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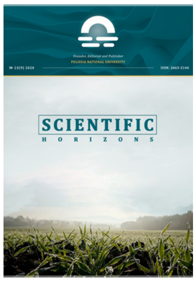

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Effect of Fertiliser on Changes in Labile and Water-Soluble Forms of Humus in Short-Term Rotations

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Abstract. Mobile (labile and water-soluble) forms of humus are one of the basic components of effective soil fertility and a precondition for high productivity of crop rotations. As a result of fermentation, these forms of humus are mineralised and take part in plant nutrition, and some of them, being included in mobilisation processes, transition into stable humus substances. Therefore, it is important to investigate agrotechnological factors for managing their dynamics and redistribution in the soil environment during the growing season of agricultural crops. The purpose of the study: to investigate the effect of complex application of mineral and organic (conventional and alternative) fertilisers on the change of water-soluble and labile forms of humus during the growing season of agricultural crops grown in short-term rotations. The following research methods were used in this study: field, laboratory-analytical, computational-comparative, mathematical-statistical. Higher level of labile accumulation (359.59 mg kg^{-1} of soil) and water-soluble (11.69 mg kg^{-1} of soil) humus forms under winter wheat crops occur when the predecessor of the crop in the crop rotation is meadow clover. The application of $N_{60}P_{90}K_{90}$ specifically for winter wheat and 40 t/ha of manure in the conventional fertilisation system of grain-grass crop rotation contributes to the formation of 529.07 and 20.20 mg kg^{-1} of soil of the organic substances under study. The application of $N_{120}P_{100}K_{100}$ and 40 t/ha of manure for corn for grain yields 567.42 and 22.55 mg kg^{-1} of soil, and $N_{90}P_{90}K_{90}$ and 40 t/ha of manure for potatoes yields 543.66 and 21.75 mg kg^{-1} of mobile compounds humus. The obtained research results can serve as a basis for the development of highly efficient environmentally friendly farming systems and can be used for further scientific research on the development of ways and directions for managing humus-forming processes in the soil environment

Keywords: humus substances, organic-mineral systems, secondary products, green manure, multicultural complexes

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INTRODUCTION

Ensuring food security is a defining priority of the state, which is based on the conditions of stabilisation and rationalisation of the use of land potential, improving the efficiency of the agricultural sector of the economy (Kaminsky & Saiko, 2013; Tanchik, 2009; Oliver & Gregory, 2015).

Achieving an elevated level of agricultural production productivity by introducing agricultural technologies of diverse levels of intensity in modern conditions should be synchronised with strict compliance with the conditions of environment-stabilising functioning of soil systems and regimes, ensuring the possibility of preserving and reproducing soil fertility (Carberry *et al.*, 2013; Gura & Mnkeni, 2019; Neugschwandtner *et al.*, 2014).

A functional indicator for assessing the safety of agricultural systems is indicators of the humus state of the soil cover. The humus complex, being an integrated indicator of soil fertility, represents its energy potential, nutritional capabilities, directly affects agrophysical, agrochemical, and physico-chemical properties, microbiological activity, and erosion resistance (Wozniak, 2019; Raupp, 2001; Rumpel & Kögel-Knabner, 2011). The amount of humus accumulation in the soil depends on the ratio between the mineralisation and humification of organic substances. The primary products of humus-forming processes are mobile (unstable) organic compounds (water-soluble and labile humus), which are chemically unstable and under certain conditions, namely with the activation of enzyme systems and increased oxidative processes, can be mineralised to both intermediate and final decay products, replenish soil reserves with available forms of plant nutrition elements and use them for growth, development, and bio-production. Some mobile organic compounds are involved in further synthesis processes to form stable humus (Haynes, 2005). The amount of water-soluble and labile humus substances varies during the growing season of agricultural crops (Kopecký *et al.*, 2022; Bongiorno *et al.*, 2019).

Fertiliser and crop rotation are essential agrotechnological factors influencing the formation of mobile humus forms (Tian t al., 2017; Kopecký *et al.*, 2021).

Scientifically based crop rotations, which are multicultural complexes of plants, are arranged in time and spatial dimensions in such a way that allows the most effective use of their biological potential of productivity and contribute to the optimisation of humus-forming processes, ensure a deficit-free balance of humus and nutrients and prevent the phenomena of soil fatigue and degradation (Kachmar *et al.*, 2019; Van Eerd *et al.*, 2014). Scientific studies have established that with root and post-harvest residues of agricultural crops grown in rational crop rotations, more organic matter enters the soil environment than with organic fertilisers (N'dayegamiye *et al.*, 2017). Partial accumulation of organic matter in the soil occurs even during the period of active plant development in spring and summer due to root system regeneration, root secretions, and microbiological activity (King & bless, 2017; Campbell *et al.*, 2000; McDaniel *et al.*, 2014).

The integrated use of organic and mineral fertilisers constitutes a prerequisite for maintaining crop rotation productivity, preserving and reproducing soil fertility. Organic-mineral fertiliser systems ensure the supply of organic substances to the soil system from the outside and contribute to increasing the yield of cultivated crops, the secondary products of which can serve as an added source of organic replenishment. However, in modern conditions, the livestock industry does not ensure sufficient amounts of conventional organic fertilisers, and therefore it is crucial to use alternative sources to replenish organic substances in the soil — crop secondary products, green mass of green manure crops (oilseed radish, white mustard, Perko, yellow lupine, winter rapeseed) (Degodyuk *et al.*, 2012; Triberti *et al.*, 2016; Bronick & Lal, 2005).

Studies conducted at the Institute of Agriculture of the Carpathian Region of the National Academy of Agrarian Sciences of Ukraine have established that the complex use of green fertilisers and straw on a low background of mineral fertilisers is equivalent to manure both in terms of impact on crop rotation productivity and soil fertility (Kachma *et al.*, 2020). Thus, the scientific justification of the areas of activating humus-forming processes by rationalising organic-mineral fertiliser systems in scientifically based crop rotations is critical for environmentally safe farming and determines the agronomic strategy for increasing soil productivity and managing their fertility.

The purpose of the study: to investigate the dynamics of mobile forms of humus of grey forest soil under the conditions of experimental modelling of the flow directions of soil-forming processes under various levels of anthropogenic loads in crop rotations. To achieve this purpose, the following tasks were set: 1) to investigate the influence of precursors and fertiliser systems on changes in mobile humus compounds during the growing season of winter wheat in variety crop rotations for different predecessors; 2) to assess the possibility of accumulation of unstable forms of humus under corn in grain crop rotation for conventional and alternative fertiliser systems; 3) to investigate the redistribution of water-soluble and labile humus for the main phases of potato development in vegetable rotation at various levels of anthropogenic loads.

MATERIALS AND METHODS

The study was conducted during 2018-2020 in the experimental training ground of the Institute of Agriculture of the Carpathian Region, which is located in the village of Stavchane of the Lviv District of the Lviv Oblast. The study was carried out under the conditions of a two-factor stationary experiment, which has the long-term status and is entered in the Register of Stationary Experiments of Ukraine (certificate number — 053). The experiment was laid in 2001 on grey forest surface-ogled soil. The number of factors studied is 2 (First-order plots — short-term rotation systems, second — fertiliser systems).

The experiment investigates 9 field variable crop rotations (3-4-5-field) with saturation of grain crops from 50 % to 100 %, on the use of conventional (combination of mineral fertilisers and manure) and alternative (layout of mineral fertilisers, straw, crop green manure) organic-mineral fertiliser systems and without fertiliser application (control). Experimental data covered in this paper are obtained from six crop rotations of the experiment: 1) peas – winter wheat – winter wheat – oats (four-field grain rotation); 2) peas – winter wheat – corn (grain) – oats (four-field grain rotation); 3) meadow clover – winter wheat – winter wheat – spring barley + meadow clover (four-field grain-grass rotation); 4) meadow clover – winter wheat – potatoes – spring barley + meadow clover (four-field vegetable rotation); 5) buckwheat – winter wheat – potatoes – spring barley (four-field grain-row crop rotation); 6) corn (green mass) – winter wheat – buckwheat – soy – winter wheat (five-field grain-row crop rotation). In the conventional fertiliser system, mineral fertilisers were applied against the background of manure (40 tonnes once per rotation for row crops, and in 1st and 3rd crop rotations – for winter wheat in repeated crops) in the following dosage: winter wheat – $N_{60}R_{90}K_{90}$, spring barley – $N_{60}R_{60}K_{60}$, oats – $N_{40}R_{40}K_{40}$, buckwheat – $N_{60}R_{60}K_{60}$, peas – $N_{45}R_{45}K_{45}$, soybeans – $N_{45}R_{45}K_{45}$, potatoes – $N_{90}R_{90}K_{90}$, corn – $N_{120}R_{100}K_{100}$. In an alternative system, at half doses of mineral fertilisers against the background of ploughing all secondary products of cultivated crops, oilseed radish was sown once per rotation on green manure in post-harvest crops (for the same crops where manure was applied in the conventional system, while full doses of mineral nutrition were applied). The repetition of the options is threefold, the arrangement is consistent. The total area of the plot by crop rotation factor was 864 m^2 (72 mx12 m), by fertiliser: total – 96 m^2 (12 mx8 m), accounting – 60 m^2 (10 mx6 m). The crops were entered into the rotation simultaneously in all fields.

The influence of fertiliser systems on the change of labile and water-soluble forms of humus were investigated under winter wheat of the Poliska 90 variety, corn on grain of the Zakarpatska Zubovydna variety, and potatoes of the Oksamyt variety.

The soil of the experimental plots is grey forest surface-gleyed coarsely dusty light loamy with the following agrochemical properties (before laying the experiment): humus content 1.67-1.71%, the sum of the absorbed bases 4.4-5.0 mg-eq kg^{-1} soil, alkaline hydrolysis nitrogen 9.2-9.9, mobile phosphorus and exchangeable potassium 10.8-11.13 and 9.3-9.5 mg $kg^{-1}$of soil, respectively. The reaction of the soil pH_{KCl} solution is 4.70-4.84, hydrolytic acidity is 2.26 mg-eq kg^{-1} of soil.

Soil samples of experimental variants and their preparation for laboratory and analytical work were taken according to DSTU 4287:2004 (2005) and DSTU ISO 11464-2001 (2002). Labile humus was determined in the obtained soil samples according to DSTU 4732:2007 (2007b), water-soluble humus – according to DSTU 4731:2007 (2007a).

The values of these indicators were determined from the arable layer (0-30 cm) for three years (2018-2020) in 3 repetitions and in 2 analytical parallels (in general, n=18).

Statistical analysis of results, namely the analysis of variance *ANOVA* (under conditions of significance level α=0.05) was performed using Excel 11.0.6560.0.

The study employed general scientific and special research methods. Using a field experiment, data on the variability of labile and water-soluble forms of humus under the influence of agrotechnological factors were obtained; laboratory and analytical methods provided quantitative characteristics of the redistribution of mobile humus substances in the soil environment; computational and comparative methods justified the magnitude of changes in the indicators under study; mathematical and statistical reliability of experimental material and mathematical calculations was evaluated.

RESULTS AND DISCUSSION

The study of the redistribution of mobile organic substances in the soil under winter wheat was carried out in five short-term rotations with different crop precursors and conventional and alternative fertiliser systems.

It was found that the accumulation of labile forms of humus was considerably influenced by precursors. Parallel studies of the authors conducted under a spring grain crop – barley, also confirmed differences in the accumulation of unstable humus compounds in the soil after winter wheat and potatoes (Kachmar *et al.*, 2020). The influence of precursors (corn, barley, oats) on potato yield has been proven by Canadian scientists (N'Dayegamiye *et al.*, 2017). Similar patterns have been observed by other authors (Gura & Mnkeni, 2019; Van Eerd *et al.*, 2014; McDaniel *et al.*, 2014).

Analysis of soil samples on variants without fertiliser (control) showed an elevated level of values of labile organic compounds after meadow clover in vegetable rotation and after peas in grain rotation. At the time of sprouting of winter wheat in terms of crop rotations, they were 359.59 mg kg^{-1} and 341.88 mg kg^{-1} of soil. Its predecessors – winter wheat (grain-grass crop rotation) and buckwheat (grain-row crop rotation) – provided the formation of 330.54 mg kg^{-1} and 312.54 mg kg^{-1} of soil of labile forms of humus. Their lowest values were formed after corn to grain and amounted to 290.40 mg kg^{-1} of soil. This influence of precursors can be explained by their biological characteristics, namely the amount of organic residues left in the soil, the ability to accumulate symbiotic nitrogen in legumes. The duration of the period between harvesting the predecessor and sowing winter wheat is also important. Studies by Kachmar *et al.* (2020) found that the larger it is, the deeper is the magnitude of the mineralisation processes of organic substances that have entered the soil environment and the immobilisation of the formed compounds into labile forms of humus (Table 1).

***Table 1**. Influence of fertiliser systems and precursors in crop rotations on changes in labile humus content during the growing season of winter wheat (m±m; 2018-2020)*

No. and type of crop rotation	Fertilisation of winter wheat	From labile humus, mg kg^{-1} of soil		
		Phases of plant development		
		Sprouts	Earing	Complete ripeness
Predecessor – meadow clover				
4-field vegetable	Control	359.59±1.62	318.17±1.65	326.37±2.07
	$N_{60}P_{90}K_{90}$	478.64±3.18^{a}	435.59±1.74^{a}	449.76±2.15^{a}
	$N_{30}P_{45}K_{45}$	439.92±1.38^{a,b}	405.82±2.41^{a,b}	416.04±2.76^{a,b}
Predecessor – peas				
1 grain	Control	341.88±1.70	295.20±3.51	307.00±2.02
	$N_{60}P_{90}K_{90}$	459.17±1.79^{a}	418.94±1.87^{a}	432.55±2.55^{a}
	$N_{30}P_{45}K_{45}$+ s.p.	417.88±2.21^{a,b}	377.69±1.59^{a,b}	385.26±2.93^{a,b}
Predecessor – buckwheat				
5 row-crop grain	Control	312.26±1.84	269.96±2.44	276.44±2.99
	$N_{60}P_{90}K_{90}$	438.32±1.74^{a}	394.66±2.40^{a}	405.96±2.92^{a}
	$N_{30}P_{45}K_{45}$ + s.p.	393.46±1.40^{a,b}	337.24±2.66^{a,b}	347.11±1.89^{a,b}
Predecessor – winter wheat				
3 grain-grass	Control	330.54±1.84	287.61±1.68	293.59±2.27
	Manure, 40 t/ha + $N_{60}R_{90}K_{90}$	529.07±2.02^{a}	492.23±1.37^{a}	509.92±2.04^{a}
	Green manure + $N_{60}R_{90}K_{90}$ + s.p.	486.21±1.42^{a,b}	449.90±1.93^{a,b}	465.26±2.37^{a,b}
Predecessor – corn				
6 row-crop grain	Control	290.40±1.40	247.17±2.34	251.32±2.48
	$N_{60}P_{90}K_{90}$	467.16±1.76^{a}	429.40±1.33^{a}	442.62±1.62^{a}
	$N_{30}P_{45}K_{45}$	369.63±1.45^{a,b}	328.49±1.68^{a,b}	337.56±2.25^{a,b}
The level of significance of differences between the average values of indicators of the variants under study according to ANOVA data: P<0.001				

***Note**: s.p. – secondary products; indices a, b – the level of significance of the difference for each control, and the subsequent fertiliser system*

The use of organic-mineral fertiliser systems in crop rotations had a considerable impact on the formation of labile forms of humus.

Complex application directly for winter wheat $N_{60}R_{90}K_{90}$ and 40 t/ha of manure in the conventional fertiliser system of grain-grass crop rotation contributed to the formation of 529.07 mg kg^{-1} of soil of the organic substances under study. For the introduction of the same level of mineral nutrition of plants under the culture, and the organic component – under the predecessors, higher values of labile humus compounds (478.64 mg kg^{-1} of soil) were formed in a vegetable rotation after meadow clover. The data obtained are consistent with studies performed at the National Centre "Institute of Agriculture of the National Academy of Sciences", according to which the introduction of an organic-mineral fertiliser system in a ten-field crop rotation provided the highest values of labile humus of grey forest soil in winter rye crops (Raupp, 2001). The positive effect of organic-mineral and organic fertilisers on the redistribution of labile humus forms in the soil was noted in previous studies by O. Kachmar *et al.* (2019), as well as a number of other scientists (Raupp, 2001; Bongiorno *et al.*, 2019; Bronick & Lal, 2005).

Joint combination of green mass of oilseed radish grown in post-harvest crops against the background of compressed straw of winter wheat with the introduction of $N_{60}R_{90}K_{90}$ in an alternative fertiliser system, grain-grass crop rotation contributed to the formation of 486.21 mg kg^{-1} of soil of labile forms of humus. The combination of half doses of mineral fertilisers and post-harvest products (straw) of peas in the grain crop rotation and buckwheat in the grain-row crop rotation provided the values of the indicators under study at the level of 417.88 and 393.46 mg kg^{-1} of soil. The lowest values of labile forms of humus were formed under winter wheat crops in grain-row crop rotation after corn to grain under an alternative fertiliser system upon applying half doses of mineral fertilisers and amounted to 369.63 mg kg^{-1} of soil.

Analysis of the dynamics of labile forms of humus during the growing season of winter wheat showed a decrease in their values during crop earing in all crop rotations, both on non-fertilised variants and for both organic-mineral fertiliser systems under study. This is explained by the activation of mineralisation processes due to the intake of sufficient heat into the soil during this period of winter wheat development and the increased consumption of released nutrients by plants for crop formation. The authors' research found that in fertilised areas the amount of labile humus compounds decreased by 9.0-7.8% in fruit crop rotation, by 8.8-9.6% in grain, by 9.9-14.3% in grain-row rotation with buckwheat crop as the predecessor, by 7.0-7.5% in grain-grass rotation, by 8.1-11.1% in grain-row rotation with corn as the predecessor.

By the end of the winter wheat growing season, an increase in the amount of labile humus was observed in all variants under study. Evidently, this is due to a decrease in the needs of the crop for nutrients, a shift in the chemical equilibria of "synthesis – decomposition" of mobile humus substances towards their immobilisation, and the involvement of organic matter that has entered the soil environment with organic litter in mineralisation processes. In the phase of full ripeness of the crop, the highest amount of labile humus substances was on fertilised versions of grain-grass crop rotation and amounted to 465.26-509.92 mg kg^{-1} of soil. The lowest level of accumulation of labile humus on organic-mineral backgrounds was observed in grain-row crop rotations. In the conditions of the conventional system with direct application of $N_{60}R_{90}K_{90}$ under the culture after buckwheat as the predecessor, their amount was 405.96 mg kg^{-1} of soil, according to an alternative system using $N_{30}R_{45}K_{45}$ after corn – 337.56 mg kg^{-1} of soil.

Studies of changes in water-soluble forms of humus under winter wheat showed that their number depended on fertiliser systems, the precursor of the crop in rotation and the phase of its vegetation (Table 2). It was found that in the control variants, higher values of this indicator were observed after meadow clover in a vegetable rotation. At the time of sprouting of the crop, they were at the level of 11.69, in the earing phase – at 10.24, at full ripeness – at 10.65 mg kg^{-1} of soil. Analysis of the influence of fertiliser systems on humus-forming processes reveals the advantages of direct application of a complex of organic and mineral components for winter wheat. Thus, the combined use of 40 t/ha of manure and $N_{60}R_{90}K_{90}$ in the grain-grass crop rotation, the accumulation of 20.20 mg kg in the sprouting phase of the crop provided 20.20 mg kg^{-1} of soil of water-soluble humus compounds. Complex application of green mass of post-harvest oilseed radish, winter wheat straw and $N_{60}R_{90}K_{90}$ in the same crop rotation, contributed to the formation of their number at the level of 18.40 mg kg^{-1} of soil.

***Table 2**. Dynamics of water-soluble humus during the growing season of winter wheat depending on fertiliser systems and precursors (m±m; 2018-2020)*

No. and type of crop rotation	Fertilisation of winter wheat	From water-soluble humus, mg kg^{-1} of soil		
		Phases of plant development		
		Sprouts	Earing	Complete ripeness
Predecessor – meadow clover				
4 vegetable	Control	11.69±0.20	10.24±0.28	10.65±0.25
	$N_{60}P_{90}K_{90}$	18.97±0.23^{a}	16.74±0.26^{a}	17.00±0.23^{a}
	$N_{30}P_{45}K_{45}$	14.93±0.24^{a,b}	12.90±0.24^{a,b}	13.24±0.23^{a,b}
Predecessor – peas				
1 grain	Control	11.53±0.20	10.23±0.26	10.36±0.28
	$N_{60}P_{90}K_{90}$	18.47±0.35^{a}	16.33±0.39^{a}	16.63±0.34^{a}
	$N_{30}P_{45}K_{45}$+s.p.	14.76±0.26^{a,b}	12.68±0.28^{a,b}	12.88±0.25^{a,b}
Predecessor – buckwheat				
5 row-crop grain	Control	11.20±0.26	9.99±0.22	10.14±0.23
	$N_{60}P_{90}K_{90}$	18.06±0.28^{a}	15.36±0.37^{a}	15.58±0.39^{a}
	$N_{30}P_{45}K_{45}$ + s.p.	14.59±0.24^{a,b}	12.49±0.23^{a,b}	12.73±0.34^{a,b}
Predecessor – winter wheat				
3 grain-grass	Control	11.44±0.23	9.76±0.32	9.92±0.35
	Manure, 40 t/ha + $N_{60}R_{90}K_{90}$	20.20±0.48^{a}	17.83±0.49^{a}	18.23±0.47^{a}
	Green manure + $N_{60}R_{90}K_{90}$ + s.p.	18.40±1.07^{a,b}	15.65±0.84^{a,b}	15.86±0.81^{a,b}
Predecessor – corn on green mass				
6 row-crop grain	Control	11.15±0.24	9.93±0.29	10.09±0.26
	$N_{60}P_{90}K_{90}$	16.81±0.27^{a}	15.22±0.28^{a}	15.51±0.28^{a}
	$N_{30}P_{45}K_{45}$	14.43±0.22^{a,b}	12.18±0.20^{a,b}	12.41±0.20^{a,b}
The level of significance of differences between the average values of indicators of the variants under study according to *ANOVA* data: P<0.001				

***Note**: s.p. – secondary products; indices a, b – the level of significance of the difference for each control, and the subsequent fertiliser system*

Observations of the dynamics of water-soluble humus substances during the growing season of the crop showed that in all crop rotations, their highest values were at the time of sprouting of winter wheat, decreased to the earing phase due to the active consumption of decomposition products by plants and increased to full ripeness due to the predominance of immobilisation processes over mineralisation.

The study of changes in mobile forms of humus under corn (row-crop) was carried out in one (grain) crop rotation. Its predecessor was winter wheat. Variants without fertilisation and with a complex application of 40 t/ha of manure and $N_{120}R_{100}K_{100}$ in the traditional fertiliser system were studied and the same level of mineral nutrition of plants against the background of secondary products (straw) of winter wheat and green mass of oilseed radish in an alternative system.

It was found that at the time of corn germination on the control variants, the content of labile humus was 319.63 mg kg^{-1}, water-soluble – 11.42 mg kg^{-1} of soil. Organic-mineral fertiliser systems provided a considerable increase in these indicators. On alternative fertiliser options, labile humus values were 475.44 mg kg^{-1}, water-soluble – 20.30 mg kg^{-1} in the conventional case, their values were higher and amounted to 567.42 and 22.55 mg kg^{-1} of soil. In the subsequent phases of the growing season of the crop, the content of the organic compounds under study in the soil environment decreased and acquired the lowest values at full ripeness of corn. In comparison with the germination phase, this decrease in labile and water-soluble humus indicators was 24.0% and 8.5%, respectively, for the control variants, 16.1% and 26.0% for the introduction of 40.0 t/ha of manure and $N_{120}R_{100}K_{100}$ mineral fertilisers, 13.6% and 24.8% for the composition of green mass of oilseed radish, secondary products of winter wheat and $N_{120}R_{100}K_{100}$ mineral fertilisers (Fig. 1, 2).

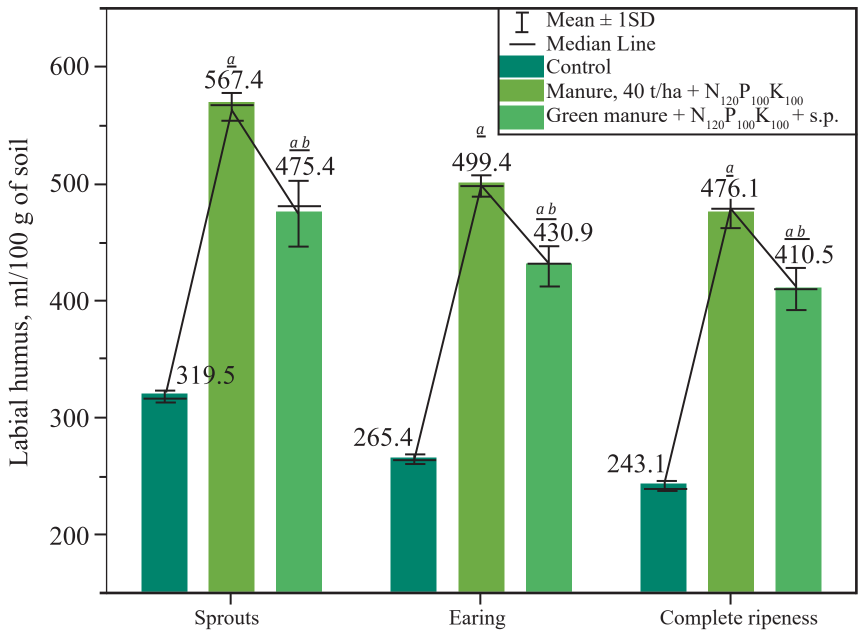

***Figure 1**. Changes in the content of labile humus under various fertiliser systems under corn to grain (m±m; 2018-2020)*
***Note**: s.p. – secondary products; indices a, b – the level of significance of the difference for each control, and the subsequent fertiliser system, respectively, P<0.001*

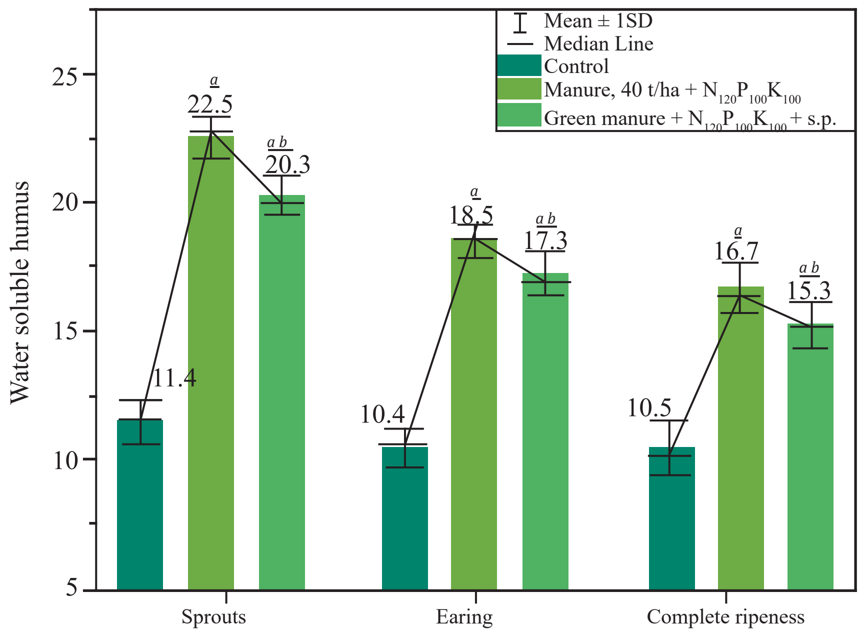

***Figure 2**. Changes in the content of water-soluble humus in various fertiliser systems under corn to grain (m±m; 2018-2020)*
***Note**: s.p. – secondary products; indices a, b – the level of significance of the difference for each control, and the subsequent fertiliser system, respectively, P<0.001*

A comparative analysis of the dynamics of changes in mobile forms of humus under winter wheat and corn showed differences in the redistribution of humus substances in the final phases of vegetation. This can be explained by the difference in the maturation period that occurs in grain crops at the end of July with high microbiological activity of the soil and in mid-September in row crops, when there is a decrease in these processes due to changes in the heat and water regimes of the soil environment.

In the vegetable rotation, changes in unstable forms of humus were observed under the row potato crop, the predecessor of which was also winter wheat. Variants without fertilisation and with complex application in the conventional fertiliser system of 40 t/ha of manure and $N_{90}R_{90}K_{90}$ were studied and the same level of mineral nutrition of plants against the background of secondary products (straw) of winter wheat and green mass of oilseed radish in an alternative system.

It was found that the dynamics of the organic substances under study in terms of fertiliser variants and vegetation phases of the crop was similar to that observed under corn crops (Fig. 3, 4).

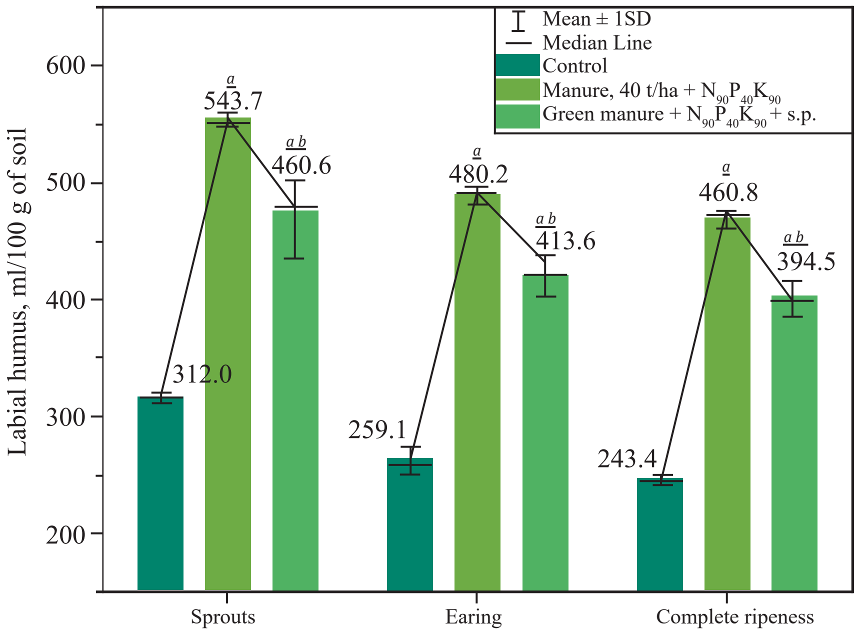

Figure 3*. Changes in labile humus content under various potato fertiliser systems (m±m; 2018-2020)*
Note*: s.p. – secondary products; indices a, b – the level of significance of the difference for each control, and the subsequent fertiliser system, respectively, P<0.001*

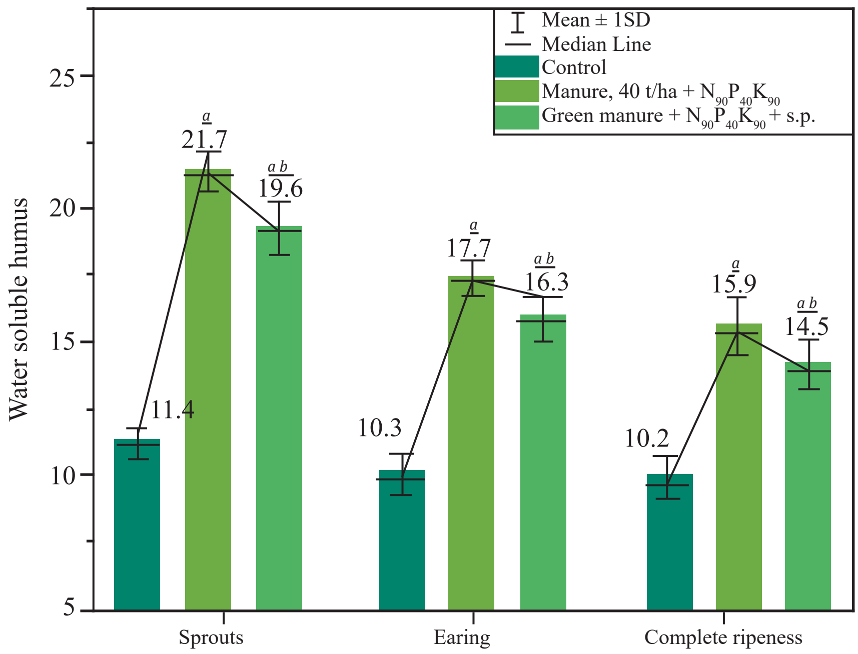

Figure 4*. Changes in the water-soluble humus content in various fertiliser systems under potatoes (m±m; 2018-2020)*
Note*: s.p. – secondary products; indices a, b – the level of significance of the difference for each control, and the subsequent fertiliser system, respectively, P<0.001*

Higher level of labile accumulation (543.66-460.60 mg kg^{-1} of soil) and water-soluble (21.75-19.57 mg kg^{-1} of soil) compounds are observed during the sprouting of the crop on organic-mineral backgrounds. By the end of the growing season, their number decreased and by the time of full ripeness was 460.81-394.48 mg kg^{-1} of soil of labile and 15.88-14.45 mg kg^{-1} of soil of water-soluble humus.

CONCLUSIONS

The formation and redistribution of unstable organic compounds in short-term rotations during the growing season of agricultural crops are considerably influenced by precursors and fertiliser systems.

The highest values of indicators of labile and water-soluble humus of grey forest surface-gleyed soil under winter wheat crops in the germination phase in the control variants were after the predecessors of meadow clover (359.59 mg kg^{-1} of soil of labile and 11.69 mg kg^{-1} of soil of water-soluble humus) and peas (341.88 and 11.53 mg kg^{-1} of soil, respectively), the lowest – after corn per green mass (290.40 and 11.15 mg kg^{-1} of soil).

The use of organic-mineral fertiliser systems provided an increase in the content of mobile forms of humus substances. Direct application under winter wheat $N_{60}R_{90}K_{90}$ and 40 t/ha of manure in the conventional system contributed to the formation of 529.07 mg kg^{-1} of labile compounds and 20.20 mg kg^{-1} of soil of water-soluble humus. The combination of the same level of mineral nutrition, predecessor straw and post-harvest green mass of oilseed radish in an alternative system yielded 486.21 and 18.40 mg kg^{-1} of soil of mobile humus substances. The introduction of the mineral component of fertiliser systems for winter wheat, and the organic component – remotely – for its predecessors, formed lower values of unstable humus compounds for all the crop rotations under study.

Organic-mineral fertiliser systems contributed to the activation of humus-forming processes in row crops. Application of $N_{120}R_{100}K_{100}$ and 40 t/ha of manure under corn for grain provided a 1.8-fold increase in the content of labile and 2.0-fold increase in water-soluble humus compared to the control. Complex application of $N_{90}R_{90}K_{90}$ and 40 t/ha of manure for potatoes contributed to the growth of these indicators by 1.7 and 1.9 times, respectively.

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Вплив удобрення на зміну лабільних і водорозчинних форм гумусу в короткоротаційних сівозмінах

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Анотація. Однією з базових складових ефективної родючості ґрунтів та визначальною умовою забезпечення високої продуктивності сівозмін є рухомі (лабільні і водорозчинні) форми гумусу. В результаті ферментних процесів, вони мінералізуються і приймають участь у живленні рослин, а частина їх, включаючись в мобілізаційні процеси, переходять у стабільні гумусові речовини. Тому важливим є вивчення агротехнологічних факторів управління їх динамікою й перерозподілом в ґрунтовому середовищі впродовж вегетації сільськогосподарських культур. Мета досліджень: вивчити вплив комплексного внесення мінеральних і органічних (традиційних та альтернативних) добрив на зміну водорозчинних і лабільних форм гумусу впродовж вегетації сільськогосподарських культур, вирощуваних у сівозмінах короткої ротації. В дослідженнях були застосовані наступні методи досліджень: польовий, лабораторно-аналітичний, розрахунково-порівняльний, математично-статистичний. Вищий рівень накопичення лабільних (359,59 мг кг$^{-1}$ ґрунту) і водорозчинних (11,69 мг кг$^{-1}$ ґрунту) форм гумусу під посівами пшениці озимої відбувається, коли попередником культури у сівозміні виступає конюшина лучна. Застосування безпосередньо під пшеницю озиму $N_{60}P_{90}K_{90}$ та 40 т/га гною у традиційній системі удобрення зерно-трав'яної сівозміни сприяє утворенню 529,07 і 20,20 мг кг$^{-1}$ ґрунту досліджуваних органічних речовин. Внесення $N_{120}P_{100}K_{100}$ і 40 т/га гною під кукурудзу на зерно забезпечує формування 567,42 і 22,55 мг кг$^{-1}$ ґрунту, а $N_{90}P_{90}K_{90}$ і 40 т/га гною під картоплю 543,66 і 21,75 мг кг$^{-1}$ ґрунту рухомих сполук гумусу. Отримані результати досліджень можуть бути основою для розробки високоефективних екологічно безпечних систем землеробства та використані для подальших наукових досліджень з розробки шляхів та напрямів управління гумусотвірними процесами в ґрунтовому середовищі

Ключові слова: гумусові речовини, органо-мінеральні системи, побічна продукція, сидерат, полікультурні комплекси