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SHALLOW AND COMBINED TILLAGE OF BLACK SOIL TYPICAL AT DIFFERENT SPECIALISATION IN AGRICULTURAL PRODUCTION IN THE LEFT BANK FOREST STEPPE OF UKRAINE

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Abstract. *The article presents the results of long-term experimental studies on the effect of different methods of main tillage on soil fertility and crop productivity when applying different degrees of fertilization. Field research was conducted during 2013–2020 on the lands of the Poltava Research Station of the Institute of Pig Breeding and Agro-Industrial Production of the National Academy of Agricultural Sciences. It has been established that the systematic use of organic and organic and-mineral fertilization systems improves the nutrient regime of typical black soil with differentiation of the arable layer by the amount of phosphorus and potassium when applying long-term minimal loosening. There is a tendency towards an increase in density in the layers of 20–40 and 40–60 cm when applying systematic shallow tillage, where this indicator exceeds the upper limit of the optimal range of 1.0–1.3 g/cm^3. Application of manure and mineral fertilizers compared to surface loosening makes it possible to additionally annually sequester 0.3–0.4 t/ha of carbon, which is equivalent to 1.2–1.6 t of carbon dioxide. By the average multi-year yield of corn per silage, shallow loosening is inferior to combined tillage by an average of 10 %. Tendencies to a decrease in the average long-term productivity of soybean, spring barley, and pea crops when using minimal tillage compared to the combined one are manifested only in certain fertilizer options. Under optimal conditions of heat and moisture supply, the ratio of grain and straw in soybeans decreases. On winter wheat, after peas, there is a tendency towards the preference of shallow loosening. The ratio of wheat grain to straw increases significantly under favorable conditions. Corn responds better to the combined tillage system, which prevails shallow loosening in terms of grain yield by the fertilizer options by 6–10 %. Under favorable conditions, the ratio of stems to grain increases significantly, especially on fertilized grounds. From the studied crops, the productivity of sugar beets fluctuates to a greater extent in relation to the conditions of the year, and to a lesser extent – winter wheat, grown after peas and corn for grain. By the average long-term crop productivity, shallow tillage is inferior to combined tillage by 4–8 % having a confidence level as 5 %. When applying manure, it is advisable to use a combined system of soil tillage, for plant-oriented agrarian production, it is economically advisable to use surface loosening for all crops.*

Key words: *soil tillage, fertilizers, specialization, agricultural production, crop rotation, moisture supply, productivity, efficiency*

Relevance of research. Agriculture is a land use that inevitably leads to the greatest soil loss on all continents and in all climates [1, 2]. Soil degradation is recognized as a serious problem of the 21st century worldwide in the global agroecosystem [3]. Increasing soil degradation threatens agricultural production and food supply for the growing population in developing countries and regions [4, 5]. The basic cultivation plays not the last role in the degradation processes. The analysis of global trends in this area indicates a gradual elimination of deep moldboard tillage in favor of shallow or surface tillage. The transition from plowing to shallow tillage includes a reduction in the depth of the basic cultivation, the absence of direct soil overturning, and a change in energy consumption. All this affects the physical characteristics and functioning of the soil [6].

Along with this, it is well known that modern climate changes have a negative impact on the moisture supply of soils, and this factor limits the use of their fertility potential. Also, scientific research and practical experience have proven that irrigation is the most effective measure to prevent this impact. However, given the significant shortage of water resources in Ukraine, widespread irrigation is problematic. Under such conditions, regulation of the water-air regime of soils is carried out by other agrotechnical measures, in particular, soil cultivation systems. Therefore, the issue of controlling soil processes under the effect of minimal and differentiated tillage systems, taking into account their influence on moisture accumulation, is relevant.

Analysis of recent research and publications. The main task of soil cultivation in modern agriculture is to create optimal conditions for sowing, further growth and development of agricultural crops [7, 8]. At the same time, to increase the profitability of production activity, it is important to reduce the costs of chemical and technological resources without reducing crop yield and the productivity of crop rotations [9, 10]. Therefore, special attention is currently being paid to the issue of improving existing and developing new energy-saving cultivation technologies, taking into account their impact on agrochemical, water-agrophysical, physicochemical and other soil properties [11].

In the agricultural system, tillage is one of its effective components in view of combating various harmful organisms, particularly weeds [12–15]. They are closely related to erosion processes and the intensity of mineralization of soil organic matter [16–20]. Rational tillage of the soil improves the supply of cultivated plants with elements of mineral nutrition, moisture, and it largely determines the final productivity of agrocenoses [21–23].

Solving many issues related to soil cultivation largely depends on the physical and mechanical properties of the soil, and in particular the soil compaction density. The physical parameters of the soil should be as close as possible to the optimal ones, that is, those that provide the best conditions for plant development. Increased soil density negatively affects the processes of gas exchange between the soil and the atmosphere, assimilation and evaporation of moisture [24–26].

If there is optimal soil density of the sowing layer before sowing and in the initial phases of development, agricultural crops form the maximum yield. Therefore, the prerequisite for reducing the intensity of mechanical loosening, in particular, the application of the "No-Till" system, is achieving such a state when the equilibrium density of the soil corresponds to the characteristics and requirements of the cultivated crop [27, 28]. Therefore, the problems related to the determination of the optimal system of soil cultivation in crop rotation, taking into account the specific features of soil and climatic conditions, production specialization and fertilization systems are relevant. In this regard, the study of the long-term impact of different cultivation systems on the properties of typical black soil and the productivity of the main crops grown on it in the Left Bank Forest Steppe of Ukraine is practical and scientific interest.

The purpose of the research is to establish the dynamics of the changes in the properties of typical black soil, the crop yield and the productivity of crop rotation typical for the Left Bank Forest Steppe under the influence of minimal and combined tillage systems against the background of organic and organo-mineral fertilization systems that correspond to crop or livestock specialization of agricultural production.

Research materials and methods. To analyze the practicability of minimizing tillage, the information base of the long-term stationary field experiment of the Poltava Experimental Station of the Institute of Pig Breeding and Agro-Industrial Production of the National Academy of Agricultural Sciences of Ukraine "The effect of systematic application of fertilizers when applying various types of tillage on crop productivity and quality as well as soil fertility" was used. The field experiment was made in 1987. The soil was a typical black soil with a humus content of 5 %, low availability with plant-available nitrogen compounds, medium availability with phosphorus and high availability with potassium.

Soil samples were taken in accordance with DSTU [29], namely: the content of organic matter in the soil, total nitrogen, mobile compounds of phosphorus and potassium [30, 31, 32] and soil density [33]. Analytical study of the soil was carried out in the agrochemical laboratory of the Poltava Research Station of the Institute of Pig Breeding and Agro-Industrial Production of the NAAS.

Crop rotation included corn for silage, winter wheat, soybeans, sugar beet, spring barley, peas, winter wheat and corn for grain.

The following basic tillage systems were studied: combined (plowing for row crops, surface tillage to the depth of sowing with a combined unit for other crops); shallow boardless tillage (surface tillage to the sowing depth with a combined unit for all crops). The fertilization systems were the following (Table 1): without fertilizers – reference area (RA); manure 10 t/ha (M); manure + $N_{52}P_{52}K_{52}$ (M+NPK); by-products (BP); by-products +NPK (BP+NPK).

The coefficient of variation was used to estimate the range of fluctuations in crop yields and productivity of crop rotations by years. The estimated variation coefficient of the studied indicator can be grouped by the accepted scale of qualitative assessment: less than 15 % is low; 15–30 is medium; more than 30 is high.

Research results. First of all, it should be noted that at the time of the experiment was started, the content of easily hydrolyzable nitrogen compounds, available phosphorus, and exchangeable potassium in the 0–20 cm soil layer averaged 155, 70, and 152; in the 20–40 cm soil layer it was 137, 58 and 124 mg/kg respectively. Over the years of conducting research, the improvement of the nutrient regime of typical black soil on all fertilization grounds was recorded, especially when applying the minimal system of basic cultivation, where soil nitrogen content has changed from low to medium, for phosphorus and potassium – to high and very high.

One of the negative consequences of applying minimal or zero tillage systems can be soil over-compaction. This leads to oversaturation of the upper layers with moisture, which can cause a lack of oxygen for the roots. Under anaerobic conditions, denitrification can lead to significant losses of nitrogen to the atmosphere. In case of overcompaction detection, the expected economic effect of its elimination is significant, and the increase in yield can reach 20 %. The optimal value of soil density (bulk mass) of the soil for most agricultural crops is 1.0–1.3 g/cm^3, and when the density is higher than the optimal by 0.1 g/cm^3, the grain yield decreases by 10–30 % [34].

Study on the effect of fertilization and tillage systems on the agrophysical properties of typical black soil has not established reliable changes in the equilibrium density of the soil arable layer, which fluctuated between 1.30–1.35 g/cm^3 by the experiment variants. There is a tendency towards an increase in the compaction density in layers of 20–40 and 40–60 cm when applying systematic shallow tillage, where this indicator also exceeds the upper optimal limit of 1.0–1.3 g/cm^3 for all fertilization variants except the reference area. This may be due to the formation of various moisture reserves deeper than 20 cm during the long-term applying the investigated soil loosening methods, and also it was possible due to the formation or destruction of the tillage pan.

If traditional and minimal tillage systems have different effects on the agrophysical parameters of typical black soil, then we can make assumptions about changes in its other properties over time [35]. Thus, it was established that tillage systems did not reliably affect the amount of nitrogen and phosphorus in the 0–20 cm layer. At the same time, it can be seen from Figure 1 that when minimizing loosening, there is a tendency to the decrease in the amount of these nutrients in the 20–40 cm layer. Only the content of exchangeable potassium when applying shallow tillage in the lower part of the profile is higher, which is obviously can be explained by its greater mobility compared to phosphorus.

On fertilized grounds, differentiation of the upper part of the soil profile was traced by the total phosphorus content. When applying plowing, its amount is higher in the deeper 20–40 cm layer, and lower in the upper 0–20 cm layer compared to surface loosening. Such trends were not found for total nitrogen.

All this may indicate that in view of the hydrothermal conditions of the year and biological characteristics of individual crops, their yield may also depends on the technology of soil cultivation and the location of nutrients.

When applying both investigated tillage systems, humus reserves in the 0–40 cm layer in the reference area without fertilizers amount to 277 t/ha. At first glance, it seems that the systematic application of manure is accompanied by an increase in the amount of organic matter (Fig. 2). It seems logical that the organo-mineral fertilization system contributes to the increase in crop yield and thanks to the additional accumulation of root and post-harvest residues the humus condition of the typical black soil significantly improves, especially when applying

1. Scheme of fertilization of agricultural crops in crop rotation

Fertilization systems	Corn for silage			Winter wheat			Soy			Sugar beet			Spring barley			Peas			Winter wheat			Corn for grain		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	Manure, t/ha	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	Manure, t/ha	N	P_2O_5	K_2O
without fertilizers – reference area (RA)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
manure 10 t/ha (M)	–	–	–	–	–	–	–	–	–	40	–	–	–	–	–	–	–	–	–	–	–	–	30	–	–	–
manure + $N_{52}P_{52}K_{52}$ (M + NPK);	60	45	45	45	45	45	–	15	15	40	140	140	155	30	30	30	–	15	15	45	45	45	30	30	45	45
By-products (BP)	50	–	–	–	–	–	25	–	–	–	40	–	–	210	–	–	25	–	–	30	–	–	45	–	–	–
By-products+NPK (BP+NPK)	60	45	45	45	45	45	–	15	15	–	140	140	155	30	30	30	–	15	15	45	45	45	–	30	45	45

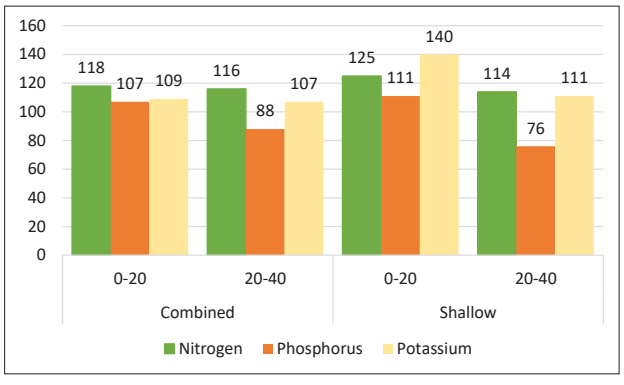

Fig. 1. The effect of tillage systems on the nutrient content in typical black soil when systematically applying manure and mineral fertilizers, mg/kg (2013–2020)

a combined tillage system. However, balance studies indicate that during the crop rotation without applying fertilizers, humus reserves in the 0–40 cm layer decreased by 5 t/ha, that is, the initial level of this indicator was 282 t/ha.

Therefore, the manure fertilization system when applying shallow tillage does not ensure the reproduction of the humus state of the typical black soil; when applying the combined one, the humus reserves are kept at the initial level. On the grounds where manure is supplemented with mineral fertilizers, organic matter reserves are stabilized when applying surface loosening and accumulated (5 t/ha) when applying the organo-mineral fertilization system. In the latter case, it can be explained by the formation of better conditions for humification processes with a more uniform distribution of organic biomass with a small ratio of nitrogen and carbon along the profile of the upper plowed layer.

Similar, but due to the greater C/N ratio, stronger orientation of the processes of transformation of fresh organic mass is more pronounced when applying crop by-products as fertilizer. In this regard, it is only necessary to emphasize the equivalence the methods of loosening.

As a result, it can be considered that cultivation methods under certain conditions make it possible to effectively deposit atmospheric carbon in the soil. For example, plowing of manure and mineral fertilizers compared to surface loosening makes it possible to additionally annually sequester 0.3–0.4 t/ha of carbon, which is equivalent to 1.2–1.6 t of carbon dioxide. It is clear that such a factor must be taken into account when assessing the practicability of applying soil cultivation technologies.

Therefore, the minimization of soil cultivation is accompanied by changes in its various

parameters, which in turn should obviously lead to the fluctuations in the yield of individual crops compared to the traditional combined tillage system, especially in relation to variable agrometeorological factors. That is, in some specific conditions of a particular year, one system may prevail in favor of growing a certain crop, in others – another. To determine such features of the studied cultivation technologies, the following were compared: the average long-term and maximum yield in the most favorable year of 8 crops on 5 fertilization grounds; the multiplicity of crop productivity growth as a result of the combined effect from applying the methods of loosening and fertilizers compared to the natural ground of fertility.

The analysis of the research results showed that both by the average multi-year and maximum yield of corn per silage, shallow loosening is inferior to the combined tillage by 10 % on average on the variants of experiment. Multiplicity of increase in the average crop yield when applying fertilizers for both loosening methods is 1.2 times. In favorable growing conditions, applying fertilizers increases the yield of green mass only when applying the combined tillage. On all fertilizer variants, when applying shallow loosening in favorable conditions the crop productivity increases to the average long-term one (Table 2).

On winter wheat, after corn for silage, there is also a tendency to the decrease in the yield when applying shallow tillage (Table 3). Compared to the other fertilization systems, the multiplicity of

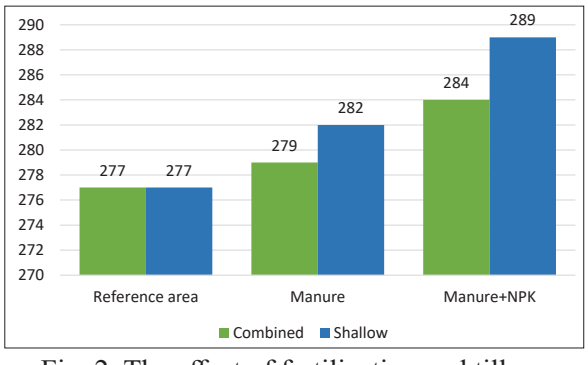

Fig. 2. The effect of fertilization and tillage systems on humus reserves in the 0–40 cm layer of typical black soil, t/ha (2013–2020)

rise of both medium and high yields compared to the reference area without applying fertilizers did not depend on tillage; it was the lowest with long-term manure application and amounted to 1.1–1.2 times, on other variants – 1.5–1.6 times.

On the contrary, the ratio of high yield in a favorable year and average multi-year yield (1.6–1.7) is larger when applying manure, which indicates an increase in its efficiency in near-optimal hydrothermal conditions. In general, it can be noted that under all investigated fertilization systems, winter wheat responses poorly to cultivation methods, so, to reduce the cultivation costs, it is advisable to use shallow loosening during its cultivation.

From a technological point of view, an important indicator is the ratio of straw to grain,

2. The effect of tillage methods on the yield of corn for silage under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure + NPK	BP	BP+NPK
Average, t/ha	Combined	30.8	35.8	40.1	38.2	39.5
	Shallow	29.0	32.0	35.4	33.6	36.4
	Difference, %	–7	–13	–15	–8	–3
Multiplicity of yield growth compared to the reference area	Combined	–	1.2	1.3	1.2	1.3
	Shallow	–	1.1	1.2	1.2	1.3
Maximum, t/ha	Combined	65.1	75.0	82.1	70.5	74.6
	Shallow	69.6	65.2	70.1	65.1	72.3
	Difference, %	–6	–10	–12	–12	–8
Multiplicity of yield growth compared to the reference area	Combined	–	1.2	1.3	1.1	1.1
	Shallow	–	0.9	1.0	0.9	1.0
Maximum compared to average, multiplicity	Combined	2.3	1.8	1.7	1.7	1.8
	Shallow	2.4	2.0	2.0	1.9	2.0

3. The effect of tillage methods on the yield of winter wheat after corn under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure + NPK	BP	BP + NPK
Average, t/ha	Combined	2.2	2.5	3.5	3.2	3.6
	Shallow	2.2	2.4	3.4	3.1	3.4
	Difference, %	–2	–5	–3	–2	–4
Multiplicity of yield growth compared to the reference area	Combined	–	1.1	1.6	1.5	1.6
	Shallow	–	1.1	1.6	1.5	1.6
Maximum, t/ha	Combined	3.7	4.8	5.6	5.4	5.9
	Shallow	3.7	4.5	5.6	5.3	5.7
	Difference, %	0	–6	0	–1	–5
Multiplicity of yield growth compared to the reference area	Combined	–	1.3	1.5	1.5	1.6
	Shallow	–	1.2	1.5	1.4	1.5
Maximum compared to average, multiplicity	Combined	1.7	1.9	1.6	1.7	1.7
	Shallow	1.7	1.9	1.6	1.7	1.6

which is used for making balance calculations. By the average long-term yield data, this indicator varied between 1.3 and 1.4 depending on the fertilization and tillage variants. However, under favorable conditions of the most productive year, this ratio significantly gets bigger and is 2.3–2.4 in the reference area, 1.8–2.0 – when applying manure and by-products, and 1.5–1.8 – when applying organo-mineral fertilization system.

On sugar beet, we also note a tendency to decrease both average and maximum productivity in a favorable year when applying shallow loosening of soil; on average it is 10 % on the fertilization variants (Table 4). At the same time, it should be noted that during the long-term use of crop production waste for fertilizer, this negative effect grows significantly weaker, and in near-optimal conditions of heat and moisture supply, it is completely eliminated. The average long-term root yield growth factor when applying manure compared to the reference area is 1.2–1.3 and 1.6–1.8 on the other fertilizer variants. This also indicates the leveling effect of fertilizers on the negative impact of shallow tillage. In favorable hydrothermal conditions, similar, but less pronounced patterns can

4. The effect of tillage methods on sugar beet yield under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure+ NPK	BP	BP+NPK
Average, t/ha	Combined	25.4	31.3	40.1	39.5	41.6
	Shallow	21.3	26.8	35.8	36.9	38.2
	Difference, %	–16	–14	–11	–7	–8
Multiplicity of yield growth compared to the reference area	Combined	–	1.2	1.6	1.6	1.6
	Shallow	–	1.3	1.7	1.7	1.8
Maximum, t/ha	Combined	37.6	42.8	52.7	50.5	52.9
	Shallow	35.4	39.8	43.4	53.8	53.6
	Difference, %	–6	–7	–18	7	1
Multiplicity of yield growth compared to the reference area	Combined	–	1.1	1.4	1.3	1.4
	Shallow	–	1.1	1.2	1.5	1.5
Maximum compared to average, multiplicity	Combined	1.5	1.4	1.3	1.3	1.3
	Shallow	1.7	1.5	1.2	1.5	1.4

5. The effect of tillage methods on soybean yield under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure + NPK	BP	BP + NPK
Average, t/ha	Combined	1.2	1.4	1.7	1.5	1.6
	Shallow	1.2	1.3	1.7	1.6	1.7
	Difference, %	3	–7	–1	3	9
Multiplicity of yield growth compared to the reference area	Combined	–	1.2	1.5	1.3	1.3
	Shallow	–	1.1	1.4	1.3	1.4
Maximum, t/ha	Combined	1.9	2.2	3.1	2.6	2.3
	Shallow	2.2	2.7	2.8	3.1	2.8
	Difference, %	17	19	–10	21	18
Multiplicity of yield growth compared to the reference area	Combined	–	1.2	1.6	1.3	1.2
	Shallow	–	1.2	1.2	1.4	1.2
Maximum compared to average, multiplicity	Combined	1.6	1.6	1.8	1.7	1.5
	Shallow	1.9	2.0	1.6	2.0	1.6

be noted. Comparing the root yield in such conditions with the average long-term indicator, it can be noted a higher multiplicity of growth on the variant without fertilizers, which also indicates an increase in the efficiency of the sugar beet plants' use of the natural fertility in favorable weather conditions.

Tendencies to a decrease in the average long-term productivity of soybean crops when applying minimal tillage compared to the combined tillage are manifested only on certain fertilizer variants (Table 5).

In favorable conditions of the most productive year, the positive effect of soil loosening minimization on crop yield compared to the traditional technology is mostly noted. Multiplicity of growth compared to the reference area for different variants of fertilization and tillage fluctuates significantly, which can be caused by other factors of plant growth and development. In favorable hydrothermal conditions when having natural soil fertility, as well as when applying organic fertilizer systems under soybeans for a long time, it is advisable to use the shallow tillage, while when applying organo-mineral fertilization systems it is more reasonable, to use the combined one.

By the long-term yield data, the grain-to-straw ratio on the investigated variants is mostly 1.4 with a tendency to its increase shallow tillage, in particular when applying by-products for fertilizer constantly (1.6). In contrast to previously described winter wheat and sugar beets, in close to optimal conditions of heat and moisture supply, the ratio of grain and straw in soybeans does not increase, but, on the contrary, decreases to 0.9–1.2.

The response of spring barley, which is considered to be an indicator crop in crop rotation, to the tillage methods is ambiguous. Based on the average long-term data on its yield, it is possible to note the advantage of the combined tillage when applying organic fertilization systems (Table 6). This is obviously related to the more uniform mixing of organic biomass of by-products with the soil and the formation of a better nutritional regime as it decomposes.

In the conditions of the most productive year with active microbiological processes in the soil, combined loosening has an advantage only on the variants with manure application, which indicates the need to plow it after application. That is also proven by the fact that the multiplicity of barley grain yield growth when applying manure fertilization systems is always significantly lower when applying shallow tillage. Moreover, the degree of crop yield growth in favorable conditions compared to average data is also significantly higher when manure is plowed.

In most studied variants, the ratio of barley grain to straw fluctuates at the level of 1.3–1.4. It is also possible to note a tendency towards a slight increase of this indicator in close to optimal hydrothermal conditions. Both by the average multi-year yield data for peas and by the data of the most productive year, it is possible to note a tendency towards the prevailing (by 5–10 %) of the combined tillage over the shallow one on almost all fertilizer variants (Table 7).

6. The effect of tillage methods on spring barley yield under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure+ NPK	BP	BP+NPK
Average, t/ha	Combined	1.7	2.2	2.7	2.6	2.7
	Shallow	1.7	2.0	2.7	2.5	2.7
	Difference, %	1	–9	–1	–5	0
Multiplicity of yield growth compared to the reference area	Combined	–	1.3	1.6	1.5	1.6
	Shallow	–	1.1	1.5	1.5	1.6
Maximum, t/ha	Combined	3.0	4.5	4.9	4.6	4.7
	Shallow	3.2	3.2	4.6	5.0	4.7
	Difference, %	9	–28	–7	8	0
Multiplicity of yield growth compared to the reference area	Combined	–	1.5	1.7	1.6	1.6
	Shallow	–	1.0	1.4	1.6	1.5
Maximum compared to average, multiplicity	Combined	1.7	2.0	1.8	1.8	1.7
	Shallow	1.9	1.6	1.7	2.0	1.7

7. The effect of tillage methods on peas yield of under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure+ NPK	BP	BP + NPK
Average, t/ha	Combined	2.4	2.6	3.0	2.8	2.8
	Shallow	2.2	2.5	2.7	2.6	2.7
	Difference, %	–6	–6	–10	–5	–7
Multiplicity of yield growth compared to the reference area	Combined	–	1.1	1.2	1.2	1.2
	Shallow	–	1.1	1.2	1.2	1.2
Maximum, t/ha	Combined	3.9	5.1	4.6	4.0	4.4
	Shallow	3.3	4.9	4.1	4.0	4.2
	Difference, %	–15	–4	–10	0	–3
Multiplicity of yield growth compared to the reference area	Combined	–	1.3	1.2	1.0	1.1
	Shallow	–	1.5	1.3	1.2	1.3
Maximum compared to average, multiplicity	Combined	1.6	1.9	1.6	1.5	1.5
	Shallow	1.5	2.0	1.6	1.5	1.6

The average productivity of this crop is almost independent of the fertilization system, with the exception of the aftereffect of applying manure with a significant negative difference compared to other fertilizer variants, where the growth factor of crop productivity is 1.2 compared to the reference area. At the same time, it is rather difficult to explain why, in a favorable year, a significantly higher grain yield was obtained under this fertilization system compared to other variants. Accordingly, the increase in the productivity of peas from the optimization of growing conditions when applying the organic fertilization system with manure reaches 100 % against 50–60 % on other variants.

The ratio of peas grain to straw by the average multi-year yield data is mostly 1.1 with a range of 1.0–1.3. In a favorable year, there is a tendency to increase this indicator to 1.3–1.5, excluding the organic system with manure – 1.1.

Unlike other crops, winter wheat after peas both by the average and high yields practically does not respond to the tillage system for all fertilizer variants (Table 8).

As in the case of peas, the organic system with manure is distinguished from other variants by significantly lower yield and crop growth rate

8. The effect of tillage methods on winter wheat and peas yield of under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure+ NPK	BP	BP+NPK
Average, t/ha	Combined	3.0	3.4	3.9	3.8	3.8
	Shallow	3.2	3.4	3.9	3.9	3.9
	Difference, %	6	0	1	2	2
Multiplicity of yield growth compared to the reference area	Combined	–	1.1	1.3	1.3	1.3
	Shallow	–	1.1	1.2	1.2	1.2
Maximum, t/ha	Combined	5.1	5.2	5.6	5.7	5.2
	Shallow	5.0	5.5	5.7	5.6	5.9
	Difference, %	–3	7	1	–1	12
Multiplicity of yield growth compared to the reference area	Combined	–	1.0	1.1	1.1	1.0
	Shallow	–	1.1	1.1	1.1	1.2
Maximum compared to average, multiplicity	Combined	1.7	1.5	1.5	1.5	1.4
	Shallow	1.5	1.6	1.5	1.4	1.5

compared to the reference area. It is obvious that under the favorable conditions of the most productive year, the positive effect of peas as a forecrop results in a high yield in the reference area and a low coefficient of its growth under almost all investigated fertilization systems. At the same time, the role of near-optimal conditions is manifested in a significant increase in the productivity of wheat crops compared to the average long-term indicators, which in turn indicates the low frequency of such conditions.

The assessment of the grain-to-straw ratio by the average long-term yield data shows that the systematic application of the entire low-value part of crops as fertilizer can contribute to the increase of this indicator from 1.3–1.4 to 1.4–1.5, and in close to optimal conditions even up to 1.7–2.2. There is also a tendency to increase this ratio when applying shallow tillage.

Unlike the other crops, all studied fertilization systems have a lesser effect on the yield of corn per grain (Table 9). The multiplicity of its growth compared to the reference area is 1.1–1.2, which is obviously related to biological features and the ability to more fully use the available soil and climatic potential.

Corn responds better to the combined tillage, which prevails in terms of grain yield, shallow loosening on the fertilizer variants by 6 – 10 %. In near-optimal conditions of the most productive year, this advantage is preserved only when applying manure fertilization systems. In such conditions, on the soils with natural fertility, on the contrary, when applying shallow tillage, the productivity of corn is 10 % higher than when applying the combined one, 8.1 versus 7.4 t/ha, respectively. The multiplicity of crop yield growth in a favorable year compared to the average multi-year yield data turned out to be higher when applying shallow loosening for all investigated fertilization systems.

When having the average multi-year yield of corn, the ratio of grain to stalks on the fertilizer variants in most cases is 1.7. In favorable conditions of the most productive year, this indicator increases to 2.1. In the reference area without fertilizers, as well as under the organic and mineral fertilization system with plowing crop by-products, the ratio is 2.6 and 2.5, respectively, with a tendency to decrease it when applying shallow tillage.

As the previously presented research results show, the crop yields fluctuate significantly under the influence of various factors. In particular, the effect of the studied fertilization and tillage systems on individual crops is completely different, especially in different conditions.

A variation coefficient was used to estimate the range of fluctuations in crop yield and productivity of crop rotation by year. The fluctuations in crop yield data over time in studied variants in view of applying fertilization systems and soil tillage indicate that a variation coefficient of crop productivity is high for all crops. Such a situation, in turn, testifies to the significant influence of weather conditions on the

9. The effect of tillage methods on the yield of corn for grain under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure+ NPK	BP	BP+NPK
Average, t/ha	Combined	4.7	5.2	5.4	5.4	5.5
	Shallow	4.3	4.7	5.1	4.9	5.1
	Difference, %	–8	–10	–6	–8	–7
Multiplicity of yield growth compared to the reference area	Combined	–	1.1	1.2	1.2	1.2
	Shallow	–	1.1	1.2	1.1	1.2
Maximum, t/ha	Combined	7.4	9.1	9.9	8.6	8.4
	Shallow	8.1	8.3	9.7	8.7	8.7
	Difference, %	10	–9	–2	2	4
Multiplicity of yield growth compared to the reference area	Combined	–	1.2	1.3	1.2	1.0
	Shallow	–	1.0	1.2	1.1	1.1
Maximum compared to average, multiplicity	Combined	1.6	1.7	1.8	1.6	1.5
	Shallow	1.9	1.8	1.9	1.8	1.7

processes of plant growth and development. Of the investigated crops, the productivity of sugar beets fluctuates to a greater extent (50 %), to a lesser extent – winter wheat after peas and corn for grain (30 %).

Having a rather high instability in hydrothermal conditions over the years, crop rotation productivity fluctuates much less. The variation coefficient for this indicator varies in the range of 15–18 % for fertilization systems, having 13 % for the reference area without fertilizers. This is one of the most important functions of crop rotation – crops response differently to different factors, accordingly, the more crops, the more diverse the system is, which in general significantly increases the sustainability of agriculture.

Therefore, by the general indicator of the average long-term productivity of crop rotation, shallow tillage is inferior to combined tillage by 4–8 %, when having 5 % confidence level (Table 10). That is, the systematic application of manure along with shallow loosening is inferior to the combined cultivation system in terms of the yield of fodder units, which is obviously related to the different quality of plowing the organic fertilizers in the arable layer. The disadvantages of shallow tillage are leveled by the effect of by-products on fertilizer. Optimizing

10. The effect of tillage on crop rotation productivity under different fertilization systems (2013–2020)

Crop yield	Tillage	Fertilizer variants				
		Reference area	Manure	Manure + NPK	BP	BP + NPK
Average, t/ha	Combined	3.2	3.6	4.2	4.1	4.2
	Shallow	3.0	3.4	4.0	3.9	4.1
	Difference, %	–5	–8	–6	–5	–4
Multiplicity of yield growth compared to the reference area	Combined	–	1.1	1.3	1.3	1.3
	Shallow	–	1.0	1.3	1.2	1.3
Maximum, t/ha	Combined	5.4	6.5	7.2	6.5	6.6
	Shallow	5.5	6.0	6.7	6.6	6.7
	Difference, %	3	–7	–7	1	2
Multiplicity of yield growth compared to the reference area	Combined	–	1.2	1.3	1.2	1.2
	Shallow	–	1.1	1.2	1.2	1.2
Maximum compared to average, multiplicity	Combined	1.7	1.8	1.7	1.6	1.6
	Shallow	1.8	1.8	1.7	1.7	1.7

hydrothermal conditions makes it possible to increase the average long-term crop rotation productivity for all tillage and fertilization variants by 1.6–1.8 times up to the level of 6.0–7.0 tons of fodder units per hectare.

When applying fertilizer systems with manure, the productivity of crop rotation under the traditional combined tillage system is significantly higher by 0.2 tons of fodder units per hectare compared to the variant with shallow loosening. In terms of the profitability of winter wheat grain, it will be about UAH 400 /ha (prices in 2021). At the same time, fuel consumption in the first case will be higher than in the second one by 5 l/ha, which is equivalent to UAH 150/ha at current prices. This indicates that when having livestock specialization with the production of a significant amount of organic fertilizers of animal origin, it is advisable to use a combined system of soil cultivation, for plant-oriented agrarian production to save fuel surface loosening should be used for all crops.

Conclusions. The methods of soil cultivation under different fertilization systems significantly affect some properties of typical black soil. When applying shallow loosening, there is a tendency to increase the density of the subsoil layer, the differentiation of the upper soil layer by the content of nitrogen, phosphorus and potassium, and the growth of humus reserves.

From the studied crops, only winter wheat almost does not respond to the tillage method, in particular after peas, which can be explained by a rather long period from the previous plowing and better conditions of nitrogen nutrition. When applying shallow tillage, row crops reduce their productivity, especially when applying manure for a rather long time. Obviously, this situation can be explained by a decrease in the effectiveness of organic fertilizers during surface distribution without their plowing due to uneven mixing with the arable layer of the soil.

In years of favorable moisture conditions, the negative impact of shallow tillage is leveled by the systematic use of plant waste as a fertilizer when growing sugar beet, corn for grain, peas and barley. This can be explained by the positive effect of mulch, previously left by-products for fertilizer, which decompose faster in the years with favorable hydrothermal conditions, with the release of additional macro- and microelements. Moreover, soybeans always respond well to straw fertilization under both studied tillage systems.

The multiplicity of crop productivity growth when applying different fertilization systems fluctuates greatly by crops in terms of favorable conditions and tillage systems, and by the indicator of crop rotation productivity, it mostly varies in the range from 1.2 to 1.3. The yields of fodder units in favorable years prevail over the ones obtained in average years by 1.7–1.8 times.

When applying fertilization systems with manure, the productivity of the crop rotation under the traditional combined tillage system is significantly higher by 2 centners of fodder units per hectare compared to the variants with shallow loosening. In terms of the profitability of winter wheat grain, it will be about UAH 400/ha. At the same time, fuel consumption in the first case will be higher than in the second one by 5 l/ha, which is equivalent to UAH 150/ha at current prices. This indicates that when having livestock specialization with the production of a significant amount of organic fertilizers of animal origin, it is advisable to use a combined system of soil cultivation, for plant-oriented agrarian production to save fuel surface loosening should be used for all crops.

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ПОВЕРХНЕВИЙ І КОМБІНОВАНИЙ ОБРОБІТОК ЧОРНОЗЕМУ ТИПОВОГО ЗА РІЗНОЇ СПЕЦІАЛІЗАЦІЇ АГРАРНОГО ВИРОБНИЦТВА В ЛІВОБЕРЕЖНОМУ ЛІСОСТЕПУ УКРАЇНИ

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Анотація. *У статті наведено результати довгострокових експериментальних досліджень впливу різних способів основного обробітку ґрунту на показники родючості ґрунту та продуктивність культур сівозміни на різних фонах удобрення. Польові дослідження проводили протягом 2013–2020 років на землях Полтавської дослідної станції інституту свинарства та агропромислового виробництва НААН. Встановлено, що систематичне застосування органічних і органо-мінеральних систем удобрення супроводжується поліпшенням*

поживного режиму чорнозему типового з диференціацією орного шару за кількістю фосфору і калію за тривалого мінімального розпушення. Відзначається тенденція до зростання щільності у шарах 20–40 і 40–60 см на фоні систематичного мілкого обробітку, де цей показник перевищує верхню риску оптимальних меж 1,0–1,3 г/см^3. Фон заорювання гною і мінеральних добрив порівняно з поверхневим розпушуванням дає змогу додатково щорічно секвеструвати 0,3–0,4 т/га вуглецю, що еквівалентно 1,2–1,6 т вуглекислого газу. За середньою багаторічною врожайністю кукурудзи на силос мілке розпушення поступається комбінованому обробітку у середньому на 10 %. Тенденції до зниження середньої багаторічної продуктивності посівів сої, ячменю ярого і гороху при застосуванні мінімального обробітку ґрунту відносно комбінованого проявляються лише на окремих варіантах удобрення. В оптимальних умовах тепло- і вологозабезпечення співвідношення зерна і соломи у сої звужується. На пшениці озимій після гороху відзначається тенденція до переваги мілкого розпушення. Співвідношення зерна до соломи культури у сприятливих умовах значно зростає. Кукурудза краще реагує на комбіновану систему обробітку, яка переважає за виходом зерна мілке розпушення за варіантами удобрення на 6–10 %. В сприятливих умовах співвідношення стебел до зерна істотно зростає, особливо на удобрених фонах. З досліджуваних культур у більшій мірі стосовно особливостей умов року коливається продуктивність буряків цукрових, в меншій мірі – пшениці озимої по гороху і кукурудзи на зерно. За показником середньої багаторічної продуктивності сівозміни мілкий обробіток поступається комбінованому на 4–8 % за рівня достовірності 5 %. За внесення гною доцільно використовувати комбіновану систему обробітку ґрунту, за рослинницької спрямованості аграрного виробництва під усі культури економічно доцільно застосовувати поверхневе розпушення.

Ключові слова: *обробіток ґрунту, добрива, спеціалізація, аграрне виробництво, сівозміна, вологозабезпечення, урожайність, ефективність*