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Dynamics of fertility of typical deep chernozem depending on system of fertilizing and link of crop rotation

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The purpose. To determine rational alternatives of fertilizer system and rotation of crops of grain-tilling link of 10-field crop rotation for preserving soil fertility, restoring the content of humus and heightening values of agrochemical indexes of soil. **Methods.** Field test, physical and chemical, agrochemical. **Results.** Agrochemical researches were carried out in formation of fertility of typical deep chernozem in links of field crop rotation depending on system of fertilizing. Use during 40 years of organic-mineral systems of fertilizing in grain-beet crop rotation has not ensured restoration of the content of humus in typical chernozem up to the level of layland. At importation of decomposed manure in dose of 8,3 t/hectare + N29.3P45K36.7 the content of humus in arable layer on completion of 4 rotations made 4,59%; 16,7 t/hectare of decomposed manure + N29.3P45K36.7 — 4,72%, and in layland — 5,20%. Application of decomposed manure in dose of 8,3 t/hectare + N29,3P45K36,7 has ensured to the end of 4-th rotation the content of mineral nitrogen in arable layer in the link barley-pease-sugar beet — 19,1 mg/kg of soil; in the link vetch-oats-winter wheat-sugar beet — 16,4 mg / kg of soil. At increase of dose of fertilizers up to 8,3 t / hectare of decomposed manure + N36P85K76.7 — 21 mg / kg of soil. That exceeds initial indexes on 8,1; 5,4 and 10 mg/kg of soil. Resources saving fertilizer system (8,3 t/hectare of decomposed manure + N29,3P45K36,7) formed to the end of 4-th rotation the heightened content of mobile phosphorus in arable layer — 119,3 mg/kg of soil, at increase of dose of fertilizers up to 8,3 t / hectare of decomposed manure + N36P85K76.7 mg/kg of soil — its content reached 200 mg/kg of soil. At importation during 4 rotations of decomposed manure in dose of 8,3 t / hectares + N29.3P45K36.7 the content of mobile potassium in arable layer made 129,2 mg/kg of soil; 8,3 t/hectare of decomposed manure + N36P55K46.7 — 145,1 mg/kg of soil. That exceeded initial indexes accordingly on 18,9; 35 mg/kg of soil. Long use during 40 years of organic-mineral system of fertilizing caused acidification of soil solution. At importation of decomposed manure in dose of 8,3 t/hectares + N36P35K46.7 pHsalt in comparison with layland decreased on 1,0 – 1,2, Ng increased on 2,2 – 2,4 smol/kg of soil, at absolute values — accordingly on 5,2 – 5,3 and 4,0 – 3,6 smol/kg of soil. **Conclusions.** Use of organic-mineral system of fertilizing in dose of 8,3 t/hectare of decomposed manure + N29.3P45K36.7 on typical deep chernozem in the link of field crop rotation promotes optimization of agrochemical nature of soil and preserves its fertility.

Key words: *humus, agrochemical indexes, arable layer, optimization, organic substances.*

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Anthropogenic load on agroecosystem affects the soil as a means of production. As the soil is enriched with compounds of mineral nitrogen, mobile phosphorus, and exchangeable potassium, the conditions of growth and development of plants improve. However, at the same time, the balance of nutrients in crop rotation is not always taken into account. Thus, in particular, the balance of organic matter and the CO_2 cycle in agroecosystems [13] change significantly and depend to a large extent on the fertilization practice [3,4,5,6,8,9]. The studies carried out on typical low-salinity chernozems in short crop rotations showed that losses of humus depend on the saturation of crop rotation with hoed crops and inclusion of bare fallow; however, they can be stabilized by the application of the organo-mineral fertilization system [9]. To illustrate, in degraded chernozem soils, the application of 10 t/ha manure + $N_{62}P_{62}K_{62}$ per 1 hectare of arable land for 32 years decreased humus content by 0.2 %. When applying the increased rates of manure, 15 t/ha in combination with $N_{63}P_{63}K_{63}$ create conditions for the increasing and reproduction of humus availability in the soil, resulting in an increase from 3.03 to 3.10 % [1]. Under the effect of fertilization and the system of crop rotation, the physicochemical characteristics of the soil change as a result of the removal of calcium and magnesium from the soil-absorbing complex [2,3,4,5], which requires liming to optimize the balance of calcium and magnesium. The application of mineral and organic fertilizers and introduction of pulses into crop rotation increases the content of mineral nitrogen compounds and has a positive effect on soil fertility and crop productivity [6,11,12].

A significant factor affecting soil fertility is the content of mobile phosphorus, which depends on the application of optimal rates per crop rotation [3,4,7,9,10].

Under the effect of fertilizers and crop rotatory system, the potassium stock in chernozem soils changes; it tends to increase with the observance of a scientifically substantiated fertilization system [3,4,9,11].

The goal of the study. To determine the rational fertilization system and crop alternation in the grain-hoed 10-course crop rotatory system in order to preserve soil fertility, humus content and agrochemical characteristics.

Research methods. The research was carried out in the years 2009–2012 at the Ivanivska Experimental Breeding Station of IBCISB NAAS (Okhtyrka district, Sumy region) in the north-eastern part of the Left Bank Forest-Steppe of Ukraine in the zone of unstable water provision in the long-term stationary experiment (established in 1964).

The soil of the experimental field was typical low-humus heavy-loamy loess chernozem with the following agrochemical indicators: the content of humus (by Tyurin) 3.5–3.8%, pH_{sal} 5.8–5.6, H_h 1.3–3.4 mg/equivalent per 100 g of soil, S 31–35 mg/equivalent per 100 g of soil, mobile phosphorus and exchange potassium (by Chirikov) 110–160 and 80–120 mg/kg of soil, respectively.

The design of the ten-course crop rotatory system was as following:

- treatments 1, 2, 4, 5, 6, 7, 8, 9 of the crop rotatory system had the following alternation of crops: 1) vetch & oat; 2) winter wheat; 3) sugar beet; 4) barley & perennial grasses; 5) perennial grasses; 6) winter wheat; 7) sugar beet; 8) pea; 9) maize for grain; 10) maize for grain. Perennial grasses comprised 10 %, vetch and oat for 10 %, hoed crops for 40 % (20 % beet sugar and 20 % maize for grain), 40 % of grain crops and pulses (20 % winter wheat, 10 % barley and 10 % pea);
- treatment 3 included: 1) barley; 2) pea; 3) sugar beet; 4) barley; 5) maize for silage; 6) winter wheat; 7) sugar beet; 8) pea; 9) winter wheat; 10) maize for grain. Grain crops and pulses accounted for 60 % (20 % barley, 20 % winter wheat, 20 % peas, 40 % hoed crops (20 % sugar beet, 10 % maize for grain, 10 % maize for silage);
- treatment 10 included: 1) vetch & oat; 2) winter wheat; 3) sugar beet; 4) barley & perennial grasses; 5) perennial grasses; 6) winter wheat; 7) sugar beet; 8) pea; 9) winter wheat; 10) maize for grain. The share of perennial grasses was 10 %, vetch and oat 10 %, hoed crops 30 % (20 % sugar beet, 10 % maize for grain), grain crops and pulses 50 % (30 % winter wheat, 10 % barley, 10 % pea);
- treatment 11: 1) bare fallow; 2) winter wheat; 3) sugar beet; 4) barley & perennial grasses; 5) perennial grasses; 6) winter wheat; 7) sugar beet; 8) pea; 9) winter wheat; 10) sugar beet. Perennial grasses amounted to 10 %, bare fallow 10 %, hoed crops 30 % (30 % sugar beet), grain crops and pulses 50 % (30 % winter wheat, 10% barley, 10 % pea).

In treatment 1, the elements of biological farming were used, namely incorporation of harvest residues into the soil. In treatment 6, chemical crop protection of crops was not used; instead, mechanized soil tillage was used as a means of weed control.

The experiment was designed in three replicates. The sown area was 300 m^2; the accounting area was 200 m^2.

Soil samples for agrochemical analyses were taken at the stage of emergence and at the end of the sugar beet vegetation season. Nitrate and ammonium nitrogen were determined according to the method of TsINAO, alkali hydrolysed nitrogen was determined in the line with Cornfield. Total humus content was determined according to Turin's method. The acidity of soil pH_{sal} was measured with pH-meter (State Standard of Ukraine ISO 10390-2001); hydrolytic acidity was measured according to Kappen; the amount of absorbing alkali was determined according to the Kappen-Gilkovits method. Mobile phosphorus and exchange potassium were determined by the method of Chirikov in accordance with the State Standard of Ukraine 2002.

When evaluating the soil fertility, the source soil samples dated 1962–1963 yrs were taken into account.

Research results. The content of humus in the arable layer of typical chernozem reached 5.63, whereas when applying the starting rate of fertilizer $N_{9.3}P_{11.6}K_{6.7}$ in the crop rotation humus content reached 4.38 and 3.37 % which was inferior to the values obtained in the link with fallow by 1.25 and 1.66 % and is related with the mineralization of organic matter (Table 1).

Application of 8.3 t/ha of manure + $N_{29.3}P_{45}K_{36.7}$ promoted an increase in the humus content compared to the starting rate of fertilizers of 0.21 and 0.25 %. This increase was 4.59 % and 3.62 % respectively.

1. ***The content and stocks of humus in typical deep chernozem as affected by fertilization system and crop rotation (average for 2011-2012)***

No	Link	Fertilization system	Depth (cm)	Mineral N (mg/kg of soil)	Mobile P (mg/kg of soil)
	Fallow 50 yrs	Fallow 50 yrs.	0–30	5.63	221.13
			30–45	5.03	188.63
7	Vetch and oat – winter wheat – sugar beet	$N_{9.3}P_{11.6}K_{6.7}$	0–30	4.38	164.25
			30–45	3.37	126.38
8	Vetch and oat – winter wheat – sugar beet	Manure 8.3 t/ha + $N_{29.3}P_{45}K_{36.7}$	0–30	4.59	172.13
			30–45	3.62	141.18
9	Vetch and oat – winter wheat – sugar beet	Manure 8.3 t/ha + $N_{36}P_{55}K_{46.7}$	0–30	4.59	172.13
			30–45	3.69	138.38
10	Vetch and oat – winter wheat – sugar beet	Manure 16.7 t/ha + $N_{29.3}P_{45}K_{36.7}$	0–30	4.72	177.00
			30–45	3.67	137.63
11	Bare fallow – winter wheat – sugar beet	Manure 8.3 t/ha + $N_{29.3}P_{45}K_{36.7}$	0–30	4.57	171.38
			30–45	3.46	134.94
$LSD_{0.05}$			0–30	0.2	8.9
			30–45	0.2	3.7

Similar results were obtained against the background of 8.3 t/ha of manure + $N_{36}P_{55}K_{46.7}$, where humus content in the corresponding layers reached 4.59 and 3.69 %. As the rate of manure increased in the fertilizer system of crop rotation and the balanced use of fertilizers, an increase in the content of humus was observed. In the version where 16.7 t/ha of manure + $N_{29.3}P_{45}K_{36.7}$ was applied per crop rotation link, the humus content was 4.7 2 and 3.67 %.

In the experiment on typical leached chernozem, application of $N_{50}P_{66}K_{66}$ + harvest residues at the end of the fourth rotation, the humus content stabilized at 3.80 %, while with the application of $N_{50}P_{66}K_{66}$ + 9 t/ha manure it was 3.67 %, against the background of $N_{50}P_{66}K_{66}$ 3.34% and at the beginning of the third rotation 3.80, 3.71, 3.64 %, respectively. Without the use of fertilizers, the content of humus at the beginning of the third rotation was 3.49 %, and at the end 3.15 % [4].

In the link with bare fallow against the background of the organic-mineral fertilization system (treatment 11), the content of humus was maintained at the level of 4.57 and 3.46 %, which was not inferior to the characteristics of the vetch & oat link.

Similar results were obtained in short-term crop rotations against the background of an organic-mineral fertilization system under the conditions of the Veselyi Podil Experimental Breeding Station in the zone of insufficient water availability [9].

Under the influence of the application of fertilizers and crop rotatory system, the physical and chemical parameters of the soil change, soil acidity increases as a result of the removal of calcium and magnesium from the soil-absorbing complex, which causes acceleration of organic matter degradation [2,3].

In the studies carried out at the long-term application of fertilizers, acidification of the soil was observed. Thus, if in the link with fallow, the acidity (pH_{sal}) in the ploughed and under ploughed layer was 6.2 and 6.5, the hydrolytic acidity was 1.2 and 0.9 mg/equivalents per 100 g of soil, and the amount of absorbing alkali was 26.0 and 27.0 mg/equivalent per 100 g of soil (Table 2).

In the treatments, where only the start rates of fertilizers were used, pH_{sal} in the 0–30 cm layer was 5.4, H_h 3.4 mg/equivalent per 100 g of soil. As the fertilization rate increases, the acidity of the soil increases significantly. In the treatments with 8.3 t/ha of manure + $N_{29.3}P_{45}K_{36.7}$ and 8.3 t/ha of manure + $N_{36}P_{55}K_{46.7}$, pH ranged from 5.2 to 5.3, H_h from 3.4 to 3, 6 mg/equivalent per 100 g of soil.

2. The effect of fertilization system on physical and chemical characteristics of typical deep chernozem as affected by fertilization system and crop rotation (average for 2011-2012)

No	Link	Fertilization system	Depth (cm)	Mineral N (mg/kg of soil)	Mobile P (mg/kg of soil)
	Fallow 50 yrs	0–30	6.2	1.2	26.0
		30–45	6.5	0.9	27.0
7	$N_{9.3}P_{11.6}K_{6.7}$	0–30	5.4	3.4	21.6
		30–45	5.3	3.7	18.3
8	Manure 8.3 t/ha + $N_{29.3}P_{45}K_{36.7}$	0–30	5.2	3.6	24.2
		30–45	5.2	3.7	18.0
9	Manure 8.3 t/ha + $N_{36}P_{55}K_{46.7}$	0–30	5.3	3.4	24.3
		30–45	5.4	3.5	17.5
11	Manure 8.3 t/ha + $N_{29.3}P_{45}K_{36.7}$	0–30	5.8	3.0	24.1
		30–45	5.7	3.5	18.0
$LSD_{0.05}$		0–30	0.28	0.3	1.5
		30–45	0.28	0.2	1.0

In the treatment with bare fallow due to the upward movement of Ca and Mg in the upper layer of soil, the pH level was, respectively, 5.8–5.7, however, the level of H_h was 3.0–3.5 mg/equivalent per 100 g of soil, the content of S was 24.1 and 18.0 mg equivalents per 100 g of soil. In general, the introduction of organic fertilizers against the background of mineral fertilization does not contribute to the neutralization of the soil physiological acidity, and the presence of calcium and magnesium does not restore their balance in crop rotation.

The fertility of chernozem soils also is related to the content of mineral nitrogen [4, 6]. Thus, under the long-term anthropogenic load on the soil in those treatments of crop rotation, where only the start application rate of fertilizers was applied, the content of mineral nitrogen in the arable layer was 13.7 mg/kg. Under the application of 8.3 t/ha of manure + $N_{29.3}P_{45}K_{36.7}$, the content of mineral nitrogen in the soil was 16.4 mg/kg, which was higher by 2.7 mg/kg than in the treatment with the start rate of fertilizers. The highest content of mineral nitrogen was noted in the treatment where the application rate of fertilizer in the link of crop rotation was increased to 8.3 t/ha of manure + $N_{76.7}P_{66.7}K_{76.7}$. Accordingly, the content of mineral nitrogen in the soil was 20.0 mg/kg, which was higher than in the above crop rotation by 3.6 mg/kg and by 9.0 mg/kg compared to the initial value.

The practice of bare fallow in the crop rotation system enhances the mineralization processes in the soil, increases the amount of nitrate nitrogen. Thus, against the background of 8.3 t/ha of manure + $N_{29.3}P_{45}K_{36.7}$, the content of mineral nitrogen in the arable layer was 17.1 mg/kg, which was higher by 3.4 mg/kg than in the treatment with the start application rate of fertilizers (Table 3).

Against the background of application of fertilizers, increase in the mineral nitrogen content in the lower layers of the soil due to migration of nitrates was observed, as well as the increase of mineralization processes in the soil.

An important role in the formation of chernozem soil fertility plays phosphate content because it contributes to the increase of nitrification processes in the soil, the uptake of phosphorus by plants, which leads to a significant increase in crop productivity [3,4,7,9].

3. Agrochemical characteristics of typical deep chernozem as affected by fertilization system and crop rotation (average for 2011-2012)

No	Link	Fertilization system	Depth (cm)	Mineral N (mg/kg of soil)	Mobile P (mg/kg of soil)	Exchange K (mg/kg of soil)
	Start characteristics		0–30	11.0	110.1	110.1
			30–45	10.4	90.3	70.4
1	Vetch and oat – winter wheat – sugar beet	Harvest residues + N_{50}	0–30	17.2	113.4	95.2
			30–45	15.0	81.5	64.1
2	Vetch and oat – winter wheat – sugar beet	Manure 8.3 t/ha + $N_{76.7}P_{66.7}K_{76.7}$	0–30	20.0	193.2	119.2
			30–45	19.6	130.1	77.3
3	Barley– pea – sugar beet	Manure 8.3 t/ha + $N_{29.3}P_{45}K_{36.7}$	0–30	19.1	162.1	114.2
			30–45	19.0	94.4	71.4
4	Vetch and oat – winter wheat – sugar beet	Manure 8.3 t/ha + $N_{56}P_{85}K_{76.7}$	0–30	20.1	200.2	168.0
			30–45	16.9	124.0	87.4
5	Vetch and oat – winter wheat – sugar beet	Manure 8.3 t/ha + $N_{36}P_{85}K_{76.7}$	0–30	18.6	182.2	155.2
			30–45	15.2	108.3	77.3
6	Vetch and oat – winter wheat – sugar beet	Manure 8.3 t/ha + $N_{76.7}P_{66.7}K_{76.7}$ (without chemical treatment)	0–30	17.6	190.5	155.4
			30–45	14.5	101.0	82.0
7	Vetch and oat – winter wheat – sugar beet	$N_{9.3}P_{11.6}K_{6.7}$	0–30	13.7	107.4	90.4
			30–45	12.3	71.3	63.2
8	Vetch and oat – winter wheat – sugar beet	Manure 8.3 t/ha + $N_{29.3}P_{45}K_{36.7}$	0–30	16.4	129.2	119.3
			30–45	16,3	87.4	73.4
9	Vetch and oat – winter wheat – sugar beet	Manure 8.3 t/ha + $N_{36}P_{55}K_{46.7}$	0–30	16.3	159.0	145.1
			30–45	17.5	107.2	90.0
10	Vetch and oat – winter wheat – sugar beet	Manure 16.7 t/ha + $N_{29.3}P_{45}K_{36.7}$	0–30	13.5	138.0	117.0
			30–45	13.7	110.1	74.2
11	Vetch and oat – winter wheat – sugar beet	Manure 8.3 t/ha + $N_{29.3}P_{45}K_{36.7}$	0–30	17.1	163.2	137.3
			30–45	17.4	108.0	83.4
$LSD_{0.05}$			0–30	0.8	7.7	6.4
			30–45	0.7	5.1	3.9

For the use of only the starting application rate of fertilizers, the content of mobile phosphorus in soil was 107.4 mg/kg in the arable layer and 71.3 mg/kg of soil in the under ploughed layer. Fertilizers provide for the mobility of phosphorus, especially when it concerns the use of manure and mineral fertilizers (Table 3). Against the background of 8.3 t/ha of manure + $N_{29.3}P_{45}K_{36.7}$, the amount of mobile phosphorus increased by 21.8 mg/kg in the arable layer and by 16.1 mg/kg in the under ploughed one compared with the use of only the starting fertilizer dose of $N_{9.3}P_{11.6}K_{6.7}$ and was respectively 107.4 and 71.3 mg/kg. Such a low increase in the content of mobile phosphorus is due to the peculiarity of this soil province of the Left-Bank Forest-Steppe Ukraine, where plants use phosphorus better than potassium [7].

In the treatment where 8.3 t/ha of manure + $N_{36}P_{55}K_{46.7}$ was applied, the increase in the content of mobile phosphorus in the arable soil layer was up to 159.0 mg/kg of soil, which was higher than the treatment with the starting rate of fertilizers by 51.6 mg/kg, and in the layer of 30–45 cm it was 35.9 mg/kg of soil.

As fertilization rate increased in the link of crop rotation up to 8.3 t/ha of manure + $N_{76.7}P_{66.7}K_{76.7}$, the content of mobile phosphorus was 193.2 mg/kg in the arable layer, which was by 83.1 mg/kg more than at the start application rate of the first rotation. The same pattern was observed in the treatment with 8.3

t/ha of manure + $N_{56}P_{85}K_{76.7}$, where the content of mobile phosphorus in the arable soil layer reached 200.2 mg/kg.

Bare fallow in crop rotation increases the nitrification processes in the soil, which increases the mobility of phosphates and their better use by plants. At application of 8.3 t/ha of manure + $N_{29.3}P_{45}K_{36.7}$, the content of mobile phosphorus was equal to that of the vetch & oat link and its content in the arable layer was 163.2 mg/kg.

The content of exchange potassium in chernozem is affected by the fertilization system and the zone of water availability and the presence of potassium in the soil-absorbing complex. In the treatments with a starting rate of fertilizers in the arable layer, only 90.4 mg/kg of exchangeable potassium was measured, while in the under ploughed layer the potassium content was 63.2 mg/kg. Such low content is due to the increased uptake of potassium by crops in crop rotation. When manure and mineral fertilizers are used, the content of exchangeable potassium in the soil increases, and the plants can better use it [3,4,9].

Our research has shown that under the application of 8.3 t/ha of manure + $N_{29.3}P_{45}K_{36.7}$ the content of exchangeable potassium was in the arable and subsoil layer of 119.3 73.4 mg/kg, which is 28.9 and 10.2, mg/kg soil higher than at the start application rates of fertilizers (Table 3).

With the use of higher fertilizer rates per crop rotation in the dose of 8.3 t/ha of manure + $N_{56}P_{85}K_{76.7}$, the content of exchange potassium in the arable soil layer was 168.0 mg/kg, while in the under ploughed layer it was 87.4 mg/kg, which was higher than start values by 57.9 and 17.0 mg/kg, respectively. The same values were obtained in the treatment with 8.3 t/ha of manure + $N_{36}P_{55}K_{46.7}$, where the level of exchangeable potassium was equal to the fertilization system described above.

In general, the amount of exchange potassium is more affected by the use of increased application rate of potassium and to a lesser extent by the use of organic fertilizer. Against the background of 16.7 t/ha of manure + $N_{29.3}P_{45}K_{36.7}$, the content of exchange potassium in the arable soil layer was 117.0 mg/kg and in the under ploughed layer 74.2 mg/kg.

Conclusions

The agrochemical and physicochemical state of the typical chernozem is affected by the fertilization system and crop rotation.

In typical deep chernozem, humus content at a level of 4.59% should be maintained and 8.3 t/ha of manure + $N_{29.3}P_{45}K_{36.7}$ per rotation link should be applied.

The use of fertilizers worsens physicochemical soil characteristics: against the background of application of 8.3 t/ha of manure + $N_{29.3}P_{45}K_{36.7}$ and 8.3 t/ha of manure + $N_{36}P_{55}K_{46.7}$ pH ranged between 5.2 and 5.3 and H_h ranged between 3.4 and 3.6 mg/equivalents per 100 g of soil. An increase in mineral nitrogen compound of fertilizer ensured an increase in soil nitrogen content to 20.0 mg/kg against the background of 8.3 t/ha of manure + $N_{76.7}P_{66.7}K_{76}$, which exceeded the start characteristics by 9.0 mg/kg.

The content of mobile phosphorus at the background of 8.3 t/ha of manure + $N_{76.7}P_{66.7}K_{76.7}$ in the ploughed soil layer was 193.2 mg/kg, whereas against the background of 8.3 t/ha of manure + $N_{56}P_{85}K_{76.7}$ it was 200.2 mg/kg, which was almost twice as much as at the beginning of the experiment, which causes a reduction in the dose of the application rate.

Under the application of 8.3 t/ha manure + $N_{56}P_{85}K_{76.7}$ the content of exchange potassium in the arable and subsoil layer increased to 168.0–87.4 mg/kg, which exceeded starting values by 57.9 and 17.0 mg/kg, respectively.

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