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**IMPACT OF BASIC TILLAGE SYSTEMS AND FERTILIZATION
ON AGROCHEMICAL INDICES OF SOIL FERTILITY IN THE RIGHT BANK
OF THE FOREST-STEPPE OF UKRAINE**

Abstract: The paper presents the results of stationary multifactor field experiment on study of the mutual impact of various systems of soil deep and surface tillage in combination with various levels of organic and mineral fertilizers application on crop rotation performance, as well as on a number of agrochemical indicators of black soil fertility. Researches were carried out as a stationary field experiment on the experimental field of Bila Tserkva National Agrarian University in 2013-2018. During the crop rotation in all the studied tillage methods, especially mouldboardless and disking tillage, the hydrolytic acidity of the arable layer increased with increase in fertilizer rates, and the amount of bases absorbed, saturation degree, level of exchangeable calcium and magnesium cations decreased, but in most cases these changes were not significant. Systematic mouldboardless and disking tillage enhance the topsoil heterogeneity in relation to agrochemical indicators of its fertility. Heterogeneity increases with increase in the level of applied fertilizers. With the mouldboard tillage during the crop rotation period at unfertilized areas, the largest part of humus loss in the arable layer is observed in the top, and the smallest - in its bottom parts; the opposite pattern was observed on fertilized areas at the highest rate. With mouldboardless and disking tillage, directly opposite patterns were observed in comparison with mouldboard tillage. An annual application of 8 t/ha of manure + N₇₆P₆₄K₅₇ stabilizes the humus state of the arable soil layer when carrying out differentiated and disking tillage in crop rotation. Fertilization rate of 12 t/ha of manure + N₉₅P₈₂K₇₅ for these tillage options a significant increase in humus and total nitrogen reserves is provided.

Keywords: tillage, fertilizer, soil, humus, black soil, agrochemical properties, fertility, crop rotation, productivity

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**ИЗМЕНЕНИЕ АГРОХИМИЧЕСКИХ ПОКАЗАТЕЛЕЙ ПЛОДОРОДИЯ ПАХОТНОГО СЛОЯ ЧЕРНОЗЁМА
ТИПИЧНОГО ЗА РОТАЦИЮ ПОЛЕВОГО СЕВООБОРОТА ПОД ВОЗДЕЙСТВИЕМ СИСТЕМ
ОСНОВНОГО ВОЗДЕЛЫВАНИЯ И УДОБРЕНИЯ В ПРАВОБЕРЕЖНОЙ ЛЕСОСТЕПИ УКРАИНЫ**

Аннотация: В статье представлены результаты стационарного многофакторного полевого опыта по изучению взаимовлияния различных систем глубокой и поверхностной обработки почвы в сочетании с различными уровнями применения органических и минеральных удобрений на продуктивность севооборотов, а также на ряд агрохимических индикаторов плодородия черноземной почвы. Исследования выполнены в стационарном полевым опыте на

опытном поле Белоцерковского национального университета в 2013–2018 гг. На протяжении ротации севооборота при всех исследуемых возделываниях, особенно безотвального и дискового, с повышением норм удобрений гидролитическая кислотность пахотного слоя росла, а сумма поглощенных оснований, степень насыщения ими, содержание обменных катионов кальция и магния уменьшались, однако в большинстве случаев эти изменения не существенны. Систематическая безотвальная и дисковое возделывание усиливают гетерогенность пахотного слоя почвы относительно агрохимических показателей его плодородия. С повышением уровня внесенных удобрений гетерогенность усиливается. При отвальном на протяжении ротационного периода севооборота возделывания удобренных участков наибольшая часть убыли гумуса в пахотном слое наблюдается в верхней, наименьшая – в нижней его частях; на удобренных наивысшей нормой удобрений вариантах зафиксирована обратная закономерность. При безотвальном и дисковом возделывании прослеживались прямо противоположные закономерности по сравнению с отвальным. Ежегодное внесение 8 т/га гною + $N_{76}P_{64}K_{57}$ стабилизирует гумусное состояние пахотного слоя почвы при проведении в севообороте дифференцированного и дискового возделывания. Норма удобрений 12 т/га гною + $N_{95}P_{82}K_{75}$ на этих вариантах возделывания обеспечивает существенный рост запасов гумуса и общего азота.

Ключевые слова: возделывание, удобрение, почва, гумус, чернозем, агрохимические свойства, плодородие, севооборот, производительность,

Для цитирования: Изменение агрохимических показателей плодородия пахотного слоя чернозёма типичного за ротацию полевого севооборота под воздействием систем основного возделывания и удобрения в правобережной лесостепи Украины / И. Д. Примак, Ю. В. Федорук, В. Н. Караульна, Л. В. Езерковская, А. Б. Панченко, И. А. Покотыло, С. В. Горновская, И. А. Панченко, Н. Н. Федорук, С. В. Ображей // Вес. Нац. акад. навук Беларусі. Сер. аграр. навук. – 2021. – Т. 59, № 1. – С. 41–50. <https://doi.org/10.29235/1817-7204-2021-59-1-41-50>

Introduction. Almost 65 % of the total area and 72.7 % of arable land in Ukraine are black soils. The share of Ukrainian black soil is 13-14 % from European and 6-8 % from world's reserves [1].

The integral indicator of soil fertility, which most objectively characterizes it, is the content of humus in it. The largest annual losses of it in Ukraine occurred in the 60-80s of the twentieth century, reaching 0.55-0.60 t/ha. This is due to the intensification of the agricultural industry, in particular, unreasonably high proportion of row crops (especially sugar beet and corn) and energy-intensive measures of mechanical soil tillage. During 2006-2010 the humus balance in soils was severely deficient: annual losses ranged from 0.40 t/ha in 2008 to 0.53 t/ha in 2010, and the average value in Ukraine was 0.46 t/ha [1].

Soil dehumification processes, especially in arable land, have become so widespread today that they have threatened the food security of the state. The results of agrochemical certification of agricultural land during the last 5 rounds (1986-2010) showed that the humus content in soils decreased on 0.22 % and now is 3.14 %.

The decrease in humus content in the soils of Ukraine is due to the following reasons: high share of ploughed territory (53.9 %) and agricultural land (78.0 %); very low rates of organic fertilizers application (less than 0.6 t/ha, with recommended 8-14 t/ha); unbalanced use of mineral fertilizers, too high or low; gross violation of the crop area structure (excessive proportion of row or cereal crops with continuous sowing method, monoculture, almost complete absence of perennial grasses, low share of legumes); intensive mechanical tillage [1].

The data of the last land certification also testified about the expansion of acid soils in Polissia and the Forest-Steppe of Ukraine. And the main reasons scientists believe: washing water regime of soil, acidic or carbonate parent rock, anthropogenic factors. Among the latter, scientists point to the large volumes use of chemically and physiologically acidic mineral fertilizers, acid precipitation, decalcification (taking by crops and infiltration of calcium and magnesium due to the washout by rainfall and melt water), climate change [2].

According to the State Institution “Soils Protection Institute”, Ukraine has almost 4 million hectares of acidic soils, 1978 thousand hectares of which were found in the Forest-Steppe zone. Scientists state the constant acidification of black soils caused by intense decalcification (Periodychna dopovid. Pro stan hruntiv na zemliakh silskohospodarskoho pryznachennia Ukrainy, 2015).

The agricultural practice convinces the necessity of urgent implementation of a complex of scientifically grounded measures concerning the reproduction of fertile arable land of Ukraine in order to obtain environmentally friendly, economically competitive crop production.

Some scientists propose to calculate the amount of compensation for losses to the state in the case of a decrease in soil fertility as a result of the reduction humus in it. Between 1986 and 2005, the annual loss of arable ground humus was about 29 million t, equivalent to \$ 57 billion [3].

Analysis of recent research and publications. The decrease in the humus content in soils after their plowing cannot be explained only by mechanical tillage. The agricultural use of the soil causes the alienation of the major part of the organic matter created by the plants through photosynthesis.

On the Luvisol soils with 1.7-2.0 % humus content, its annual losses are on average 0.5-1.0 t/ha, and the residues left after harvest provide formation of 0.3-0.5 t/ha humus. In a typical ten-crop grain-row rotation of the Forest-Steppe with the average annual mineralization of humus 0.9 t/ha on the unfertilized black soil and the annual flow of plant residues 3-5 t/ha [4].

A certain number of scientists link the decrease in arable soil humus with the use of ploughing [5-11].

According to Ovsinskyi I. Ye., the most fertile top layer of soil should always be on the surface. Only under this condition soil can be enriched with humus. On this basis, he strongly recommended to apply only surface tillage to a depth of 5-7 cm without turning the top layer [5]. To prevent further decline of soil fertility, Faulkner E. advised to use only surface (to a depth of 7.5 cm) soil tillage with disk ploughed [7].

In the opinion of Maltsev T. S., an annual plowing with the turning of the slice due to a significant change in the conditions of the microbiota with increasing aerobic processes, inevitably leads to a decrease in soil fertility. And mouldboardless tillage helps to accumulate humus and improve the structural condition of the soil. Ideas of Maltsev T. S. were further developed in the soil protection system of arid agriculture regions of Kazakhstan, Siberia, and the Altai Territory [12].

According to the domestic supporters of “non-plowing agriculture”, mouldboardless tillage combined with the application of mineral and organic fertilizers promotes the growth of soil humus reserves more than mouldboard tillage and can ensure its deficit-free balance with less manure. The localization of vegetative litterfall, fertilizers and root systems in the surface layer of soil under non-plowing tillage is necessary to ensure soil protection effect and modeling of the natural sod (black soil) formation process in production conditions [13, 14].

According to some scientists, differentiation of arable layer on fertility with insufficient moistening of its upper (0-10 cm) part deprives plants to use fully localized nutrients there and can adversely affect the yield. The humus content in the soil layer 0-40 cm did not change significantly over the nine-year with mouldboardless tillage, but in the upper part (0-10 cm) it increased on 0.25 %. Therefore, scientists propose to combine mouldboard and mouldboardless tillage at different depths [15].

It is known that the effective humification of plant residues occurs due to their decomposition in close contact with the mineral part of the soil. It is this circumstance, and not the large mass of litterfall that is localized on the surface of the soil under mouldboardless tillage, determines the best conditions of humus formation. Poor contact of soil with organic matter that coming from mouldboardless tillage, constant impact of atmospheric factors on them cause chemistry process of substances transformation, reminiscent of smoldering or slow burning. Root residues localized in the surface layer of soil due to systematic impact of agricultural machinery undergo more intense mineralization than during cultural plowing. In the lower layers, where anaerobic processes predominate and the best conditions for the formation of humus are created, a small number of humus-forming agents are produced under the mouldboardless tillage [16-18].

In the case of mouldboardless tillage, the areas of receipt of humus-forming agents (plant residues, organic fertilizers, elements of ash and nitrogen nutrition of plants) do not coincide with the zones of their effective humification. In the case of intra-soil intake of organic substances, the inclusion of their decomposition products in the composition of humic substances is 2-3 times higher than that of the surface [19]. On this basis, Linnik M.K. and Batsula O.O. strongly believe that not a thin soil layer any kind of humification is of paramount importance in achieving high yields and stabilizing them in different weather conditions, but, if possible, a deeper and more well-humidified root layer. Scientists have concluded that in order to stabilize the humus state and the effective work of humus-formers and especially manure, the combination of minimal tillage with deep wrapping of organic fertilizers is the most rational [20].

Most domestic scientists to improve the agrochemical properties of soil recommend to plow in crop rotations once in 3-5 years (usually in fields under row crops where organic fertilizers are applied), and in other years - surface, shallow, mouldboardless tillage for different depth taking into account soil and climatic conditions, biological features of crops and their alternation in rotation, weediness, etc. [21-25].

In the experiment conducted by Institute for soil science and agrochemistry research named after O. N. Sokolovsky, as well as by Kharkiv National Agrarian University named after V. V. Dokuchaev, humus content is reduced under “No till” compared to ploughing and disking of typical heavy loam black soil [26].

On the usual heavy-loam black soils of the Private JSC “Agro-Soyuz” in Sinelnikovskiy district of Dnipropetrovsk region in the layer 0-40 cm, humus increase is reliable under mouldboardless and zero tillage, compared with plowing [27].

Materials and methods. Studies were conducted during 2013-2018 in a stationary field experiment at the field of Bila Tserkva National Agrarian University. Soil is a black typical deep with low humus, light loamy. Experiment was done in three times replications, accounting area is 112 m². Four basic tillage treatments (Table 1) and four fertilizer levels were studied: zero - no fertilizer, first - 8 t/ha of manure + N₇₆P₆₄K₅₇, second - 12 t/ha of manure + N₉₅P₈₂K₇₂, third - 16 t/ha of manure + N₁₁₂P₁₀₀K₈₆.

T a b l e 1. Systems of basic tillage in crop rotation

Field No	Crop in crop rotation	Tillage*			
		1 mouldboard (control)	2 mouldboardless	3 mouldboard & mouldboardless (differentiated)	4 disking (continuous shallow)
		Depth (cm) and cultivation			
1	Soybean	16-18 (p.)	16-18 (d. t.)	16-18 (d. t.)	10-12 (d. h.)
2	Winter wheat + white mustard on green manure	10-12 (d. h.)	10-12 (d. t.)	10-12 (d. h.)	10-12 (d. h.)
3	Sunflower	25-27 (p.)	25-27 (d. t.)	25-27 (p.)	10-12 (d. h.)
4	Spring barley + white mustard on green manure	10-12 (d. h.)	10-12 (d. t.)	10-12 (d. h.)	10-12 (d. h.)
5	Maize	25-27 (p.)	25-27 (d. t.)	25-27 (d. t.)	10-12 (d. h.)

*Note: p. – ploughing, d. h. – disc harrow, d.t. – deep tiller.

Ploughing to a depth of 16-18 and 25-27 cm was carried out by the mounted ploughshare plow PLN - 3-35, shallow tillage on 10-12 cm - by heavy disk harrow BDV - 3.0, mouldboardless tillage - by deep-tiller GR - 3.4. Organic fertilizers, such as semi-rotted manure from cattle, ammonium nitrate, simple granular superphosphate and potassium salt from the mineral fertilizers were applied.

Analyzes and calculations were performed according to modern methods of agrochemical research: humus - by the Tyurin method (State standard of Ukraine 4289:2004); exchange acidity - by potentiometric method (State standard of Ukraine ISO 10390-2001); hydrolytic acidity - pH - by the Kappen metric method (State standard 2612 -91); the sum of the absorbed bases - by Kappen - Gilkowitz; the degree of basics saturation - by the calculation method according to the formula (State standard of Ukraine ISO 11260-2001); mobile phosphorus and potassium – in one sample weight by the Chirikov method (State standard of Ukraine 4115: 2002); ammonia nitrogen – using Nessler’s reagent (method of Central Research Institute of Agrochemical Services for Agriculture - CINAO); nitric nitrogen - by photocolometric method with disulphophenolic acid (State standard of Ukraine 4729: 2007); total nitrogen - by Kjeldahl; calcium and magnesium exchange cations - by the trilonometric method [28].

Results and discussion. The annual reduction of humus content in arable layer of typical black soil on the unfertilized plots under mouldboard, mouldboardless, differentiated and disking tillage in crop rotation was respectively 1.12, 1.42, 0.72 and 0.90 t/ha. Under mouldboard and mouldboardless tillage with application 8 t of manure on each hectare of rotation + N₇₆P₆₄K₅₇, the annual loss of humus was 0.20 and 0.48 t/ha, respectively, and under differentiated and disking tillage its increase was on 0.22 and 0.06 t/ha. The annual increase of humus content in the areas fertilized with 12 t/ha of manure + N₉₅P₈₂K₇₂ and 16 t/ha of manure + N₁₁₂P₁₀₀K₈₆ was respectively: under mouldboard tillage - 0.34 and 0.54 t/ha, under mouldboardless - 0.20 and 0.46, differentiated - 0.66 and 0.92, disking - 0.48 and 0.72 t/ha (Table 2).

Table 2. Agrochemical indices of fertility of arable (0-30 cm) soil layer: in the numerator for 2013, in the denominator for 2018

Tillage	Level of fertilizers	Humus	Total Nitrogen, t/ha	pH KCl	Hr	S	V, %	P ₂ O ₅	K ₂ O	N-NH ₄ ⁺	N- NH ₄ ⁺ + N-NO ₃ ⁻	Ca ²⁺	Mg ²⁺
					mmol per 100 g of soil			mg/kg of soil				mmol per 100 g of soil	
mouldboard (control)	1	<u>121,5</u> <u>115,9</u>	<u>10,56</u> <u>10,05</u>	<u>6,36</u> <u>6,25</u>	<u>2,43</u> <u>2,51</u>	<u>22,3</u> <u>21,2</u>	<u>90,2</u> <u>89,4</u>	<u>118,2</u> <u>110,1</u>	<u>77,8</u> <u>74,0</u>	<u>33,1</u> <u>29,9</u>	<u>42,9</u> <u>37,4</u>	<u>15,71</u> <u>15,26</u>	<u>2,25</u> <u>2,19</u>
	2	<u>123,9</u> <u>122,9</u>	<u>10,77</u> <u>10,55</u>	<u>6,34</u> <u>6,18</u>	<u>2,46</u> <u>2,58</u>	<u>21,9</u> <u>20,5</u>	<u>89,9</u> <u>88,8</u>	<u>117,9</u> <u>121,3</u>	<u>78,4</u> <u>80,3</u>	<u>33,6</u> <u>34,8</u>	<u>42,5</u> <u>44,6</u>	<u>15,66</u> <u>15,03</u>	<u>2,23</u> <u>2,09</u>
	3	<u>121,2</u> <u>122,9</u>	<u>10,53</u> <u>10,68</u>	<u>6,41</u> <u>6,20</u>	<u>2,49</u> <u>2,64</u>	<u>22,1</u> <u>20,4</u>	<u>89,9</u> <u>88,5</u>	<u>116,8</u> <u>124,5</u>	<u>79,0</u> <u>84,8</u>	<u>32,7</u> <u>37,0</u>	<u>43,3</u> <u>47,3</u>	<u>15,75</u> <u>14,88</u>	<u>2,24</u> <u>1,95</u>
	4	<u>123,2</u> <u>125,9</u>	<u>10,71</u> <u>10,95</u>	<u>6,38</u> <u>6,14</u>	<u>2,43</u> <u>2,61</u>	<u>21,8</u> <u>19,9</u>	<u>90,0</u> <u>88,4</u>	<u>117,3</u> <u>126,7</u>	<u>78,8</u> <u>87,2</u>	<u>32,9</u> <u>38,3</u>	<u>42,7</u> <u>49,5</u>	<u>15,64</u> <u>14,60</u>	<u>2,25</u> <u>1,86</u>
mouldboardless	1	<u>121,2</u> <u>114,1</u>	<u>10,53</u> <u>9,83</u>	<u>6,37</u> <u>6,34</u>	<u>2,49</u> <u>2,60</u>	<u>22,4</u> <u>20,9</u>	<u>90,0</u> <u>88,9</u>	<u>116,5</u> <u>104,2</u>	<u>78,3</u> <u>71,7</u>	<u>33,3</u> <u>28,5</u>	<u>43,1</u> <u>35,8</u>	<u>15,58</u> <u>15,01</u>	<u>2,25</u> <u>2,16</u>
	2	<u>122,0</u> <u>119,6</u>	<u>10,60</u> <u>10,20</u>	<u>6,40</u> <u>6,35</u>	<u>2,41</u> <u>2,55</u>	<u>21,7</u> <u>19,8</u>	<u>90,0</u> <u>88,6</u>	<u>118,3</u> <u>119,5</u>	<u>77,5</u> <u>78,3</u>	<u>32,9</u> <u>32,2</u>	<u>43,3</u> <u>42,5</u>	<u>15,67</u> <u>14,91</u>	<u>2,23</u> <u>2,01</u>
	3	<u>123,2</u> <u>124,2</u>	<u>10,71</u> <u>10,78</u>	<u>6,43</u> <u>6,46</u>	<u>2,47</u> <u>2,65</u>	<u>21,9</u> <u>19,5</u>	<u>89,9</u> <u>88,0</u>	<u>119,0</u> <u>123,5</u>	<u>77,7</u> <u>81,4</u>	<u>32,8</u> <u>35,9</u>	<u>42,8</u> <u>46,1</u>	<u>15,69</u> <u>14,70</u>	<u>2,26</u> <u>1,93</u>
	4	<u>120,8</u> <u>123,1</u>	<u>10,50</u> <u>10,78</u>	<u>6,39</u> <u>6,44</u>	<u>2,39</u> <u>2,60</u>	<u>22,0</u> <u>19,3</u>	<u>90,2</u> <u>88,1</u>	<u>116,7</u> <u>123,3</u>	<u>79,1</u> <u>85,9</u>	<u>33,1</u> <u>37,3</u>	<u>43,5</u> <u>48,0</u>	<u>15,64</u> <u>14,47</u>	<u>2,24</u> <u>1,83</u>
mouldboard & mouldboardless (differentiated)	1	<u>123,3</u> <u>119,8</u>	<u>10,73</u> <u>10,41</u>	<u>6,35</u> <u>6,39</u>	<u>2,39</u> <u>2,46</u>	<u>21,6</u> <u>20,8</u>	<u>90,0</u> <u>89,4</u>	<u>117,7</u> <u>112,1</u>	<u>78,6</u> <u>75,7</u>	<u>33,2</u> <u>30,9</u>	<u>42,6</u> <u>39,0</u>	<u>15,66</u> <u>15,34</u>	<u>2,25</u> <u>2,21</u>
	2	<u>120,7</u> <u>121,8</u>	<u>10,49</u> <u>10,55</u>	<u>6,39</u> <u>6,45</u>	<u>2,37</u> <u>2,48</u>	<u>22,2</u> <u>21,1</u>	<u>90,4</u> <u>89,5</u>	<u>116,9</u> <u>122,0</u>	<u>78,9</u> <u>82,7</u>	<u>32,8</u> <u>35,4</u>	<u>42,8</u> <u>45,8</u>	<u>15,70</u> <u>15,20</u>	<u>2,23</u> <u>2,14</u>
	3	<u>124,3</u> <u>126,7</u>	<u>10,80</u> <u>11,11</u>	<u>6,37</u> <u>6,45</u>	<u>2,38</u> <u>2,54</u>	<u>22,1</u> <u>20,6</u>	<u>90,3</u> <u>89,0</u>	<u>118,5</u> <u>127,3</u>	<u>77,6</u> <u>85,5</u>	<u>33,2</u> <u>38,2</u>	<u>43,2</u> <u>47,8</u>	<u>15,72</u> <u>14,99</u>	<u>2,26</u> <u>2,07</u>
	4	<u>123,1</u> <u>127,7</u>	<u>10,70</u> <u>11,16</u>	<u>6,41</u> <u>6,51</u>	<u>2,41</u> <u>2,60</u>	<u>21,8</u> <u>20,1</u>	<u>90,0</u> <u>88,5</u>	<u>119,1</u> <u>131,0</u>	<u>78,6</u> <u>88,3</u>	<u>32,7</u> <u>39,3</u>	<u>43,4</u> <u>50,9</u>	<u>15,68</u> <u>14,77</u>	<u>2,27</u> <u>1,96</u>
disking (continuous shallow)	1	<u>120,9</u> <u>116,4</u>	<u>10,51</u> <u>10,08</u>	<u>6,37</u> <u>6,33</u>	<u>2,37</u> <u>2,49</u>	<u>21,9</u> <u>20,5</u>	<u>90,2</u> <u>89,2</u>	<u>118,6</u> <u>109,0</u>	<u>78,0</u> <u>72,6</u>	<u>32,4</u> <u>28,4</u>	<u>43,0</u> <u>37,7</u>	<u>15,74</u> <u>15,26</u>	<u>2,24</u> <u>2,19</u>
	2	<u>120,4</u> <u>120,7</u>	<u>10,46</u> <u>10,32</u>	<u>6,35</u> <u>6,29</u>	<u>2,40</u> <u>2,55</u>	<u>21,6</u> <u>19,8</u>	<u>90,0</u> <u>88,6</u>	<u>117,6</u> <u>120,0</u>	<u>78,7</u> <u>80,1</u>	<u>33,0</u> <u>33,6</u>	<u>42,8</u> <u>44,3</u>	<u>15,68</u> <u>15,01</u>	<u>2,25</u> <u>2,13</u>
	3	<u>122,2</u> <u>124,6</u>	<u>10,62</u> <u>10,86</u>	<u>6,40</u> <u>6,45</u>	<u>2,35</u> <u>2,53</u>	<u>22,1</u> <u>19,9</u>	<u>90,4</u> <u>88,7</u>	<u>118,0</u> <u>124,0</u>	<u>79,4</u> <u>84,0</u>	<u>33,3</u> <u>37,3</u>	<u>43,6</u> <u>47,0</u>	<u>15,64</u> <u>14,72</u>	<u>2,27</u> <u>2,01</u>
	4	<u>123,2</u> <u>126,8</u>	<u>10,71</u> <u>11,08</u>	<u>6,38</u> <u>6,46</u>	<u>2,43</u> <u>2,64</u>	<u>22,3</u> <u>19,8</u>	<u>90,2</u> <u>88,2</u>	<u>116,8</u> <u>125,9</u>	<u>79,3</u> <u>87,0</u>	<u>32,6</u> <u>37,8</u>	<u>43,2</u> <u>48,9</u>	<u>15,65</u> <u>14,56</u>	<u>2,24</u> <u>1,87</u>
SD ₀₅		2,3	0,22	0,21	0,24	2,5	3,6	3,9	2,8	2,1	3,0	0,95	0,34
Differentiated	0	<u>123,3</u> <u>119,8</u>	<u>10,73</u> <u>10,41</u>	<u>6,35</u> <u>6,39</u>	<u>2,39</u> <u>2,46</u>	<u>21,6</u> <u>20,8</u>	<u>90,0</u> <u>89,4</u>	<u>117,7</u> <u>112,1</u>	<u>78,6</u> <u>75,7</u>	<u>33,2</u> <u>30,9</u>	<u>42,6</u> <u>39,0</u>	<u>15,66</u> <u>15,34</u>	<u>2,25</u> <u>2,21</u>
	1	<u>120,7</u> <u>121,8</u>	<u>10,49</u> <u>10,55</u>	<u>6,39</u> <u>6,45</u>	<u>2,37</u> <u>2,48</u>	<u>22,2</u> <u>21,1</u>	<u>90,4</u> <u>89,5</u>	<u>116,9</u> <u>122,0</u>	<u>78,9</u> <u>82,7</u>	<u>32,8</u> <u>35,4</u>	<u>42,8</u> <u>45,8</u>	<u>15,70</u> <u>15,20</u>	<u>2,23</u> <u>2,14</u>
	2	<u>124,3</u> <u>126,7</u>	<u>10,80</u> <u>11,11</u>	<u>6,37</u> <u>6,45</u>	<u>2,38</u> <u>2,54</u>	<u>22,1</u> <u>20,6</u>	<u>90,3</u> <u>89,0</u>	<u>118,5</u> <u>127,3</u>	<u>77,6</u> <u>85,5</u>	<u>33,2</u> <u>38,2</u>	<u>43,2</u> <u>47,8</u>	<u>15,72</u> <u>14,99</u>	<u>2,26</u> <u>2,07</u>
	3	<u>123,1</u> <u>127,7</u>	<u>10,70</u> <u>11,16</u>	<u>6,41</u> <u>6,51</u>	<u>2,41</u> <u>2,60</u>	<u>21,8</u> <u>20,1</u>	<u>90,0</u> <u>88,5</u>	<u>119,1</u> <u>131,0</u>	<u>78,6</u> <u>88,3</u>	<u>32,7</u> <u>39,3</u>	<u>43,4</u> <u>50,9</u>	<u>15,68</u> <u>14,77</u>	<u>2,27</u> <u>1,96</u>
Shallow tillage	0	<u>120,9</u> <u>116,4</u>	<u>10,51</u> <u>10,08</u>	<u>6,37</u> <u>6,33</u>	<u>2,37</u> <u>2,49</u>	<u>21,9</u> <u>20,5</u>	<u>90,2</u> <u>89,2</u>	<u>118,6</u> <u>109,0</u>	<u>78,0</u> <u>72,6</u>	<u>32,4</u> <u>28,4</u>	<u>43,0</u> <u>37,7</u>	<u>15,74</u> <u>15,26</u>	<u>2,24</u> <u>2,19</u>
	1	<u>120,4</u> <u>120,7</u>	<u>10,46</u> <u>10,32</u>	<u>6,35</u> <u>6,29</u>	<u>2,40</u> <u>2,55</u>	<u>21,6</u> <u>19,8</u>	<u>90,0</u> <u>88,6</u>	<u>117,6</u> <u>120,0</u>	<u>78,7</u> <u>80,1</u>	<u>33,0</u> <u>33,6</u>	<u>42,8</u> <u>44,3</u>	<u>15,68</u> <u>15,01</u>	<u>2,25</u> <u>2,13</u>
	2	<u>122,2</u> <u>124,6</u>	<u>10,62</u> <u>10,86</u>	<u>6,40</u> <u>6,45</u>	<u>2,35</u> <u>2,53</u>	<u>22,1</u> <u>19,9</u>	<u>90,4</u> <u>88,7</u>	<u>118,0</u> <u>124,0</u>	<u>79,4</u> <u>84,0</u>	<u>33,3</u> <u>37,3</u>	<u>43,6</u> <u>47,0</u>	<u>15,64</u> <u>14,72</u>	<u>2,27</u> <u>2,01</u>
	3	<u>123,2</u> <u>126,8</u>	<u>10,71</u> <u>11,08</u>	<u>6,38</u> <u>6,46</u>	<u>2,43</u> <u>2,64</u>	<u>22,3</u> <u>19,8</u>	<u>90,2</u> <u>88,2</u>	<u>116,8</u> <u>125,9</u>	<u>79,3</u> <u>87,0</u>	<u>32,6</u> <u>37,8</u>	<u>43,2</u> <u>48,9</u>	<u>15,65</u> <u>14,56</u>	<u>2,24</u> <u>1,87</u>
SD _{0,95}		2,3	0,22	0,21	0,24	2,5	3,6	3,9	2,8	2,1	3,0	0,95	0,34

The content of total nitrogen in the arable layer of soil on unfertilized plots and fertilized by 8 t of manure + $N_{76}P_{64}K_{57}$ decreased annually on 0.102 and 0.044 t/ha under mouldboard tillage, 0.140 and 0.080 – mouldboardless, 0.086 and 0.028 t/ha under systematic shallow tillage respectively. In the case of mouldboard & mouldboardless tillage, this indicator decreased on 0.064 t/ha on unfertilized plots and increased on 0.012 t/ha on fertilized treatments.

For five years of research, this figure declined on 0.51, 0.70, 0.32 and 0.43 t/ha under mouldboard, mouldboardless, differentiated, and disking tillage, respectively.

The applying of 8t/ha of manure + $N_{76}P_{64}K_{57}$ provided its stabilization only under mouldboard & mouldboardless tillage. For the fertilizer rate of 12t/ha + $N_{95}P_{82}K_{72}$ the increase of this indicator was recorded in all plots, but significantly only under differentiated and shallow tillage (on 0.31 and 0.24 t/ha respectively).

The most noticeable changes in the exchange acidity occurred at the plots under mouldboard tillage. Here, on variants unfertilized, fertilized with 8 t/ha of manure + $N_{76}P_{64}K_{57}$, 12 t/ha of manure + $N_{95}P_{82}K_{72}$ and 16 t/ha of manure + $N_{112}P_{100}K_{86}$, pH index decreased on 0.11, 0.16, 0.21 and 0.24 during the rotation period, respectively, with SD_{05} 0.21.

During the five years of observations, hydrolytic acidity increased, and the sums of absorbed bases and the degree of bases saturation decreased. It is noted, that as the level of fertilizer application increases, the difference in these indices at the beginning and end of crop rotation increases.

So the hydrolytic acidity of the arable layer of typical black soil in 2018, compared to 2013, on unfertilized plots, fertilized with 8 t/ha of manure + $N_{76}P_{64}K_{57}$, 12 t/ha of manure + $N_{95}P_{82}K_{72}$ and 16 t/ha of manure + $N_{112}P_{100}K_{86}$ increased respectively on 0.08, 0.12, 0.15 and 0.18 mmol/100 g under mouldboard tillage, on 0.11, 0.14, 0.18 and 0.21- under mouldboardless, 0.07, 0.11, 0.16 and 0.19 - under mouldboard & mouldboardless, on 0.12, 0.15, 0.18 and 0.21 mmol/100 g under disking tillage in crop rotation.

The sum of the absorbed bases and the degree of bases saturation during the specified period of researches on plots unfertilized and fertilized with the above mentioned treatments decreased on 1.1, 1.4, 1.7, 1.9 mmol/100 g and 0.8, 1.1, 1.4, 1.6 % under mouldboard tillage, on 1.5, 1.9, 2.4, 2.7 and 1.1, 1.4, 1.9, 2.1 under mouldboardless, on 0.8, 1.1, 1.5, 1.7 and 0.6, 0.9, 1.3, 1.5 under mouldboard & mouldboardless, 1.4, 1.8, 2.2, 2.5 mmol/100 g and 1.0, 1.4, 1.7, 2.0 % under constant shallow tillage, respectively. The most noticeable changes were in the hydrolytic acidity, the sum of the absorbed bases, the degree of bases saturation under the mouldboardless and disking, the least noticeable – under the differential tillage treatment.

The annual application of physiologically and chemically acidic forms of mineral fertilizers has led to an increase in the hydrolytic acidity of the arable soil layer, a decrease in the amount of absorbed bases and the degree of bases saturation, especially under constant mouldboardless and shallow tillage in crop rotation.

With increasing rates of fertilizers, there was noted a decrease of exchangeable cations content of the arable soil layer. For example, on unfertilized plots, with the application of 8 t/ha of manure + $N_{76}P_{64}K_{57}$, 12 t/ha of manure + $N_{95}P_{82}K_{72}$, 16 t/ha of manure + $N_{112}P_{100}K_{86}$, the loss of exchangeable calcium and magnesium cations for a cycle of rotation was respectively 0.45 and 0.06, 0.63 and 0.14, 0.87 and 0.29, 1.04 and 0.39 mmol/100 g under mouldboard tillage, 0.57 and 0.09, 0.76 and 0.22, 0.99 and 0.33, 1.17 and 0.41 under mouldboardless, 0.32 and 0.04, 0.50 and 0.09, 0.73 and 0.19, 0.91 and 0.31 under mouldboard & mouldboardless, 0.48 and 0.05, 0.67 and 0.12, 0.92 and 0.26, 1.09 and 0.37 mmol/100 g - under disking tillage. Obviously, this is due to the systematic use of fertilizers, especially nitrogen, which accelerate the loss of calcium and magnesium from soil. Therefore, the acidifying action of nitrogen, especially ammonia fertilizers is associated not only with their physiological acidity, but also with the accelerated leaching of calcium.

It has been established that systematic mouldboardless and shallow tillage in crop rotation enhances the heterogeneity of the arable layer, and periodic cultural ploughing (once every 5 years) reduces it. With increasing level of fertilizers, heterogeneity is also increased, which is related to the surface covering them and crop residues into the soil. Thus, on unfertilized plots, the annual humus loss in parts of the plow layer 0-10, 10-20 and 20-30 cm was respectively: under mouldboard tillage in crop rotation - 0.55, 0.35 and 0.22 t/ha (or 49.1, 31.3 and 19.6 % of all its losses from the arable layer); under mouldboardless - 0.33, 0.47 and 0.62 t/ha (23.2; 33.1 and 43.7 %, respectively); under mouldboard &

mouldboardless - 0,25, 0.24 and 0.23 t/ha (35.1, 33.5 and 31.4 %); under disking tillage - 0.18, 0.31 and 0.41 t/ha (20.0, 34.4 and 45.6 %). Under the application per 1 ha of crop rotation, 16 tons of manure + $N_{112}P_{100}K_{86}$ annual humus replenishment in the mentioned parts of the arable layer of black typical soil was respectively: under mouldboard tillage – 0.12, 0.18 and 0.24 t/ha (22.3, 33.3 and 44.4 % of the total weight gain in the arable layer); under mouldboardless - 0.21, 0.16 and 0.09 t/ha (45.6, 34.8 and 19.6 %), under differentiated - 0.34, 0.31 and 0.27 t/ha (37.0, 33.7 and 29.3 %); under disking tillage - 0.36, 0.22 and 0.14 t/ha (50.0, 30.6 and 19.4 %).

Thus, under mouldboard tillage on unfertilized plots of the experiment, the highest proportion of humus loss in the arable layer is recorded in its upper part (0-10 cm), the smallest - in the lower (20-30 cm) part; under mouldboardless and disking tillage there is the opposite regularity.

On fertilized plots with 12 t/ha of manure + $N_{95}P_{82}K_{72}$ and 16 t/ha of manure + $N_{112}P_{100}K_{86}$ under mouldboard tillage, the maximum share of humus replenishment in the arable layer was observed in its lower (20-30 cm), minimum - in the upper (0-10 cm) part; under mouldboardless and shallow tillage, the opposite relation has been noted. In the case of differentiated tillage, both the loss and the replenishment of humus in different parts of the arable layer occur more evenly. Such changes in the humus condition of the soil under the studied tillage systems are explained by different redistribution of plant residues, micro biota and fertilizers in parts of the arable layer, as well as by different ways of receipt of humus-forming agents, conditions of moistening, air and thermal regimes, etc.

Indicators of acidity, amount of absorbed bases, degree of bases saturation, content of exchangeable cations of calcium and magnesium did not differ significantly in parts of soil arable layers 0-10, 10-20 and 20-30 cm under mouldboard and mouldboard & mouldboardless tillages on the unfertilized and fertilized plots with the same rates of fertilizers. Under mouldboardless and disking tillage with increasing depth within the arable layer, there is a decrease in soil acidity, an increase in the degree of bases saturation and the amount of absorbed bases, as well as the content of calcium and magnesium exchange cations. Thus, under the application of the highest rates of fertilizers, soil fertility indices, such as pH, hydrolytic acidity, degree of bases saturation, sum of absorbed bases, content of exchangeable calcium and magnesium cations in 2018 in the upper (0-10 cm) and lower (20-30 cm) parts of the arable layer were respectively: 6.12 and 6.15, 2.65 and 2.56 mmol/100 g, 19.6 and 20.5 mmol/100 g, 88.0 and 88.7 %, 14.32 and 15.01 mmol/100 g, 1.84 and 1.88 mmol/100 g under mouldboard tillage, 6.18 and 6.68, 2.96 and 2.37, 18.1 and 20.4, 86.8 and 90.4, 13.35 and 15.29, 1.75 and 1.90 under mouldboardless tillage, 6.44 and 6.61, 2.65 and 2.57, 19.6 and 20.6, 88.0 and 89.1, 14.49 and 15.03, 1.90 and 2.00 – under mouldboard & mouldboardless tillage, 6.20 and 6.65, 3.02 and 2.37 mmol/100 g, 17.7 and 21.1 mmol/100 g, 87.1 and 90.0 %, 13.96 and 15.47 mmol/100 g, 1.76 and 1.96 mmol/100 g under disking tillage in crop rotation.

Scientists from the Institute of Bioenergy Crops and Sugar Beet also found an increase in soil acidity under mouldboardless tillage in a ten-year stationary experiment on typical low-humus medium-loam black soil. To eliminate this problem, as scientists indicate, it is necessary to periodically (once every 4-5 years) apply the ploughing to the entire depth of the arable layer, thereby equalizing the acidity in different parts, or more often carry out chemical reclamation [29].

Therefore, according to the researchers, not only organic manure, but also limestone ameliorants should be used to prevent degradation of the typical black Forest-Steppe lands of Ukraine with extended reproduction of their fertility in order to intensify tillage. Scientists associate the improvement of physicochemical properties and humus state with the optimization of agrochemical indices of fertility in these soils under scientifically grounded system of fertilization and chemical reclamation [1, 2].

Medvedev V. V., pointing to the role of calcium as a sentinel for soil structure and the inappropriateness of applying the excessive doses of nitrogen and potassium fertilizers, recommends a complex application of manure and full nitrogen-phosphorus-potassium fertilizer in small and moderate doses. He also proposes to prevent the applying of high doses of mineral fertilizers in reserve [30].

On unfertilized plots, a significant reduction of nitrogen and ash elements content in the arable layer in 2018 compared to 2013 was recorded in all tillage treatments; it was not observed on fertilized plots.

The use of fertilizers did not prevent the absorption of calcium and magnesium in the arable soil layer in all treatments, however, in the case of differentiated tillage this process slowed down.

Deep cultivation of black typical soil under differentiated tillage in crop rotation eliminates the heterogeneity of the arable soil layer for 2-2.5 years. In the soybean sprouting phase, it is observed in

Table 3. Impact of the tillage treatments and fertilizers on crop rotation productivity, t/ha

The system of soil tillage in crop rotation (factor A)	Levels of fertilizing (factor B)	Dry matter	Feed units	Digestive protein
Mouldboard	0	2.96	3.01	0.250
	1	4.21	4.32	0.370
	2	5.37	5.49	0.460
	3	6.26	6.36	0.520
Mouldboardless (chisel)	0	2.59	2.61	0.210
	1	3.73	3.81	0.310
	2	4.80	4.88	0.400
	3	5.61	5.67	0.460
Mouldboard & mouldboardless	0	2.92	2.94	0.250
	1	4.22	4.35	0.370
	2	5.38	5.53	0.460
	3	6.25	6.40	0.530
Disking	0	2.68	2.77	0.220
	1	3.80	3.91	0.330
	2	4.93	5.07	0.420
	3	5.82	5.95	0.480
SD ₀₅ for factor	A	0.67	0.77	0.015
	B	2.77	3.07	0.030
	AB	1.87	2.07	0.019

the accumulation of plant residues, mobile forms of the nutrition elements and other indices of soil fertility.

The productivity of crop rotation did not differ significantly under mouldboard and differentiated tillage, but under mouldboardless and disking it was significantly reduced (Table 3).

The highest level of profitability and energy efficiency in all variants of the main crop rotation was determined under the application 12 t/ha of manure + N₉₅P₈₂K₇₂ per hectare of arable land.

On unfertilized plots, a significant reduction in the arable layer of nitrogen and ash elements in 2018 compared to 2013 was recorded in all arable systems; it was not observed on fertilizer treatments.

Under the application of the highest rate of fertilizers, the increment of P₂O₅, K₂O, N - NH₄⁺ and N - NH₄⁺ + NO₃⁻ content in the arable soil layer for the five-year period was respectively 9.4, 8.4, 5.4 and 6.8 mg/kg - under mouldboard tillage, 6.6, 6.8, 4.2 and 4.5 - under mouldboardless, 11.9, 9.7, 6.6 and 7.5 - under mouldboard & mouldboardless, 9.1, 7.7, 5.2 and 5.7 mg/kg - under disking tillage. Thus, the highest efficiency of fertilizers was followed by differentiated tillage.

Conclusions

1. Annual application of 8 t/ha of manure + N₇₆P₆₄K₅₇ stabilizes the humus state of the arable soil layer during differentiated and disking tillage. Application of 12 t/ha of manure + N₉₅P₈₂K₇₅ on these tillage treatments provides a significant increase in humus and total nitrogen reserves.

2. The rate of the acidification of plow soil layer in the case of mouldboard tillage during five years accelerated with the increase of fertilizer rates: on unfertilized plots pH value decreased on 0.11, but on fertilized with 16 t/ha of manure + N₁₁₂P₁₀₀K₈₆ - on 0.24. Differentiated tillage showed the opposite pattern, but these changes did not reach significant values.

3. During cycles of crop rotation in all studied tillage's, the hydrolytic acidity of the arable layer increased with increasing fertilizer rates. The amount of absorbed bases, their degree of saturation, the exchangeable calcium and magnesium content has been decreased, but in most cases these changes were not significant.

4. Systematic mouldboardless and disking tillage enhance the heterogeneity of the arable soil layer concerning to agrochemical parameters of its fertility. With increasing fertilizer rates, heterogeneity also increases.

5. Under mouldboard tillage unfertilized plots during the period of crop rotation, the highest proportion of humus loss in the arable layer is observed in the upper, lowest - in its lower parts; on plots with the highest level of fertilizers we recorded the opposite pattern. In the case of mouldboardless and disking tillage, the opposite patterns were observed in comparison with mouldboard.

6. Significant increase of the content of P₂O₅, K₂O, N - NH₄⁺ and N - NH₄⁺ + NO₃⁻ in the arable layer of soil during the annual application of 8 t/ha of manure + N₇₆P₆₄K₅₇ in cycles of crop rotation occurred only under differentiated tillage; for the rest of the studied treatments, changes in these indices did not reach statistically significant differences.

7. The crop rotation productivity was higher, almost at the same level under mouldboard and differentiated tillage; under mouldboardless and disking treatments it was significantly lower.

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