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Effect of various tillage systems on the agrophysical properties of black soils of the right-bank forest-steppe of Ukraine

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The article deals with the changes of the basic agrophysical properties of the arable layer of typical black soil (chernozems) within ten-year basic cultivation and fertilization in the five-field grazing crop rotation. The aim of the research was to optimally combine the systems of basic cultivation and fertilization of typical chernozem, which provides the best agrophysical state of the soil and the productivity of field crop rotation at 5.5 t ha^{-1} of dry matter. We studied four basic cultivating systems and four levels of fertilization of chernozems. The levels of annual fertilization per hectare of arable crop rotation were zero level - without fertilizers; the first level – 8 t ha^{-1} of cattle manure+$N_{76}P_{64}K_{57}$; the second – 12 t ha^{-1} of cattle manure+$N_{95}P_{82}K_{72}$; the third – 16 t ha^{-1} of cattle manure+$N_{112}P_{100}K_{86}$.
The research was carried out on the experimental field of the Bila Tserkva National Agrarian University (Ukraine) during 2007-2017. All the experiments were dealed with typical, black soil with loamy granulometric composition and low cattle manure contamination on a carbonate deposits. The annual introduction of 12 tons of cattle manure+$N_{95}P_{82}K_{72}$ per 1 hectare of crop ensured a significant improvement in soil structural under moldboard and beardless tillage for 10 years. The arable layer has been substantially compacted only at in uncooled fields with moldboard tillage, while a substantial increase in bulk mass was recorded in all plots with beardless tillage. We obtained the best results on fields with combined tillage with introduction of 12 t ha^{-1} of cattle manure+$N_{95}P_{82}K_{72}$ and on the fields with mulching disk tillage with 16 t ha^{-1} of cattle manure+$N_{112}P_{100}K_{86}$. The total porosity decreased significantly in all the plots with beardless tillage, in the plots with moldboard and combined tillage fertilized by 8.0 t ha^{-1} of cattle manure+$N_{76}P_{64}K_{57}$, and in the no-till plots with introduction of 12 t ha^{-1} of cattle manure+$N_{95}P_{82}K_{72.}$ We fixed the slight increase of capillary porosity of the arable layer on the plots with moldboard and combined tillage and highest fertilizer rate on the last year of experiments. We observed the stabilization of the least moisture content in the plots with moldboard, mulching, and beardless tillage under the highest fertilizer rate; this was also typical for the plots with combined tillage at introduction of eight t ha^{-1} of cattle manure+$N_{76}P_{64}K_{57}$. We estimated a significant decrease in soil permeability in 2017 compared to 2007 in non-fertilized areas and fertilized by 8 t ha^{-1} of cattle manure+$N_{76}P_{64}K_{57}$ under beardless and disk tillage. Application of 16 t ha^{-1} of cattle manure+N_{112} $P_{100}K_{86}$ caused the insignificant increase of the soil permeability on the plots with combined and moldboard tillage. We suggested that the productivity of crop rotation was almost equal at the fields with moldboard and combined tillage, but the latter is more energetically effective. We could recommend the combined tillage with a deep plowing in one field and disk (10-12 cm) with beardless (16-18 and 25-27 cm) plowing with application of 12 t ha^{-1} of cattle manure+$N_{95}P_{82}K_{72}$.
Keywords: Soil; cultivation; fertilizers; crop rotation; agrophysical properties; productivity

Problem statement

Izmailskiy and Kostychev proposed measures for the regulation of agrophysical properties of chernozems, namely rational cultivation, fertilization, mulching, and snow removal. According to them, the main condition for improving the soil properties was the favorable structural state of the arable layer (Izmailskiy, 1883; Kostychev, 1898). V.R. Williams considerably deepened and developed this suggestion, but he proposed to restore and maintain the structural-aggregate soil composition by herbivorous and annual cultural plowing and the introduction of the grassland farming system (Williams, 1939). Subsequent works by K.K. Gedroits, O.N. Sokolovsky, N.A. Kachinsky, O.G. Doyarenko, P.V. Vershinin, V.A. Frantsesson and other Russian soil scientists convincingly proved the decisive importance of the soil structure.
Considerably more complete agrophysical state of soils characterizes their structure, which could be described by many indicators. The main is density of formation, that caused the water-air regime, the efficiency of mineral fertilizers, the mobility

of the soil solution, the thermal regime are considered. However, this indicator cannot objectively and fully present an idea of the complex physical processes occurring in the soil environment. G. Doyarenko, expressing his critical remarks on this subject, preferred the study of differentiated porosity and structural state (Doyarenko, 1966).
Agricultural science and crop practice did not always conclude that only structured soils are characterized by higher fertility. Due to the experiments of some scientists, the crop was higher rather on sprained than intact soil (Ryzhov et al., 1968). Therefore, many scientists gradually ceased to regard the structural state as the basis of soil fertility, and during the criticism of the grassland system of agriculture, few researchers considered it necessary to exclude the structural and aggregate composition of indicators that determine soil fertility.
Since soils with a good structural state are resistant to drainage and overconsolidation, erosion and deflation, require less energy inputs for cultivation. They can preserve the structure after the tillage for a longer period, although the structure and soil fertility are not identical, but there is a direct relationship between them.
Agricultural activity and especially mechanical tillage should be aimed at reproduction and improvement of the structural state and acceleration of aggregation processes, which will ensure the growth of soil fertility. Therefore, it is important to fix the level of structure as a standard for a particular groundbreaking in order to prevent the decreasing of this value.
Nowadays, the phenomena of agro-physical degradation of soils have become so wide in Ukraine that they can be observed with the naked eye. This is, first of all, the deterioration of the structural state, the root-, air- and water permeability, the decrease in the depth of the roots of the soil layer, the narrowing of the active moisture range, the deterioration of technological parameters and water regime of the arable layer, the formation of soil crusts, frequent manifestations of droughts, which significantly degrade the productive and ecologically soil cover functions. This leads to lumpy arable land, stagnation of water in the fields after the fall of storm rainfall, poor seed earnings on turning lanes, development of root systems in surface soil layers.

Analysis of recent publications

There is no consensus regards the influence of depth, methods, measures, means and systems of basic soil cultivation on the structural condition, structure and other agrophysical indices of soil fertility among Ukrainian scientists.
Scientists at the Institute of Agriculture of the National Agrarian Academy of Science (Gritsay, Kolomiets, 1981), Sumy Oblast Experimental Station (Taranenko, Pokulenko, 1985), the former Crimean State Agrarian University (Ilyin, Osenniy, 2003) point out the insignificant influence of plowing depth on porosity of soil arable layer.
Remenyuk Yu.O. (2005) reported that At Uladovo-Lyulinetsky experimental station non-capillary porosity increased by 1.2 and 2.8%, respectively, while the capillary decreased by only 0.7 and 1.3% after increasing the depth of the plow of deep black soil from 12-14 to 20-22 and 30-32 cm. The usual replacement of plows by fine work led to a decrease in the total porosity of the arable layer of chernozem by 3.4% and the porosity of aeration by 4.1% (Gordienko, Pichugin, 2000). Other scientists (Ivanova et al., 2007) obtained similar results.
In the long-term experiments of the Kirovograd Institute of Agro-Industrial Production, the structural and aggregate composition, density of structure and porosity of black earth of ordinary heavy-grained in the subzone of the Right Bank Steppe in Ukraine for the various systems of main cultivation have not substantially undergone significant changes (Cheryachunin, 2016).
The density of arable layer did not undergo significant deviations after replacement of moldboard multi-depth tillage by beardless or combined typical deep, low-cattle manure experimental chernozem field of the Kharkiv National Agrarian University in seven-grain grazing-breeding crop rotation during 1997-2008. The use of constant minimum and zero cultivation caused a significant increase of topsoil bulk density by 0.07 g/cm3. In conditions of systematic moldboard tillage and periodic plowing with minimal cultivation in crop rotation, the growth of watertight particles was 3.0-4.1% in comparison with the traditional plowing-based technology. The highest rate was recorded for direct sowing, where it exceeded the control variant in the arable layer by 11.0% (Shevchenko, 2015).
The moldboard-beardless cultivation in typical ten-grain grazing crop rotation provided significant growth (by 3.2%) of the content of waterproof aggregates in the layer of 0-10 cm, compared with control (combined tillage) on typical low-cattle manure middle-gravel chernozem research fields the National University of Bioresources and Natural Resources of Ukraine. This index increased by 8-14% in the layer of soil 10-20 cm under systematic subsurface and surface cultivation. Moreover, it significantly (almost by 19%) exceeded the control values under constant surface cultivation in a layer of 20-30 cm.
Tsyuk O.A. (2013) concluded that moldboard-beardless tillage provides optimization of soil and agrophysical properties and reported significant puddling of typical black soil (0.03-0.04 g/cm^3) in subsurface and surface cultivation.
Pavlov O.S. (2013) performed the similar research and determined that moldboard-beardless tillage reduces the density of topsoil by 2-3% and increases in the content of waterproof aggregates by 3.5% against control. Later, Odarnchenko O.M. (2017). established that the density of topsoil under spring barley was optimal within the entire vegetation for all the tillage systems in crop rotation; this indicator increased by 13% and 8% in the soil layers of 10-20 and 20-30 cm under the direct sowing compared to plowing. Surface and zero cultivation significantly increased the content in the arable layer of waterproof aggregates (Odarchenko, 2017).
The positive influence of deep/shallow moldboard-beardless and beardless cultivation on the density of southern chernozem was established in the experiments of the Odessa State Agrarian University (Al-Janabi, 2017).

The best structural condition of the arable layer of chernozem in the experimental field of the Bila Tserkva National Agrarian University was recorded in small-scale cultivation in the five-field crop rotation; the worst was recorded for beardless tillage, while moldboard and combined tillage cased the intermediate state of soil structure (Panchenko, 2016).
Shallow (10-12 cm) moldboard cultivation contributed to growth of the topsoil bulk density of chernozem by 0.3-0.5 g cm^{-3} and decrease in total porosity by 0.6-0.9% compared to plowing by depth of 20-22 cm in field experiment of the National University of Life and Environmental Sciences of Ukraine (Yevtushenko et al., 2018).
The density of the gray forest medium loamy soil in 0-20 cm layer was higher by 6-9% in the plots with No-till technology than in plots processed up to 20-22 cm in experiments of the Institute of Feed and Agriculture in Podolia (Petrichenko et al., 2013).
Tsilyurik et al. (2015) reported that the topsoil bulk density of heavy-grained chernozem in the fields with moldboard, combined and mulching tillage was 1.09 -1.17, 1.12-1.,23, and 1.23-1.29 g cm^{-3} respectively in the beginning of spring - field operations done with five-grain cereal crop rotation at the Institute of Agriculture of the Steppe Zone. Colleagues from Kharkiv National Academy of Sciences, performed the research and revealed that the density of 0-10 and 20-30 cm layers of chernozem was 0.05 and 0.09 g/cm^3 (4.5 and 7.2%) in the beginning of peas vegetation on the plots with direct sowing and plowing. In addition, this indicator exceeded the optimum values for cereals and crop rotation in the layer of 20-30 cm on the plots with direst sowing. Shallow beardless tillage did not lead to an increase of soil puddling in these layers, compared to plowing. The content of agronomic valuable aggregates in topsoil was higher by 12.7 – 16.6% in the plots with direct sowing than with plowing (Sviridov, Kolos, 2016).
Savchenko et al. (2016) suggested that plowing at the depth of 20-22 cm reduced the density of gray forest sandy soils in 20-30 cm layer in the fields with soybean and maize by 0.06 g cm^{-3} (4.7%) compared to zero cultivation in the experiments of the Institute of Forage and Agriculture of Podolia (2011-2015).
The thickness of the structure of the arable (0-30 cm) chernozem layer was usually 1.21-1.90 on the plots with traditional cultivating technology (plowing at depth of 23-25 cm), 1.56 -2.45 with soil protection cultivation (with minimum treatment up to 4-5 cm), and 1.53-2.66 for direct sowing (Pikovskaya, 2017).
The purpose of the research is to establish an optimal combination of cultivation and fertilization in chernozem fields, which provides the best agrophysical soil state and productivity of field crop rotation at level of 5.5 t ha^{-1} of dry matter.

Methods

The research was carried out on the experimental field of the Bila Tserkva National Agrarian University in a stationary field experiment during 2007-2017. We used plots with black soils (chernozem) with typical deep, loamy granulometric composition, low-cattle manure, on a carbonate deposit.
Experiments were performed with triple replication. The replications were placed systematically on the field: first-order plots (cultivating) - sequentially in one horizon, the second (fertilizer) - consistently in four horizons. The first-order plots had a sown area of 684 m^2 (9 × 76), record area - 448 m^2 (7 × 64); the second-order, respectively, 171 (9 × 19) and 112 (7 × 16) m^2. The area of each field of experimental crop rotation was 7835.6 m^2 (without surrounding protective forest belts), and general research area was 3.7 hectares.
We studied four primary cultivation systems and four levels of standard chernozem fertilizers in crop rotation (Table 1). The levels of annual fertilization per 1 hectare of arable crop rotation were: zero level - without fertilizers; first level - 8 t ha^{-1} of cattle manure+$N_{76}P_{64}K_{57}$; the second - 12 t ha_{-1} of cattle manure+$N_{95}P_{82}K_{72}$; the third - 16 t ha_{-1} of cattle manure+$N_{112}P_{100}K_{86}$.
The soil structure was determined by the Savvinov method (DSTU4744: 2007); the structure and capillary moisture content – by method of saturation of the soil sample in water cartridges; water permeability and the lowest moisture content was determined by gravimetric method.
We used mineral fertilizers - ammonium nitrate, a simple granulated superphosphate, potassium salt, and organic ones – semi-perforated cattle manure. We tilled the soil by plow PLN-3-35, we used for the beardless plowing deep tiller GR-3.4, and for shallow tillage - disk tiller BDV-3.0 (Table 1).

Table 1. Soil tillage and crops systems.

Plot	Crops	Soil tillage*			
		1 moldboard (Control)	**2 beardless**	**3 combined**	**4 mulching**
		Depth (cm) and tillage system			
1	Soya	16-18 (p.)	16-18 (dr.)	16-18 (dr.)	10-12 (md.)
2	Winter wheat+siderat white mustard	10-12 (md.)	10-12 (dr.)	10-12 (md.)	10-12 (md.)
3	Sunflower	25-27 (p.)	25-27 (dr.)	25-27 (p.)	10-12 (md.)
4	Barley+siderat white mustard	10-12 (md.)	10-12 (dr.)	10-12 (md.)	10-12 (md.)
5	Corn	25-27 (p.)	25-27 (dr.)	25-27 (dr.)	10-12 (md.)

**Notes: p - plow, md. - mulching disk, dr.- deep ripper*

Results

The structural state of the topsoil (0-30 cm) has deteriorated over a research decade on un-fertilized plots. The decrease of waterproof aggregates was 3.7% for moldboard cultivation, 3.1% for beardless, 2.8% for moldboard-beardless - 2.4% and for shallow - 2.8%; these values under application of first level of fertilizers were, respectively, 2.5; 2.0; 1.3 and 1.7%. Thus, the deterioration of topsoil was most intense on the plots with moldboard tillage, while in the plots with combined tillage the deterioration slowed down (Table 2).

Table 2. Changes in agrophysical topsoil properties under various tillage and fertilization.

Soil tillage	Fertilizing rates	Waterproof aggregates,%	bulk weight, g/cm^3	Porosity		Permeability, mm/year/cm^2	water capacity,%	
				total	capillary		minimal	capillary
	0	53.1	1.16	55.7	33.4	5.81	33.8	37,0
1		49.4	1.22	52.4	30.6	4.42	32.4	34,3
Moldboard	1	52.9	1.18	55.0	32.8	5.77	33.6	36,2
(control)		50.4	1.22	52.6	31.1	4.96	32.8	34,2
	2	52.7	1.19	54.6	33.1	5.99	34.1	37,1
		52.5	1.21	53.8	31.9	5.59	33.6	35,7
	3	53.2	1.17	55.3	32.5	5,92	34,0	36,6
		54.3	1.18	55.0	33,0	6,13	34,1	35,9
	0	52.6	1.18	54.8	33.0	5.96	34.2	36.4
2		49.5	1.30	50.0	29.0	4.34	32.5	34.0
Beardless	1	53.0	1.20	54.3	32.7	5.83	33.7	37.0
		51.0	1.30	50.5	29.6	4.70	32.5	35.3
	2	53.2	1.17	55.0	33.0	5.93	34.1	36.4
		53.5	1.25	52.0	30.7	5.26	33.3	35.5
	3	52.8	1.29	54.6	32.8	5.78	33.5	36.3
		54.2	1.25	52.3	31.7	5.47	33.2	35.9
	0	52.5	1.18	54.9	32.6	5.76	33.9	37.4
Combined		50.1	1.26	51.9	30.3	4.65	33.1	35.6
	1	53.3	1.17	55.2	33.2	5.82	34.0	36.3
		52.0	1.23	53.1	31.8	5.25	33.7	35.5
	2	52.7	1.19	54.5	33.5	5.93	34.2	36.7
		54.3	1.22	53.6	32.8	5.65	34.5	36.4
	3	53.2	1.16	55.6	32.8	5.96	34.7	37.0
		55.0	1.18	55.0	33.7	6.24	35.2	37.5
	0	52.7	1.20	54.2	32.7	5.80	33.9	37.0
Mulching		49.9	1.30	50.3	29.3	4.17	32.4	34.8
	1	53.2	1.20	54.3	32.9	5.78	34.1	36.8
		51.5	1.28	51.1	29.9	4.59	33.1	35.4
	2	52.6	1.17	55.0	32.6	5.87	34.0	37.3
		53.7	1.23	53.0	30.6	4.99	33.4	36.5
	3	53.4	1.18	54.7	32.8	5.91	33.6	36,4
		55.0	1.22	53.4	31.7	5.34	33.3	36,3
$HIP_{0.05}$		1,3	0.05	1.7	1.2	1.06	0.5	0.8

Notes: the data in numerator/denominator correspond to years *2007/2017.*

The second level of fertilization provided for the stabilization of the structural soil condition on the pots with moldboard and beardless cultivation, insignificant growth (by 1.1%) of the waterproof aggregates on the plots with disk cultivation and a significant (by 1.6%) – on the plots with combined cultivation in crop rotation.

This indicator increased within 10 years by 1.1% on the plots with moldboard, 1.4% with beardless, by 1.8 with combined, and by 1.6% - with disk tillage under introduction of the highest fertilizer rate per one hectare of arable crops.

In 2017, the topsoil conditioning on the plots with the above-mentioned cultivating systems was 51.7, 52.1, 52.9, and 52.5% respectively.

During the ten years of research, the topsoil was densely compacted for systematic beardless cultivation, in particular, on non-fertilized plots by 0.12 g cm^3, on fertilized with 8 t ha^{-1} cattle manure+$N_{76}P_{64}K_{57}$ – by 0.10 g cm^{-3}, with 12 t ha^{-1} cattle manure+$N_{95}P_{82}K_{72}$ – by 0.08 g cm^{-3}, and with 16 t h^{-1} of cattle manure+$N_{112}P_{100}K_{86}$ – by 0.06 g cm^{-3}. The growth of the bulk mass of topsoil were correspondingly: for the moldboard cultivation - 0.06; 0.04; 0.02 and 0.01 g cm^{-3}, for combined - 0.08; 0.06; 0.03 and 0.02; for shallow - 0.10; 0.08; 0.06 and 0.04 g cm^{-3}.

Fertilizers have contributed to slowing the rate of topsoil puddling. It significantly increased on the non-fertilized plots with moldboard cultivation, in all the plots with beardless cultivation, on the non-fertilized plots and plots fertilized by the first rate with moldboard-beardless tillage, on the non-fertilized plots and fertilized by the first and second rate with disk tillage.
The average value of the topsoil density in 2017 was 1.21 g cm^{-3} on the pots with moldboard cultivation, 1.28 g cm^{-3} with beardless, 1.22 g cm^{-3} with moldboard-beardless, 1.26 g cm^{-3} with disk tillage. On average, the topsoil density was 1.27 g cm^{-3} in non-fertilized areas, 1.21 g cm^{-3} on the most intensively fertilized plots, i.e., the density decreased by 5% along with fertilization rate.
The total topsoil porosity on non-fertilized plots, plots fertilized by the first, second, and third fertilizer rates decreased by 3.3, 2.4, 0.8, and 0.3% respectively with moldboard tillage; on the plots with beardless tillage by 4.8, 3.8, 3.0, and 2.3%; with moldboard-beardless tillage – by 3.0, 2.1, 0.9, and 0.6%; and with disk tillage – by 3.9, 3.2, 2.0, and 1.3% respectively. Thus, the application of 12 t ha^{-1} of cattle manure+$N_{95}P_{82}K_{72}$ ensures the stabilization of the total topsoil porosity on the plots with moldboard and combined cultivation (did not exceed HIP 0.05 for ten years). The annual application of 12 t ha^{-1} of cattle manure+$N_{112}P_{100}K_{86}$ did prevent a significant reduction in the total porosity under beardless cultivation, and changes in porosity were insignificant for the remaining variants of cultivation under this fertilizer rate within ten years.
On average, the porosity value exceeded the control by 2.3 and 1.5% on the plots with beardless and shallow cultivation and was the same on the plots with combined tillage. The total soil porosity was 2.7% higher on the plots with the highest fertilizer rate than on non-fertilized areas.
We revealed that the capillary porosity in 2017 decreased by 2.8, 1.7, and 1.2 % on the non-fertilized plots, plots fertilized with 8 t ha^{-1} of cattle manure+$N_{76}P_{64}K_{57}$, and with 12 t ha^{-1} cattle manure+$N_{95}P_{82}K_{72}$ under moldboard cultivation to 2007; by 4.0, 3.1, and 2.3% on the plots with beardless cultivation; by 2.3, 1.4,and 0.7 % on the plots with moldboard-beardless cultivation; 3.4, 3.0, and 2.0 % - on the plots with disk tillage.
After introduction of 16 t ha^{-1} of cattle manure+$N_{112}P_{100}K_{86}$ the capillary porosity by 0.5 and 0.9 % on the plots with moldboard and combined tillage, with chisel and shallow tillage it is decreased by 1.1% within 10 years.
In 2017, the capillary porosity was by 1.3-1.4% lower compare to control on the plots with beardless and disk cultivation, and by 0.5% higher in the plots with combined cultivation. In the plots introduction of the first, second, and third fertilizer rate the capillary porosity increased by 0.8, 1.7, and 2.7% compared with non-fertilized plots.
During the research decade the lowest moisture content of topsoil decreased by 1.4, 0.8, and 0.5% on the plots with moldboard tillage and application of zero, first, and second levels of fertilizers; with beardless cultivation – by 1.7, 1.2, and 0.8% respectively, and with disk tillage – by 1.5, 1.0, and 0.6%. This value decreased by 0.8% and 0.3% on the non-fertilized plots with combined tillage and plots with first fertilizer rates, while it increased by 0.3 and 0.5% on the plots with second and third fertilizer rates. We also registered that the lowest moisture content of topsoil has not significantly changed on the plots with moldboard, beardless, and disk cultivation and the highest fertilizer rate.
In 2017, the lowest moisture content of topsoil was by 0.1-0.3% lower on the plots with beardless and shallow tillage, and by 0.9% higher on the plots with combined tillage compared to control. These values were 32.6, 33.0, 33.7, and 34.0% on the plots with introduction of zero, first, second, and third fertilizer levels.

Table 3. Crop productivity under various tillage and fertilization, t ha^{-1} (bulk dry matter is presented in numerator, crop units – in the denominator).

Fertilization rate (factor B)	**Soil tillage (factor A)**				**$HIP_{0.05}$ for the factors**		
	moldboard	**beardless**	**combined**	**mulching**	**A**	**B**	**AB**
0	2.97/3.02	2.60/2.62	2.93/2.95	2.69/2.78			
1	4.22/4.33	3.74/3.82	4.23/4.36	3.82/3.92	0.7/0.8	2.83./1	1.9/2.1
2	5.38/5.50	4.81/4.89	5.39/5.54	4.94/5.08			
3	6.27/6.37	5.62/5.68	6.26/6.41	5.83/5.96			

We calculated that, the capillary moisture content of topsoil decreased by 2.7, 2.0, 1.4, and 0.7% on the plots with moldboard and zero, first, second, and third levels of fertilizer, respectively; 2.4; 1.7; 0.9 and 0.4% – on the plots with beardless tillage, 2.2; 1.4; 0.8, and 0.1% – with disk tillage in 2017, compared to 2007.
We noticed that the capillary moisture content of topsoil decreased by 1.8, 0.8, and 0.3% on the plots with moldboard-beardless tillage and application of zero, first, and second fertilization levels, while it increased by 0.5% on the plots with the highest fertilizer rate.
In 2017, the average value of capillary moisture content was respectively 35.0, 35.2, 36.2, and 35.6% on the plots with moldboard, beardless, combined, and shallow tillage; these were 34.7, 35.1, 36.0, and 36.4% on the plots with introduction of the zero, first, second, and third rate of fertilizers. The introduction of the highest fertilizer rate in 2017 provided for the increase of soil permeability only on the plots with moldboard and moldboard-beardless tillage (by 0.22 and 0.28 mm $h^{-1}cm^{-2}$

respectively), however, it did not exceed the NIR0.05; whereas these values decreased by 23.9, 14.0, and 6.7% on the plots with moldboard tillage and zero, first, and second fertilizer rates correspondingly, 27.2; 19.4, and 11.3% – on the plots with beardless tillage, 19.3, 9.8, and 4.7% – with combined tillage, 28.1, 20.6, and 15.0% – with disk tillage.
We also concluded that the water permeability decreased in 2017 by 5.4% and 9.6 % on the plots fertilized by 16 t h^{-1} cattle manure+$N_{112}P_{100}K_{86}$ and cultivated by chisel cultivator and disk tiller compared to 2007.
In 2017, the topsoil water permeability was by 6.4 and 9.7% lower on the plots with beardless and disk cultivation, while it was by 3.2% higher on the plots with combined tillage compared to control.
We registered that the productivity of crop rotation was practically the same for moldboard and a moldboard-beardless tillage, while it considerably lower for the beardless and disk tillage. The agro-technical, economic and energy crop efficiency are the highest under combined tillage and introduction of 12 t ha^{-1} cattle manure+$N_{95}P_{82}K_{72}$.

Conclusions

1. Annual introduction of 12 tons of cattle manure+$N_{95}P_{82}K_{72}$ per 1 hectare of crop rotation within 10 years has provided a significant improvement in the structure of chernozem on the fields with moldboard/beardless tillage. The topsoil has been substantially puddled over 10 years in the non-fertilized fields only. We registered a substantial increase in bulk mass in all the plots with beardless tillage. Stabilization of this indicator was observed after the introduction of 12 t ha^{-1} cattle manure+$N_{95}P_{82}K_{72}$ for the plots with combined tillage and for after introduction of 16 t/ha cattle manure+$N_{112}P_{100}K_{86}$ for the plots with disk tillage.
2. The total porosity decreased significantly in all the plots with beardless tillage, in the plots with moldboard and combined tillage fertilized by 8.0 t ha^{-1} of cattle manure+$N_{76}P_{64}K_{57}$, and in the no-till plots with introduction of 12 t ha^{-1} of cattle manure+$N_{95}P_{82}K_{72}$ within 10 years of experiments. We observed insignificant growth of the capillary porosity of the arable layer on the tenth year of the experiment for the plots with moldboard and combined cultivation and the highest fertilizer rate.
3. We registered the stabilization of the least water capacity for moldboard, beardless, and disk tillage fields at application of the highest fertilizer rate; for the fields with combined cultivation and 8.0 t ha^{-1} of cattle manure+$N_{76}P_{64}K_{57}$.
4. We revealed a significant decrease in soil permeability in year 2017 compared to 2007 in non-fertilized fields and fields fertilized by 8.0 t ha^{-1} of cattle manure+$N_{76}P_{64}K_{57}$ with moldboard and disk cultivation. This value has insignificantly increased after introduction of 16 t ha^{-1} of cattle manure+$N_{112}P_{100}K_{86}$ on the fields with moldboard and moldboard-beardless cultivation.
5. The most favorable agrophysical indices of fertility of chernozem topsoil in 2017 were provided by combined cultivation in crop rotation.
6. The productivity of crop rotation is the same for the moldboard and moldboard-beardless cultivation, nevertheless, the latter has more higher economic and energy efficiency, which are significantly lower for systematic beardless and shallow cultivation.

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