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INFLUENCE OF SOIL TREATMENT AND FERTILIZATION SYSTEMS ON THE NUTRITIONAL REGIME OF GRAY FOREST SOIL AND PRODUCTIVITY OF SHORT-ROTATION CULTIVATION

The influence of the systems of basic tillage and fertilizer on the formation of the nutrient regime of gray forest soil in the conditions of four-field grain-row crop rotation is investigated.

It was found that the use of $N_{120}P_{90}K_{90}$ on the background of plowing at 20-22 cm under wheat in the intensive fertilizer system promotes the accumulation of the content of light hydrolysis nitrogen 16.1 mg/100 g of soil, 14.3 and 11.7 mg/100 g of mobile forms of phosphorus and potassium, and the combined application of half doses of mineral fertilizers ($N_{50}P_{90}K_{90}$), by-products – the straw of precursor in the alternative provides these values at the level of 14.6, 13.2 and 11.4 mg/100 g

Application of an intensive fertilizer system for maize with $N_{120}P_{90}K_{90}$ + 40 t of manure on plowing backgrounds at 25–27 cm promotes accumulation in 0–20 cm layer of alkaline hydrolysis nitrogen at the level of 16.6 mg/100 g of soil, mobile forms of phosphorus and potassium, respectively 15.2 and 14.1 mg/100 g, and the use of an alternative system with a combination of $N_{50}P_{40}K_{40}$ + 40 tons of manure + post-harvest products + green manure provides 14.8, 13.9 and 12.6 mg/100 g of available nutrients. During chiselling, the studied indicators acquire values: 17.9, 16.5, 14.0 mg/100 g of soil, respectively, according to the values of alkaline hydrolysis nitrogen, mobile forms of phosphorus and potassium with an intensive fertilizer system and 16.4, 14.9, 13.1 mg/100 g of soil with an alternative system.

It is investigated that content of mobile forms of nitrogen, phosphorus and potassium in fodder bean crops in 0-20 cm layer was formed at the highest concentration level during plowing by 14–16 cm when applying to the crop both

$N_{30}P_{70}K_{70}$ and $P_{30}K_{30}$ + straw of stubble precursor and oilseed radish grown after crops of oats. With a combination of such agrotechnical factors, the content of alkaline hydrolysis nitrogen was 15.1, available to plants forms of phosphorus 13.6 and potassium 13.0 mg/100 g of soil.

Disking on 10–12 cm under oat crops provides formation of indicators of alkaline hydrolysis nitrogen at the level of 15.22 at intensive and 13.8 mg/100 g of soil at alternative system of fertilizer, mobile phosphorus of 12.6 and 11.9 mg/100 g of soil, respectively, mobile potassium: 12.7 and 11.8 mg/100 g of soil.

Application per hectare of arable land of crop rotation area $N_{83}P_{78}K_{78}$ + 10 t/ha of manure (intensive fertilizer system) forms higher values of crop rotation productivity with grain yield at the level of 3.36, fodder units 23.41 t/ha, digestible protein 1.66 tons.

Key words: tillage, fertilizers, nutrient regime, crop rotation productivity.

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Вплив систем обробітку ґрунту й удобрення на поживний режим сірого лісового ґрунту і продуктивність короткоротаційної сівозміни

Досліджено вплив систем основного обробітку ґрунту та удобрення на формування поживного режиму сірого лісового ґрунту в умовах чотирипільної зерно-просапної сівозміни.

Встановлено, що застосування на фонах оранки на 20–22 см під пшеницю $N_{120}P_{90}K_{90}$ в інтенсивній системі удобрення сприяє накопиченню 16,1 мг/100 г ґрунту вмісту легкогідролізного азоту, 14,3 та 11,7 мг/100 г рухомих форм фосфору і калію, а сумісне внесення половинних доз мінеральних добрив ($N_{50}P_{90}K_{90}$), побічної продукції – соломи попередника в альтернативній забезпечує величину цих значень на рівні 14,6; 13,2 і 11,4 мг/100 г.

Застосування під кукурудзу інтенсивної системи удобрення з внесенням $N_{120}P_{90}K_{90}$ + 40 т гною на фонах оранки на 25–27 см сприяє накопиченню у шарі 0–20 см лужногідролізного азоту на рівні 16,6 мг/100 г ґрунту, рухомих форм фосфору й калію – відповідно 15,2 та 14,1 мг/100 г, а використання альтернативної системи з комбінуванням $N_{50}P_{40}K_{40}$ + 40 т гною + післяжнивна продукція + сидерат забезпечує 14,8; 13,9 й 12,6 мг/100 г доступних елементів живлення. За проведення чизелювання досліджувані показники набувають значень: 17,9; 16,5; 14,0 мг/100 г ґрунту відповідно за величинами лужногідролізного азоту, рухомих форм фосфору й калію при інтенсивній системі удобрення і 16,4; 14,9; 13,1 мг/100 г ґрунту при альтернативній системі.

Досліджено, що вміст рухомих форм азоту, фосфору й калію в посівах бобів кормових у пласті 0–20 см формувався на вищому концентраційному рівні за оранки на 14–16 см при внесенні під культуру як $N_{30}P_{70}K_{70}$, так і $P_{30}K_{30}$ + солома стерньового попередника та редьки олійної, вирощуваної в післяжнивних посівах вівса. За комбінації таких агротехнічних факторів вміст лужногідролізного азоту становив 15,1, доступних рослинам форм фосфору – 13,6 і калію – 13,0 мг/100 г ґрунту.

Дискування на 10–12 см під посіви вівса сприяє формуванню показників лужногідролізного азоту на рівні 15,22 при інтенсивній й 13,8 мг/100 г ґрунту при альтернативній системі удобрення, рухомого фосфору відповідно 12,6 й 11,9 мг/100 г ґрунту, рухомого калію: 12,7 й 11,8 мг/100 г ґрунту.

Застосування в розрахунку на гектар ріллі сівозмінної площі $N_{83}P_{78}K_{78}$ + 10 т/га гною (інтенсивна система удобрення) формує вищі значення продуктивності сівозміни з виходом зернових одиниць на рівні 3,36, кормових одиниць – 23,41 т/га, перетравного протеїну – 1,66 т.

Ключові слова: обробіток ґрунту, удобрення, поживний режим, продуктивність сівозміни.

Introduction. Substantiation of highly efficient competitive in modern conditions systems of basic tillage, focused on domestic complexes of tillage tools, which provide high yields of crops on farms of various organizational and legal forms, contribute to maintaining soil fertility and stabilizing the ecological balance in agricultural landscapes is an important and urgent task of agricultural science [4, 7, 9].

Tillage in crop rotation remains one of the determining factors of impact on the soil environment, a radical way to regulate its physical properties, water regime, a restraining factor in the development of weed resistance to herbicides, a mean of managing microbiological and agrochemical processes, soil protection measures [3, 5-7 11-13, 15, 19, 31].

Studies conducted by both Ukrainian [2, 4, 6, 10] and foreign scientists [14, 16-18, 20-31] show that in the development of tillage systems remains a range of issues, in particular on methods, depth, periodicity of carrying out technological operations, the level of wrapping of organic fertilizers and by-products of crop production, the choice of ways to achieve a soil protection effect, creating conditions for maximum sequestration of atmospheric carbon dioxide in soil organic matter.

Of particular relevance is the task of rational combination in crop rotation of different depths of plowing and surface and shallow shelfless operations. Studies have shown that intensive mechanical tillage activates mineralization processes, accelerates the decomposition of organic matter, deteriorating agrophysical properties, which leads to the development of erosion processes and deterioration of the ecological situation [1, 8]. On the other hand, unreasonable replacement of plowing by dumping methods, reduction of its depth, or transition to no-till technology is not always justified both in view of the level of crop productivity and ecological balance in the soil. To a large extent, this applies to soil and climatic conditions of the Carpathian region, in particular a range of soils of heavy particle size distribution, wetlands, as well as low-humus, with shallow arable horizon [2, 3].

In modern conditions, research on the impact of tillage technologies on its nutrient regime and crop yields is gaining great importance. Many scientists have found that in unstable weather conditions in periods with low rainfall and low soil moisture, surfacial or shallow tillage reduces the effectiveness of organic and mineral fertilizers. Under such conditions, a layer of soil with higher moisture reserves and greater return of fertilizer complexes is formed during plowing [3, 13, 29, 32].

Materials and methods. Experimental studies were carried out in the conditions of long-term stationary field two-factor experiment of the Institute of Agriculture of the Carpathian region of NAAS, laid on gray forest surface gleyed coarse-grained light loamy soil by the method of split areas. Variants of the first order – tillage systems, the second order – fertilizers. The placement of options is sequential, repeated three times.

Four-crop rotation: fodder beans – winter wheat – corn for silage – oats. The mastering of crop rotation was carried out successively in three fields. Crops of the following varieties were grown in the crop rotation: winter wheat – Benefis, oats – Ant, corn – Transcarpathian dentate, fodder beans – Pikulovytski. The scheme of the experiment is presented in Table 1.

Plowing was carried out with a plow PN-4-40, chisel cultivation – with chisel PCh-2.5, disking – using disk tools BDT-3, pre-sowing tillage – with unit "Europack", pre-sowing rolling – rollers 3 KK-6. Chemical treatment was carried out by applying the herbicide Roundup. To protect crops from weeds used: for winter wheat – tank mixture Grodil Maxi + Zenkor in autumn in the tillering phase, for fodder beans – pre-emergence drug Dual Gold, for oats – Granstar in tillering phase, for corn – MaisTer Power in phase of 5-7 leaves.

1. The scheme of the experiment

№ var.	Tillage	Fertilizer system	Fertilizer level on 1 ha of crop rotation area	Crop rotation							
				fodder beans		winter wheat		corn for silage		oat	
1	Traditional	Tradi-tional	$N_{83}P_{78}K_{78}$ + 10 t of manure	plowing on 20–22 cm	$N_{30}P_{70}K_{70}$	plowing on 20–22 cm	$N_{120}P_{90}K_{90}$	plowing on 25–27 cm	$N_{120}P_{90}K_{90}$+40 t of manure	plowing on 20–22 cm	$N_{60}P_{60}K_{60}$
2		Alterna-tive	$N_{33}P_{35}K_{35}$ + 10 t of manure + bp + siderate		$P_{30}K_{30}$ + bp + siderate		$N_{50}P_{40}K_{40}$ + bp		$N_{50}P_{40}K_{40}$ +40 t of manure + bp + siderate		$N_{30}P_{30}K_{30}$ + bp
3	Combined	Tradi-tional	$N_{83}P_{78}K_{78}$ + 10 t of manure	plowing on 20–22 cm	$N_{30}P_{70}K_{70}$	disking on 10–12 cm	$N_{120}P_{90}K_{90}$	plowing on 25–27 cm	$N_{120}P_{90}K_{90}$+40 t of manure	disking on 14–16 cm	$N_{60}P_{60}K_{60}$
4		Alterna-tive	$N_{33}P_{35}K_{35}$ + 10 t of manure + bp + siderate		$P_{30}K_{30}$ + bp + siderate		$N_{50}P_{40}K_{40}$ + bp		$N_{50}P_{40}K_{40}$ +40 t of manure + bp + siderate		$N_{30}P_{30}K_{30}$ + bp
5	Combined	Tradi-tional	$N_{83}P_{78}K_{78}$ + 10 t of manure	plowing on 14–16 cm	$N_{30}P_{70}K_{70}$	chemical treatment	$N_{120}P_{90}K_{90}$	chisel on 25–27 cm	$N_{120}P_{90}K_{90}$+40 t of manure	disking on 10–12 cm	$N_{60}P_{60}K_{60}$
6		Alterna-tive	$N_{33}P_{35}K_{35}$ + 10 t of manure + bp + siderate		$P_{30}K_{30}$ + bp + siderate		$N_{50}P_{40}K_{40}$ + bp		$N_{50}P_{40}K_{40}$ +40 t of manure + bp + siderate		$N_{30}P_{30}K_{30}$ + bp

Note. bp – by-products.

Phenological observations on plant growth and development were conducted according to the methodology of the State Commission for Variety Testing. Determination of light hydrolysis nitrogen was performed by the method of Cornfield according to DSTU 7863:2015; mobile forms of phosphorus and potassium – according to Kirsanov using to DSTU 4405: 2005.

Crop yields were analyzed at the state of technical maturity by the method of continuous collection of accounting plots in terms of standard humidity and purity of each variant, the calculation of crop rotation productivity in grain and fodder units was performed on the yield of basic products per 1 ha of arable land.

Research methods: field, laboratory, comparative-rated, mathematical and statistical.

Results and discussion. An important factor in increasing the production process of crops and an environmental indicator of soil fertility is the nutrient regime, which largely depends on farming systems, organic matter content, direction of biological processes [10, 20, 31].

Therefore, research aimed at establishing the impact of tillage technologies and fertilization systems on the dynamics of mobile compounds of nitrogen, phosphorus and potassium as the main nutrients of plants is important.

Studies conducted in a stationary experiment under winter wheat found that the highest values of mobile forms of basic nutrients, according to four-year average data for the period 2016-2017 and 2019-2020, were formed on the options of intensive fertilizer system when applied directly to wheat $N_{120}P_{90}K_{90}$ (Table 2). Thus, when plowing at 20–22 cm, the content of light hydrolysis nitrogen was at the level of 16.1 mg/100 g of soil, mobile forms of phosphorus and potassium, respectively 14.3 and 11.7 mg/100 g in the arable soil layer. The use of an alternative fertilizer system with the application of half doses of mineral fertilizers ($N_{50}P_{90}K_{90}$) on the background of by-products – the straw of predecessor provided lower nutrient levels. In terms of nutrients, they were 14.6, 13.2 and 11.4 mg/100 g, respectively, of mobile forms of nitrogen, phosphorus and potassium. The same patterns were observed on other backgrounds of basic tillage.

2. Nutrient regime of soil under winter wheat, mg/100 g of soil, average for 2016–2017, 2019–2020

№ var.	Variants of the experiment		Soil layer, cm	N	P_2O_5	K_2O
	treatment	fertilizer		mg/100 g of soil		
1	plowing 20–22 cm	$N_{120}P_{90}K_{90}$	0–20	16,1	14,3	11,7
			20–40	12,9	11,3	9,3
2		$N_{50}P_{90}K_{90}$ + bp	0–20	14,6	13,2	11,4
			20–40	11,6	9,6	8,3
3	disking 10–12 cm	$N_{120}P_{90}K_{90}$	0–20	16,7	14,7	12,3
			20–40	12,7	11,2	9,0
4		$N_{50}P_{90}K_{90}$ + bp	0–20	15,2	13,6	11,8
			20–40	11,1	9,3	8,0
5	chemical treatment	$N_{120}P_{90}K_{90}$	0–20	16,8	14,8	12,1
			20–40	12,2	11,2	8,9
6		$N_{50}P_{90}K_{90}$ + bp	0–20	14,9	12,7	11,5
			20–40	10,9	9,1	8,0

The analysis of the impact of tillage technologies on the nutrient regime showed the advantages of disking by 10–12 cm and herbicide backgrounds in comparison with plowing by 20–22 cm in arable (0–20 cm) and the opposite effect in subsoil (20–40 cm) horizons on both fertilizer systems. Thus, in the variants of disking in the 0–20 cm layer, the content of mobile forms of nutrients depending on the fertilizer was 16.7–15.2, 14.7–13.6 and 12.3–11.8 mg/100 g, in 20-40 cm layer – 12.7-11.1, 11.2-9.3 and 9.0-8.0 mg/100 g of soil; during chemical treatment – 16.8–14.9, 14.8–12.7 and 12.1–11.5 mg/100 g (0–20 cm), 12.2–10.9, 11.2– 9.1 and 8.9–8.0 (20-40 cm) mg/100 g of soil. This is due to the higher level of accumulation of organic matter in the upper horizons during dump-free operations and its subsequent mineralization with the release of mobile forms of nutrients.

Comparison of the influence of shelfless and shelf technologies of basic tillage, carried out at the same depth – 25-27 cm, on the growth of nutrient regime under corn, showed the predominance of chiseling compared to plowing in the upper (arable) layers and the inverse dependence in the subsoil (Table 3).

3. Influence of fertilizer levels and methods of cultivation on the nutrient regime of the soil under corn for silage, average for 2016–2018, 2020

№ var.	Variants of the experiment		Soil layer, cm	N	P_2O_5	K_2O
	treatment	fertilizer		mg/100 g of soil		
1	plowing 25–27 cm	$N_{120}P_{90}K_{90}$ + 40 t of manure	0–20	16,6	15,2	14,1
			20–40	15,2	13,3	11,2
2		$N_{50}P_{40}K_{40}$ + 40 t of manure + bp + siderate	0–20	14,8	13,9	12,6
			20–40	13,2	13,1	10,6
3	chise-ling 25–27 cm	$N_{120}P_{90}K_{90}$ + 40 t of manure	0–20	17,9	16,5	14,0
			20–40	14,6	13,6	10,1
4		$N_{50}P_{40}K_{40}$ + 40 t of manure + bp + siderate	0–20	16,4	14,9	13,1
			20–40	12,5	12,4	9,9

The application of an intensive fertilizer system with direct application of $N_{120}P_{90}K_{90}$ + 40 t of manure on the background of plowing by 25–27 cm contributed to the accumulation of alkaline hydrolysis nitrogen in the 0–20 cm layer at the level of 16.6 mg/100 g of soil, mobile forms of phosphorus and potassium, respectively. 15.2 and 14.1 mg/100 g, and the introduction of an alternative system with a combination of $N_{50}P_{40}K_{40}$ + 40 tons of manure + post-harvest products + green manure provided 14.8, 13.9 and 12.6 mg/100 g of available nutrients.

During chiselling, the studied indicators acquired values: 17.9, 16.5, 14.0 mg/100 g of soil, respectively, according to the values of alkaline hydrolysis nitrogen, mobile forms of phosphorus and potassium with an intensive fertilizer system and 16.4, 14.9, 13.1 mg/100 g of soil with an alternative system.

The study of the nutrient regime under fodder beans showed the advantages of minimizing shelf tillage for the mobilization of plant nutrients in the arable soil layer (Table 4).

4. Influence of fertilizer levels and methods of cultivation on the nutrient regime of the soil under fodder beans, mg/100 g of soil, average for 2016, 2018–2020

№ var.	Variants of the experiment		Soil layer, cm	N	P_2O_5	K_2O
	treatment	fertilizer		mg/100 g of soil		
1	plowing 20–22 cm	$N_{30}P_{70}K_{70}$	0–20	14,7	13,1	12,4
			20–40	12,6	10,7	11,3
2		$P_{30}K_{30}$ + bp + siderate	0–20	13,8	12,2	11,4
			20–40	11,7	9,9	10,6
1	plowing 14–16 cm	$N_{30}P_{70}K_{70}$	0–20	15,1	13,6	13,0
			20–40	12,1	10,2	10,9
2		$P_{30}K_{30}$ + bp + siderate	0–20	14,2	12,7	11,9
			20–40	11,4	9,6	10,3

It was found that the content of mobile forms of nitrogen, phosphorus and potassium in 0-20 cm layer was formed at a higher concentration level for plowing by 14-16 cm when applying to the culture $N_{30}P_{70}K_{70}$ and $P_{30}K_{30}$ + straw of stubble precursor and oilseed radish grown in post-harvest oats. With a combination of such agrotechnical factors, the content of alkaline hydrolysis nitrogen was 15.1, available to plants forms of phosphorus 13.6 and potassium 13.0 mg/100 g of soil. Increasing the plowing depth to 20–22 cm on the same fertilizer backgrounds led to the formation of lower values of nutrient values, respectively 14.7, 13.1 and 12.4 mg/100 g of soil by nutrients.

There was another dependence in the subsoil – reducing the depth of shelf operations reduced the fund of available for plants forms of nitrogen, phosphorus and potassium to the level of 12.1, 10.2, 10.9 mg/100 g of soil at 12.6, 10.7 and 11.3 mg/100 g of soil on plowing 20–22 cm.

Analysis of nutrient parameters under oat crops showed the advantages of shelf-free operations in the accumulation of mobile forms of basic plant nutrients in the upper layers (Table 5).

According to the fertilizer variants, disking by 10–12 cm provided the formation of alkaline hydrolysis nitrogen at the level of 15.22 by intensive and 13.8 mg/100 g of soil with an alternative fertilizer system, mobile phosphorus, respectively, 12.6 and 11.9 mg/100 g of soil, mobile potassium: 12.7 and 11.8 mg/100 g of soil.

5. Nutrient regime of soil in oat crops, mg/100 g of soil, average for 2017–2019

№ var.	Variants of the experiment		Soil layer, cm	N	P_2O_5	K_2O
	treatment	fertilizer		mg/100 g of soil		
1	plowing 20–22 cm	$N_{60}P_{60}K_{60}$	0–20	14,0	11,4	11,6
			20–40	12,1	10,2	10,5
2		$N_{30}P_{30}K_{30}$ + bp	0–20	12,3	10,8	10,7
			20–40	10,8	9,4	8,0
3	disking 14–16 cm	$N_{60}P_{60}K_{60}$	0–20	14,9	12,0	12,2
			20–40	11,4	10,1	10,8
4		$N_{30}P_{30}K_{30}$ + bp	0–20	8,8	11,5	11,4
			20–40	10,0	9,0	7,7
5	disking 10–12 cm	$N_{60}P_{60}K_{60}$	0–20	15,2	12,6	12,7
			20–40	11,1	9,5	10,0
6		$N_{30}P_{30}K_{30}$ + bp	0–20	13,8	11,9	11,8
			20–40	9,8	8,8	9,5

The increase in the depth of shelfless operations has led to a decrease in the concentration of mobile forms of nutrients in the arable layer. Plowing options were characterized by the lowest nutrient levels. When $N_{60}P_{60}K_{60}$ was applied against these backgrounds in the intensive fertilization system, the amount of alkaline hydrolysis nitrogen was 14.0, mobile forms of phosphorus and potassium were 11.4 and 11.6 mg/100 g of soil, respectively.

In the subsoil layers, an inverse relationship was observed between the depth of tillage and the accumulation of plant nutrients. The highest values of available plant nutrients were when plowing 20–22 cm and depending on the fertilizer system were 12.1–10.8–8.0 mg/100 g of alkaline hydrolysis nitrogen soil, 10.2–9.4 mg mobile phosphorus and 10.5–8.0 mg/100 g of mobile potassium soil.

By the end of the growing season in the studied soil horizons under all crops, fertilizer and tillage options, the content of nutrients decreased, which is explained by their use by plants for their growth, development and bioproduction.

The priority indicator of ecologically safe functioning of soil systems and regimes, stability of their functioning is the balance of plant nutrients.

The calculation of the balance of basic nutrients showed (Table 6) that in the four-field crop rotation its highest values were formed in a minimized system of basic tillage both intensive (application per hectare of crop rotation area $N_{83}P_{78}K_{78}$ + 10 t/ha of manure) and alternative (

combination $N_{33}P_{35}K_{35}$ + 10 t/ha of manure + by-products + green manure) fertilizer and amounted +107.3 – +193.6 kg/ha (for alkaline hydrolysis nitrogen), +215.3 – + 306.1 kg/ha (mobile phosphorus) and +148.9 - +234.4 kg/ha (mobile potassium).

6. Balance of basic nutrients in the systems of basic tillage, kg/ha

Tillage system	Fertilizer system	* Balance for rotation		
		N	P	K
tradi-tional	intensive, $N_{83}P_{78}K_{78}$ + 10 t/ha of manure	+53,7 +13,42	+196,8 +49,2	+176,1 +44,02
	alternative, $N_{33}P_{35}K_{35}$ + 10 t/ha of manure + bp + siderate	+133,9 +33,47	+167,8 +41,95	+208,6 +52,15
com-bined	intensive, $N_{83}P_{78}K_{78}$ + 10 t/ha of manure	+71,8 +17,95	+203,8 +50,95	+120,4 +30,1
	alternative, $N_{33}P_{35}K_{35}$ + 10 t/ha of manure + bp + siderate	+149,2 +37,3	+195,0 +48,7	+212,2 +53,05
minima-lized	intensive, $N_{83}P_{78}K_{78}$ + 10 t/ha of manure	+107,3 +26,82	+215,3 +53,8	+148,8 +37,2
	alternative, $N_{33}P_{35}K_{35}$ + 10 t/ha of manure + bp + siderate	+193,6 +48,4	+306,1 +76,52	+234,4 +58,6

Note. *Balance for crop rotation – in the numerator for crop rotation in general, in the denominator – per 1 hectare of arable land.

The lowest rates were by the traditional system with different depths of plowing and, depending on the fertilizer: +53.7 – + 133.9, +196.8 – +167.8, +176.1 – +208.6 kg/ha, respectively, for nutrients. The balance of nutrients acquired intermediate values in the combined model of basic tillage: +71.8 – +149.2, +203.8 – +195.0, +120.4 – +212.2 kg/ha. Similar patterns were observed when recalculating these indicators per hectare of crop rotation area.

The analysis of balance indicators by crops showed that positive values for all elements were formed during the cultivation of corn for silage with a range of values for fertilizer in the range of +184.5 – 238.8 kg/ha for nitrogen, +124.9 - +139.2 kg/ha for phosphorus and +171.2 – +219.6 kg/ha for potassium. These figures were slightly lower for the cultivation of fodder beans, but in all cases acquired positive marks. When growing cereals, nitrogen indicators were negative for all variants and acquired values for winter wheat, depending on the analyzed options for cultivation and fertilization at the level of -31.5 – -80.5 kg/ha, oats -58.6 – -85 .0 kg/ha. Phosphorus balance became negative only when growing oats in the traditional system of basic cultivation with an alternative fertilizer system, at the level of -17.3 kg/ha.

Potassium balance of cereals was negative in all systems of basic tillage against the background of intensive fertilization. When applied directly to winter wheat $N_{120}P_{90}K_{90}$, their variability was in the range of 11.0 – -22.0 kg/ha. When applied under oats $N_{60}P_{60}K_{60}$ and half doses of mineral fertilizers on the background of by-products ($N_{30}P_{30}K_{30}$ + bp), all values of potassium in all systems of basic tillage were negative in the range of -38.2 – -50.0 kg/ha. The exception was the system of traditional cultivation on the background of intensive fertilizer with application directly to the crop $N_{60}P_{60}K_{60}$, the values of the potassium balance in which were at the level of +10.7 kg/ha.

Crop rotation productivity is an indicator of the efficiency of agricultural production, soil fertility, and its level is determined by a complex combination of soil, biological and weather factors, agronomic factors, including systems of basic tillage, crop fertilization, set and rotation scheme. Our research has shown (Table 7) that the highest productivity of four-field grain-fodder crop rotation: fodder beans – winter wheat – corn for silage, green fodder – oats is formed by the traditional system of basic tillage. When applied per hectare of arable land crop rotation area $N_{83}P_{78}K_{78}$ + 10 t/ha of manure (intensive fertilization system), the yield of grain units was 3.36, feed units 23.41 t/ha, digestible protein 1.66 tons. Under the same system of basic cultivation when applying to the crop rotation area $N_{33}P_{35}K_{35}$ + 10 t/ha of manure + by-products on the background of green manure - oil radish (alternative fertilizer system), these figures were 3.06 t/ha, 21.41 t/ha and 1.52 tons.

Lower productivity indicators were with the combined system of basic tillage. The application of the intensive fertilizer system provided crop rotation productivity indicators at the level of 3.25 t/ha of grain, 23.26 t/ha of fodder and 1.65 t of digestible protein during the technological operations of the combined system. Under the alternative system, they were: 2.95, 21.27 t/ha and 1.51 tons.

The lowest rates for both fertilizer systems were formed against the background of the minimum system of basic tillage. These variants yielded 3.04–2.76 t/ha of grain, 22.27–20.00 t of feed units and 1.57–1.41 t of digestible protein.

7. Productivity of crop rotation depending on the systems of basic tillage and fertilizer, t/ha

Processing system	Fertilization system	Crops of rotation																For crop rotation, per 1 ha of arable land		
		fodder beans (2016, 2018-2020)				winter wheat (2016-2017, 2019-2020)				corn for silage (2016-2018, 2020)				oats (2017-2019)						
		t. o.	g. u.	f. u.	d. p.	t. o.	g. u.	f. u.	d. p.	t. o.	g. u.	f. u.	d. p.	t. o.	g. u.	f. u.	d. p.	g. u.	f. u.	d. p.
Traditional	1	plowing 20-22 cm.	4,58	4,22	0,95	plowing 20-22 cm	5,72	6,86	0,63	plowing 25-27 cm	-	78,03	4,66	plowing 20-22 cm	3,16	4,52	0,41	3,36	23,41	1,66
	2		4,28	3,95	0,89		5,07	6,08	0,56		-	71,47	4,27		2,91	4,16	0,37	3,06	21,41	1,52
Combined	1		4,58	4,22	0,95	disking 10-12 cm	5,45	6,54	0,60		-	78,03	4,66	disking 14-16 cm	2,98	4,26	0,38	3,25	23,26	1,65
	2		4,28	3,95	0,89		4,84	5,81	0,53		-	71,47	4,27		2,69	3,85	0,35	2,95	21,27	1,51
Minimized	1		4,21	3,88	0,87	chemical processing	5.21	6,25	0,57	chisel 25-27 cm	-	75,04	4,48	disking 10-12 cm	2,75	3,93	0,35	3,04	22,27	1,57
	2		3,92	3,61	0,81		4,61	5,53	0,51		-	67,27	4,02		2,53	3,61	0,32	2,76	20,00	1,41

Note. 1 – intensive tillage system ($N_{83}P_{78}K_{78}$ + 10 t/ha of manure), 2 - alternative tillage system ($N_{33}P_{35}K_{35}$ + 10 t/ha of manure + by-products + siderate); t. o. - technological operations; g. u. – grain units; f. u. – feed units; d. p. – digestible protein.

Conclusions

1. Higher values of indicators of nutrient regime of gray forest surface gleyed soil in four-field grain-row crop rotation are formed by applying an intensive fertilizer system, which provides application per hectare of crop rotation area $N_{83}P_{78}K_{78}$ + 10 t/ha of manure, compared to the alternative composition – 10 t/ha of manure, half doses of mineral fertilizers, all plant by-products and once per rotation plowing of green mass of oilseed radish grown in post-harvest crops.

2. Replacement in the main tillage systems of shelf technological operations with non-shelf and reduction of the depth of passage of tillage tools provides a higher level of accumulation of mobile forms of basic plant nutrients in arable (0-20 cm) and lower in subsoil (20-40 cm) layers of soil.

3. Higher values of the balance of basic nutrients in the four-field field crop rotation are formed in the conditions of the minimized system of the main tillage both at intensive (introduction on hectare of the crop rotation area $N_{83}P_{78}K_{78}$ + 10 t/hectare of manure), and alternative (combination $N_{33}P_{35}K_{35}$ + 10 t/hectare of manure + by-products + green manure) fertilizers and are +107.3 – +193.6 kg/ha (for alkaline hydrolysis nitrogen), +215.3 – + 306.1 kg/ha (mobile phosphorus) and +148.9 – +234.4 kg/ha (mobile potassium).

4. Application per hectare of arable land of crop rotation area $N_{83}P_{78}K_{78}$ + 10 t/ha of manure (intensive fertilization system) provides higher values of crop rotation productivity with grain yield at the level of 3.36, fodder units 23.41 t/ha, digestible protein 1.66 tons.

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