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The dependence between the indicators of the fertility of degraded chernozem for different systems of fertilizers in agrocenose of the Central Forest-Steppe

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Goal. Scientific-theoretical justification and development of the comparative base model of physical-chemical state of the soil layer for the conditions of reproduction of fertility of degraded chernozem for long-term use of organic and intensive fertilizer systems using the by-products of crops as organic fertilizer for growing crops in short-time grain-cultivated crop rotation in conditions of the Central Forest-Steppe of Ukraine. **Methods.** Field, laboratory, mathematical, comparative calculation. **Results.** A more close functional link is established between the humus content, relevant, hydrolytic acidity, and sum of accumulated bases in meter thick layer of degraded chernozem at the use of organic fertilizer system in comparison with intensive fertilizer system. The determination coefficient between the humus content and physical-chemical indicators is 56 – 72%. At the use of intensive fertilizer systems, it makes 48 – 55%, which is provided by the strengthening of the processes of regradation in the meter-thick layer of chernozem. It is also manifested in the increase of the boiling line of CaCO3, which is located at the depth of 55 – 60 cm from the soil surface (65 – 70 cm — at intensive fertilizer system). **Conclusions.** High values of the sum of accumulated bases for the top of the typical values may be associated with the presence of carbonates in the lower part of the meter depth layer, which number is growing in the organic fertilizer system: there is a strengthening regradation process. On average over 2016 – 2019, high performance for the yield of grain, forage, feed-protein units and digestible protein in the organic system had the winter wheat: 5.51 t/ha, 7.05, 6.52, and 0.92 t/ha, respectively; or 90 – 92% of the out at use of intensive fertilizer system. The coefficient of variation of grain crop yield in the organic fertilizer system was lower, except for the yield of barley compared with the intensive fertilizer system— 7.95%, against 10.5%.

Key words: *humus, active acidity, hydrolytic acidity, sum of accumulated bases, degradation, crop rotation, yield.*

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One of the most important properties of chernozem in the podzolic Central Forest-Steppe of Ukraine is its fertility, which is formed in the process of soil formation and is characterized by the totality of all its indicators. Optimal conditions for growth and development of agricultural crops in agrocenoses of modern short-rotation crop rotations are provided due to a complex of physical, biological and physicochemical properties of the soil. Fertility of chernozem depends on its physicochemical and agrophysical properties, which are subject to significant anthropogenic impact. Restoration of soil fertility and its preservation should be a priority of modern agriculture, as it is one of the important reserves to increase agricultural production. This becomes possible not only with the integrated implementation of soil protection measures, but also the simultaneous introduction of an organic fertilizer system under organic farming.

An analysis of recent research and publications that have begun to address this issue. Preservation and increase of fertility of chernozems is the main task of modern agriculture. However, now there is a real threat of its loss: decreased reserves of organic matter and nitrogen, decreased microbiological activity, the destruction of the structure and its compaction, due to erosion increases from year to year the loss of fertile layer [1-3]. The reaction of the soil solution significantly affects the development of plants and soil microorganisms, as well as the speed and direction of chemical and biological processes occurring in it. Plant assimilation of nutrients, activity of soil microorganisms, mineralization of organic substances and other physicochemical processes depend on it [4-5].

The basis for the formation of high and stable yields of crops and the manifestation of soil fertility is the creation of favorable physical and chemical conditions. The need for their systematic study is due to changes in soil caused by the level of intensification of agricultural production, as physicochemical conditions must be in a favorable range of values [5-6]. Optimization of chernozem fertility is due to proper crop rotation. In this regard, the question of establishing the optimal parameters of the main physico-chemical and agrochemical indicators of soil fertility is relevant.

When assessing the fertility of podzolic chernozems, the development of its fertility models, it is necessary to take into account the real relationship between soil properties - indicators of physical and chemical condition. Interdependence of physicochemical properties - an objective reality, it must be the subject of study. This is necessary to understand the peculiarities of chernozem cultivation, to deepen ideas about its most important property - fertility [7-8]. Prolonged agricultural use of chernozems leads to the gradual depletion of the plowed layer by cations, and especially calcium, which entails sharp changes in the agrochemical properties of chernozem, especially acid, as well as the degree of saturation of chernozem bases [9].

In the scientific literature [3-4,10-11] you can often find a description of the relationship between the individual properties of chernozems, but there is no comprehensive assessment of the relationship with fertility, which is very relevant for the development of soil fertility, its regulation and optimization when managing the functioning of agrocenoses under different fertilizer systems. Determining the quantitative relationship between soil properties of chernozem will allow to establish regular relationships between soil properties and cultivated plants that occur in the process of anthropogenic impact on the soil [9,12-13]. Establishing the relationship of physicochemical properties with agrophysical properties is valuable not only because they play a leading role in shaping the ecological state of chernozem, but also because they on chernozem soils largely determine the most important property of chernozem – fertility.

Topicality. The importance of physicochemical properties of chernozem for its fertility has never been questioned, and therefore was and remains relevant, and in the conditions of accelerated intensification of agriculture, their importance increases even more. One of the reasons for this is the growing manifestation of the facts of deterioration of the physical and chemical properties of the soil as a result of the application of intensive fertilization and tillage systems. Another reason is the need to maintain physicochemical properties in a favorable range of values. These are necessary conditions for obtaining the planned return from fertilizers and reclamation, the use of which has greatly decreased in recent years. Both of these reasons necessitate systematic research of physicochemical properties of soils in the direction of their optimization, especially in the comparative aspect of intensive and organic fertilizer system.

The purpose of research. To carry out scientific and theoretical substantiation and to develop a comparative basic model of physical and chemical condition of soil stratum for conditions of reproduction of fertility of chernozem podzolic with long-term application of organic and intensive fertilizer system with use of by-products of agricultural crops as organic fertilizers in grain crops for the conditions of the Central Forest-Steppe of Ukraine.

Research methodology. In the course of performance of work the generally accepted methods of researches were applied: field, laboratory, mathematical methods, comparative-calculation.

Materials and methods of research. The research is carried out in a stationary field experiment of the Cherkasy State Agricultural Research Station of the NSC "Institute of Agriculture NAAS", laid in 2010 on an area of 0.75 hectares, the number of fields 5 with a size of 30 m2, the plot contains four repetitions. The experiment studies rotational crop rotation with saturation of cereals, legumes and industrial crops. Soil - chernozem degraded in the carbonate forest. The content of humus in the arable layer is 2.76-3.22% according to Tyurin, the sum of absorbed bases is 24.5-28.1 mg.-eq. per 100 g of soil, hydrolytic acidity 1.99-2.19 mg.-eq. 100 g of soil, pH of salt extract – 6,0-7,1. The degree of saturation of bases is 92.8-93.3%, the content of mobile forms of phosphorus (according to Truog) – 9.0 mg per 100 g of soil, exchangeable potassium (according to Brovkina) - 12 mg per 100 g of soil.

Tillage system in crop rotation: surface tillage with disc implements, shelfless tillage to the depth of plowing and plowing. The experiment examines two fertilizer systems:

1. Intensive fertilizer system (control option) provides the following doses of fertilizers: peas $N_{30}P_{50}K_{50}$; winter wheat - $N_{30}P_{90}K_{90}$ + N_{50} + N_{40}; soybeans - $N_{20}P_{60}K_{60}$ + N_{40}; corn - $N_{20}P_{90}K_{90}$ + N_{100}; spring barley - $N_{20}P_{80}K_{80}$.

2. Organic fertilizer system (without mineral fertilizers: using by-products of the predecessor as organic fertilizer, with treatment of grain with nitrogen-fixing, phosphorus-mobilizing biologicals, growth regulators, humates and humates, plant growth regulator or biological product). To determine changes in agrochemical, physicochemical and agrophysical indicators for the study of nutrient regime, humus conditions, mixed samples were taken from soil layers one meter thick in sections of 10 cm according to experimental schemes according to DSTU 7030: 2009 (GSTU 46.001-96). The content of general humus - according to IV Tyurin in the modification of MV Simakov (DSTU 4289: 2004); pHKCI - potentiometrically (DSTU ISO 10390: 2007); hydrolytic acidity - according to G. Kappen in the modification of CINAO (GOST26212-91); the sum of absorbed bases - by the Kappen-Gilkovytsia method (GOST 27821-88); the degree of saturation of the bases - estimated; mobile phosphorus - photocolometrically. Generalization of materials and calculations of research results were performed according to the "Method of analysis of variance" [14] and the program "STATISTICA" according to non-parametric statistics.

Research results. It was found that with an intensive fertilizer system in crop rotation, the average content of mobile phosphorus in a meter layer of chernozem was 32.9 mg/100 g of soil, and the median content was 21.0 mg/100 g of soil.

The amplitude range ranged from 116 mg/100 g to 5.7 mg/100 g of soil, and the normalized standardized range of 12-48 mg/100 g. deep into the soil profile. At 10% of the security level, the content interval was 11-79 mg/100 g of soil.

1. ***Statistical parameters of agrochemical condition under different systems of fertilization of one-meter thickness of podzolic chernozem in grain-row 5-row crop rotation***

Fertility parameters	Value parameter		Amplitude swing: Δ = max-min		Normalized swing: Δ = L0.75-L0.25		*Std.Dev.	**Coef.Var., %
	mean	median	min	max	$L_{0,25}$	$L_{0,75}$		
Organic fertilizer system								
Mobile phosphorus, mg / 100g	30,4	19,0	8,00	86,0	13,0	44,0	22,5	74,2
pH_{sl}	6,96	7,00	5,81	7,51	6,75	7,20	0,34	4,93
Hr - mg-eq / 100g	1,04	1,00	0,20	2,21	0,70	1,31	0,49	47,3
The sum of absorbed bases, mg-eq per 100 g	57,6	42,0	27,6	99,1	36,0	90,4	26,7	46,3
Humus,%	2,02	2,13	0,69	3,33	1,31	2,65	0,70	34,8
Intensive fertilizer system								
Mobile phosphorus, mg / 100g	32,9	21,0	5,70	116,0	12,0	48,0	26,7	81,2
pH_{sl}	6,80	6,75	5,61	7,45	6,65	7,11	0,38	5,52
Hr - mg-eq / 100g	1,21	1,30	0,50	2,41	0,80	1,32	0,44	35,9
The sum of absorbed bases, mg-eq per 100 g	51,7	40,4	24,0	96,0	32,0	85,2	25,9	50,1
Humus,%	2,00	2,05	0,56	3,53	1,42	2,60	0,70	35,1

Note: * Std.Dev-standard deviation; ** Coef.Var.,% – coefficient of variation,%; L0.75- L0.25 – lower and upper quantiles.

In the organic fertilizer system, the average content of mobile phosphorus was 30.4 mg/100 g, and in the median – 19 mg/100 g of soil. The amplitude range of the contents was narrowed relative to the intensive fertilizer system by 1.34-1.40 times. The typical interval range of phosphorus content was narrowed by 1.2 times, and the median phosphorus content was more likely to reach the minimum typical value, and the decrease in the content of the chernozem profile was more pronounced compared to the intensive fertilizer system.

At 10% level, the content of mobile phosphorus was 10-68 mg/100 g of soil and was 1.2 times narrowed relative to the intensive fertilizer system. The coefficient of variation of the content of mobile phosphorus in the intensive fertilizer system was 1.2 times higher than in the organic fertilizer system, which indicates its lower content at the maximum typical values.

Determination of pHol of the extract showed that for an intensive fertilizer system in a meter thickness pHol = 6.80, and for the median – pHCol = 6.75. The amplitude range was pHsol = 5.61-7.45 (Δ = 0.46), and at 10% the level of pHsol = 6.65-7.25 (Δ = 0.6). In the organic fertilizer system, the average value of pHol = 6.96, and in the median pHol = 7.0, which is higher compared to the intensive fertilizer system by 2.4-3.7%. The amplitude range was narrowed, as a typical interval of pH change in the meter thickness of chernozem. At the 10% level, the pH change interval had higher values compared to the intensive fertilization system (Table 1).

The coefficient of variation of pHol in the organic fertilizer system was lower compared to the intensive system, but did not exceed 10%. The sum of absorbed bases (S) on the average and median value was 51.8-57.6 mg-eq per 100 g of soil, and on the median – 40.4-42.0 mg-eq per 100 g of soil. The amplitude range was 24.0-27.6 ÷ 96.0-99.0 mg-eq per 100 g of soil, and normalized – 32.0-85.0 and 36.0-90.4 mg-eq per 100 g soil. At 10% levels of 28.8-93.3 and 30.0-95.0 mg-eq per 100 g of soil. According to the upper typical value, the amount of absorbed bases in the intensive fertilizer system was 28.8-32.0 mg-eq per 100 g, and in the organic – 30.0-36.0 mg-eq per 100 g of soil, which is a steady trend towards increasing the amount of absorbed bases for the organic fertilizer system.

The high values of the amount of absorbed bases by the upper typical values are due to the presence of carbonates in the lower part of the meter layer, the number of which increases with the organic fertilizer system: there is an intensification of the degradation process. The $CaCO_3$ boiling line is located at a depth of 55-60 cm from the soil surface against 65-70 cm with an intensive fertilizer system.

The average humus content in a meter-thick layer of chernozem, regardless of the fertilizer system, was 2.00-2.02%, and the median of the organic fertilizer system, the humus content increased by 0.08% compared with the intensive fertilizer system.

The typical range of values of humus content was 1.31-2.65% for the organic fertilizer system and 1.42-2.60% for the intensive. At 10% level, the humus content in the organic fertilizer system was at the level of 1.13-2.85%, and in the intensive – 1.05-2.82%, which is evidence of a certain trend towards its accumulation in the organic fertilizer system in short-rotation.

2. Matrix of paired correlations between the main soil parameters in the meter thickness of podzolic chernozem under different fertilizer systems

Parameters	Mobile phosphorus, mg/100g	pH_{sl}	Hr – mg-eq/100g	The sum of absorbed bases, mg-eq per 100 g	Humus, %
Organic fertilizer system					
Mobile phosphorus, mg/100g	1,00	-0,67	0,51	-0,54	0,79
pH_{sl}		1,00	-0,76	0,64	-0,73
Hr – mg-eq/100g			1,00	-0,73	0,72
The sum of absorbed bases, mg-eq per 100 g				1,00	-0,84
Humus, %					1,00
Intensive fertilizer system					
Mobile phosphorus, mg/100g	1,00	-0,53	0,42	-0,46	0,78
pH_{sl}		1,00	-0,89	0,73	-0,69
Hr – mg-eq/100g			1,00	-0,79	0,67
The sum of absorbed bases, mg-eq per 100 g				1,00	-0,76
Humus, %					1,00

The calculation of correlations showed that, regardless of the fertilization system, reliable matrices of pair correlations were obtained. It was found that the correlation between the content of mobile phosphorus and pHol in the organic fertilizer system was at the level of R = -0.67 ± 0.03, and in the intensity of R = -0.53 ± 0.03, and in the humus content the correlation was was at the level of direct strong correlation regardless of the fertilizer system: R = + 0.78-0.79 ± 0.03 (Table 2).

A similar pattern was found between the humus content and hydrolytic acidity (Ng): regardless of the fertilizer system, the bond was at the level of a direct strong correlation: R = 0.67-0.72 ± 0.03.

It was found that the unit of increase or decrease of mobile phosphorus content in the intensive fertilizer system is 0.007 pH units, while in the organic system – 0.01 pH units, and the unit of increase or decrease of phosphorus content – 0.020-0.025% humus. With an organic fertilizer system, this process is more intense, which indicates better humus accumulation. An inverse correlation (R = -0.76-0.85 ± 0.03) is established between the sum of the absorbed bases and the humus content in the meter thickness of chernozem, and 0.26% decrease in the content per unit of growth S, regardless of the fertilizer system. humus. The relationship between the humus content and Hr is direct (R = + 0.67-0.72 ± 0.03), and the unit of humus content growth is 0.5 Hr units for organic and 0.42 Hr units for intensive fertilizer system , which is 1.2 times less (Fig. 1-2). The average yield under the organic fertilizer system for 2016-2019 was: winter wheat – 5.28 t/ha, corn 6.78 t/ha, barley – 3.58 t/ha, which is lower compared to the intensive fertilizer system or 92.7%, 76.8%, 75.8% of the intensive fertilizer system and, in accordance with the grain crops, crop rotation.

3. The relationship between the humus content, mobile phosphorus and physicochemical parameters in the meter thickness of chernozem podzolic strongly degraded by different fertilizer systems

Correlation parameter	Regression equation Y = a ± bx	Coefficient	
		correlation R	determination R^2
Humus content,%			
Organic production			
Mobile phosphorus, mg/100 g	Y= – 20,7+25,5	+0,79	0,62
pHol-metabolic acidity	Y=7,67 – 0,35x	–0,73	0,53

Hydrolytic acidity, mg·eq./100 g of soil	Y=0,03+0,51x	+0,72	0,52
The amount of absorbed bases, mg·eq./100 g	Y=121,3 – 31,9x	-0,85	0,72
Intensive fertilizer system			
Mobile phosphorus, mg/100 g	Y=-26,1+29,6x	0,78	0,61
pHol-metabolic acidity	Y=7,53 – 0,37x	–0,69	0,48
Hydrolytic acidity, mg·eq./100 g of soil	Y=0,38+0,42x	+0,67	0,45
The amount of absorbed bases, mg·eq./100 g	Y=108,2 – 28,3	–0,75	0,56
Mobile phosphorus, mg/100 g			
Organic production			
pHol-metabolic acidity	Y=7,26 – 0,01x	–0,67	0,45
Hydrolytic acidity, mg·eq./100 g of soil	Y=0,71+0,01x	+0,55	0,31
The amount of absorbed bases, mg·eq./100 g	Y=77,2 – 0,64x	–0,56	0,31
Humus content,%	Y=1,27+0,025x	+0,79	0,62
Intensive fertilizer system			
pHol-metabolic acidity	Y=7,04 – 0,07x	–0,55	0,31
Hydrolytic acidity, mg·eq./100 g of soil	Y=0,99+0,07x	+0,45	0,21
The amount of absorbed bases, mg·eq./100 g	Y=66,5 – 0,45x	–0,45	0,21
Humus content,%	Y=1,33+0,02x	+0,78	0,61

On average for 2016-2019, the yield of soybeans and peas was: 2.63 t/ha and 1.88 t/ha, which is less than with an intensive fertilizer system or 95% and 75% of the yield with an intensive fertilizer system. The average yield of grain, feed, feed-protein units and protein in the organic fertilizer system was: 21.6 t/ha, 24.8 t / ha, 25 t/ha and 3.21 t/ha, which was 82.8%, 71.1%, 83.6% and 84.7% of the output of the intensive fertilizer system.

The assessment of the dynamics of grain yields for 2011-2019 under the organic fertilizer system showed that increasing trends were found in winter wheat and barley. Compared with the growth trends of yields of these crops under the intensive system of cultivation for organic regression coefficients with variable X power function for growing barley were 1.5-1.8 times higher, and for growing winter wheat approached each other. When growing corn in the organic system, the trend of yield change was downward, as in the intensive fertilizer system, but in the organic fertilizer system, the downward trend in yield was less downward. The reliability of the equations of trends in changes in the yield of winter wheat and barley was at a high level of values (R^2 = 0.40-0.51), while in the cultivation of corn the significance of the trends was low. In general, grain yields in both organic and intensive cultivation systems were declining, but in the organic fertilization system the trend was 1.9 times lower compared to the intensive fertilization system.

Conclusions

It is established that the functional relationship between the humus content, actual, hydrolytic acidity and the sum of absorbed bases in the meter thickness of chernozem podzolized by the organic fertilizer system is closer in comparison with the intensive fertilizer system: the coefficients of determination between the humus content and physicochemical parameters is 56-72%, while with the intensive fertilizer system - 48-55%, which is provided by strengthening the processes of degradation of one meter of chernozem and is manifested in increasing boiling point $CaCO_3$, which is at a depth of 55-60 cm from the soil surface against 65-70 cm with an intensive fertilizer system.

Statistical evaluation of yield for 2011-2019 showed that the average yield of winter wheat, corn, barley was at the level of 5.16 t/ha, 8.10 t/ha 2.85 t/ha, and grain in general – 5.35 t/ha, which is 78.5-82.7% of the intensive fertilizer system. The amplitude range (max-min = Δ) of the yield under the organic system of cultivation is shifted towards smaller absolute values of the interval and much smaller compared to the intensive fertilizer system.

On average in 2016-2019, the highest productivity in terms of grain, feed, feed-protein units and digestible protein in the organic system was in winter wheat: 5.51 t/ha, 7.05 t/ha, 6.52 t/ha and 0.92 t/ha, respectively, or 90-92% of the yield under the intensive fertilizer system. The coefficient of variation of grain yield under the organic fertilizer system was lower, except for the barley yield, compared to the intensive fertilizer system: 7.95% vs. 10.5%.

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