated variant had the advantage in terms of humus content.

Increasing mineral fertilizers dose to N₆₈P₇₂K₈₂ against the background of organic fertilizers does not ensure a further increase in humus content in the soil. This is explained by the increase in acidity, the dispersion of humus by fertilizer cations, and changes in the direction of biochemical processes in the soil.

According to Tsvey (2014), the application of a high rate of N₆₈P₇₂K₈₂ fertilizers per crop rotation increases

the mineralization of organic matter in accordance with the average rate of fertilizers. From this dose of fertilizers, 0.12% of the arable layer was lost, and 0.08% of the humus was lost from the subsoil layer.

The use of the mineral fertilizer system led to a decrease in the humus content in the soil by 0.05–0.18% compared to the organic-mineral system. An insignificant average relationship between applied organic fertilizers (X) and humus content in the 0–10 cm soil layer (Y), correlation coefficient ($r = 0.64 \pm 0.24$), regression equation ($Y = -11.55X - 36.61$) was established. Insignificant weak relationship between applied organic fertilizers (X) and humus content in 10–20 cm soil layer (Y), correlation coefficient ($r = 0.16 \pm 0.31$), regression equation ($Y = -4.954X - 10.676$).

Fractional-group composition of humus under the influence of crop rotation and the use of fertilizers humus quality indicators are changed (Tsyuk, 2021). Humic acids form a single trans accumulative system in the soil, in which HA are an accumulative component and are fixed by the mineral part of the soil at the place of their genesis, and FA are partially bound into complexes with HA, and partially migrate to the depth. HA mostly do not migrate, and therefore they can serve as a marker of the process of humus formation in each specific horizon (Dmytruk *et al.*, 2012).

Determination of the group and fractional composition of the humus of the investigated Typical Chernozem proved (Table 4) that humus quality improved due to the increase HA content and the decrease in the FA content due to fraction 2, which is associated with calcium, and fraction 3, which is associated with a clay fraction and stable sesquioxides.

According to studies, proportion of FA in humus composition in the control without fertilizers decreases (Tsvey *et al.*, 2016), while according to the data of other studies (Dehtiarov, 2011), it remains unchanged or increases (Zahorcha, 1990).

Table 4. Group and fractional composition of humus in the 0–30 cm layer of Typical Chernozem

Fertilizing system	Observation period*	General, %	Humic acids (HA) by fractions, %			Σ HA, %	Fulvic acids (FA) by fractions, %			Σ FA, %	HA:FA	Insoluble residue
			1	2	3		1	2	3			
			Without fertilizers	I	2.50		0.06	1.10	0.14			
	II	2.40	0.04	0.86	0.28	1.18	0.13	0.21	0.15	0.49	2.40	0.73
Organic-mineral system	I	2.54	0.06	0.97	0.17	1.20	0.12	0.42	0.22	0.76	1.57	0.58
	II	2.70	0.03	0.86	0.23	1.12	0.15	0.05	0.25	0.45	2.48	1.13

*I – at the beginning of the first rotation; II – at the end of the second rotation.

In the process of humus synthesis, high-molecular HA are formed, which many scientists consider one of the most important components of the soil, which differ significantly in their nature and properties (Polupan, 1997).

HA show the maximum ability for ion exchange interaction, which is due to their high molecular weight and more complex chemical structure compared with FA. The use of a mineral fertilizer system for crop rotation results in the intensive destruction of all high-molecular fractions of HA, but not only HA, but also FA (Hasanova *et al.*, 2010; Balaev *et al.*, 2019).

As noted by Trus (2011), it is emphasized that the application of only mineral fertilizers increases the fulvic character of humus. At the same time, the systematic use of organic-mineral and organic fertilizer systems leads to a certain increase in humus content. Research results show that on Chernozems, long-term application of manure and mineral fertilizers ensured an increase in the content of humic acids and a decrease in the amount of fulvic acids and non-hydrolyzed residue compared to the control variant, without fertilizers (Dehtiarow, 2010).

It is a reserve of nutrients and directly determines the level of soil fertility efficiency (Chenu *et al.*, 2019).

Under the organo-mineral fertilizing system, humus indicators improved significantly. The increase of humic acids occurred in the arable layer at the expense of fraction 3 – by 21.4% compared to the variant without fertilizers. There was a decrease in the amount of fulvic acids compared to the control by 76.0% at the expense of fraction 2, but the proportion of fulvic acids in fraction 3 increased by 66.0% compared to the control at the end of the second crop rotation.

Considering the previous studies, it is possible to state the fact that under long-term anthropogenic load of chernozem, the proportion of fulvic acids typically increases and humic acids decrease in the variant without fertilizers and their application. Under the influence of fertilizer application, both the amount of humic acids and the ratio between humic and fulvic acids changed. To Typical Chernozems the humic-fulvatic type of humus formation is characteristic.

The non-hydrolyzed residue is a potential source of humus and increases the most against the background of the organo-mineral fertilizing system. Therefore, humus content in Typical Chernozem is due to increased amount of unhydrolyzed residue.

Conclusion

Systematic use of organic and mineral fertilizers, and plant by-products in short-rotational crop rotation has a noticeable positive effect on the humus content and fractional-group composition of Typical Chernozem. The humus content increase from combined organic fertilizers (11.5 t ha⁻¹) + mineral fertilizers (N₂₇P₃₈K₄₅ kg ha⁻¹) of the crop rotation area in the 0–10 cm layer against the background of shallow subsurface tillage – 4.25%, moaldboard-subsurface tillage – 4.23%, which have the best effect on preserving humus.

Different cultivation and fertilizing systems influenced the differentiation of humus concentration and stocks. With moaldboard-subsurface tillage, a uniform distribution of humus in the treated layer (0–30 cm) was noted, but with shallow subsurface tillage – an accumulation in the upper 0–10 and 10–20 cm. A more intense decrease in humus stocks was recorded in the 20–30 cm layer compared to upper ones.

The use of the organo-mineral fertilizing system in crop rotation improves the quality of humus in the soil arable layer. The humus formation type is humic-fulvatic. The application of 11.5 t ha⁻¹ of organic fertilizers in the crop rotation area in intensive agricultural crop rotation contributes to increasing the soil humus content (concentration and stocks) and improving humus quality.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Authors contributions

MV, AB – study conception and design, drafting of the manuscript;
IP, YM – performed the literature data analysis and discussion of the results;
MT, OT – analysis and interpretation of data and is the corresponding author;
OP, YS – author of the idea, guided the research;
TK – acquisition of data, drafting of the manuscript;
OH – critical revision and approval of the final manuscript.
All authors read and approved the final manuscript.

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