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Biological activity of soil under varying tillage and fertilization practices in short-rotation cropping systems

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Abstract

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Soil biological activity is a derivative indicator, influenced by the specific features of crop rotation cultivation technologies, the presence of organic matter and plant residues in Chernozem, the compaction level of the arable layer, and the methods of primary tillage. The application of deep ploughing creates favourable conditions for the development of crop root systems through sufficient aeration and water-absorbing properties, thereby ensuring maximum biological activity across all crops in the rotation. This enhances the decomposition of residues and promotes intensive mineralisation processes. The use of various tillage systems (mouldboard, differentiated, shallow (mulching) in a five-field crop rotation demonstrates equivalent productivity outcomes, except for scenarios without the application of mineral fertilisers. In such cases, the shallow (mulching) system lags behind the differentiated and mouldboard systems by 5.5–7.6%. The application of mineral fertilisers in moderate doses significantly enhances (by 5.0–13.6%) the productivity of crop rotations, particularly under shallow (mulching) tillage systems, which operate under stricter initial conditions for plant mineral nutrition. In these systems, productivity increases exceed 14.0%.

Keywords: crop rotation; soil; crop residues; tillage; fertilization; yield

Introduction

An important indicator of soil fertility is its biological activity, which reflects the qualitative and quantitative composition of microorganisms, enzyme activity, soil "respiration," and the potential capacity to supply plants with nutrients. The mineralisation-immobilisation processes in soil exhibit a cyclic nature, representing a dynamic equilibrium between them at any given moment. Soil substrate nitrogen undergoes continuous transformation: from inorganic to organic forms through assimilation processes, and from organic to inorganic forms via decomposition and mineralization (Tsyliuryk et al., 2018; Datsko and Zakharchenko, 2023; Mytsyk et al., 2025; Shevchenko et al., 2025).

Factors that intensify microbiological processes include the application of mineral and organic fertilizers, the retention of post-harvest crop residues in the field, and the implementation of rational crop rotations and primary tillage sys-

tems. Enhancing mineralisation processes to a certain extent can be considered as a positive phenomenon, as it concurrently increases the productivity of field crops in such agroecosystems. However, excessive activity of soil microorganisms may lead to rapid humus mineralization and increased unproductive losses of gaseous nitrogen through denitrification and nitrification processes, as well as the accumulation of nitrates in the soil and their subsequent leaching into groundwater. This overactivity also reduces the nitrogen use efficiency of fertilizers by field crops, as the nitrogen content in the soil is often insufficient.

Many researchers consider ploughing to enhance soil biological activity by significantly improving soil aeration and incorporating crop residues into the lower part of the arable layer (Kladivko, 2001; Gelybó et al., 2022). However, some scientists, such as Abdalla (Abdalla et al., 2016) and Huang (Huang et al., 2018), favour no-tillage systems, viewing them as a key factor in activating soil biota under favourable soil moisture conditions. Systematic application of surface or shallow chisel tillage, particularly with the addition of nitrogen-based mineral fertilisers, has been shown to yield higher levels of biological activity. This approach positively influences the nutrient regime and humus content of the soil. During the mid-growing season, biological activity under no-tillage practices increases significantly more than under conventional mouldboard ploughing (Rudakov et al., 2020; Onopriienko et al., 2025; Romashchenko et al., 2025).

The effect of fertilisers on soil microflora largely depends on the quantity and chemical composition of post-harvest residues. For instance, the application of mineral fertilisers in the presence of legume crop residues accelerates the mineralisation processes of organic matter. Meanwhile, incorporating the by-products of cereal grains into the nutrient cycle prevents excessive immobilisation of soil nitrogen compounds.

The application of moderate doses of mineral fertilisers and mulching creates favourable conditions for soil microorganisms, positively influencing the nutrient regime, humus content, and the soil-forming process (Tsyliuryk et al., 2018; Bao et al., 2021; Aich et al., 2022).

Mulch tillage is gaining increasing popularity in global agriculture due to its environmental and economic benefits. This technology involves retaining organic plant residues on the soil surface, forming a mulching layer. Such tillage is a vital component of soil conservation systems, particularly under conditions of climate change and soil degradation. Mulching is most actively practised in countries like the USA, Brazil, Argentina, Australia, India, and China, where it is integrated into no-till or minimum tillage systems (Abdalla et al., 2016; Tsyliuryk et al., 2018; Huang et al., 2018).

The primary advantages of mulch tillage include reducing erosion processes, conserving moisture, and improving soil structure. Plant residues on the soil surface act as a barrier, preventing water evaporation, which is particularly crucial in arid regions. In Latin American countries such as Brazil and Argentina, mulching is actively integrated into soybean, maize, and wheat cultivation technologies. In the USA, this practice is a cornerstone of precision agriculture systems, combining mulching with cover crop application to enhance soil quality.

Soil biological activity is closely linked to mulching. Organic residues remaining on the soil surface create favourable conditions for the development of soil microorganisms and invertebrates, such as earthworms. This process increases the mineralisation of organic compounds, improves nutrient cycling, and enhances humus content. In tropical regions with rapid organic matter decomposition, mulching helps stabilise organic carbon levels, thus reducing the carbon footprint of agricultural operations. In Europe and North America, mulching promotes the activity of nitrogen-fixing bacteria, which reduces the need for mineral fertilisers (Lamptey et al., 2017; Sain et al., 2017; Nunes et al., 2020; Ishchenko and Kozelets, 2021; Langraf et al., 2021; Wang et al., 2021; Tanchyk et al., 2022; Hellin et al., 2023; Wang et al., 2023; Yan et al., 2024).

Additionally, mulch tillage positively impacts the physicochemical properties of the soil. The mulch layer helps reduce temperature fluctuations, which is crucial for the biological activity of soil organisms. As a result, the decomposition of organic matter is activated, ensuring the availability of nutrients for plants. At the same time, soil compaction is reduced, as the absence of mechanical disturbance allows the preservation of the soil's natural porosity.

Global trends in the adoption of mulch tillage are also linked to economic benefits, as the technology reduces fuel costs, labour resources, and wear on equipment. However, the successful implementation of mulch tillage requires the adaptation of technologies to regional conditions, particularly climate, soil type, and selected agricultural crops. Therefore, mulch tillage becomes a key component of sustainable agriculture, promoting soil biodiversity conservation, enhancing soil fertility, and ensuring the ecological stability of agroecosystems (Miao et al., 2021; Li et al., 2023; Zhao et al., 2023; Chushkina et al., 2024).

Due to the diversity of soil-climatic conditions in global agriculture, and the limited information regarding the impact of shallow mulch tillage on the effectiveness of agricultural crop cultivation, as well as the contradictory views among different researchers concerning specific tillage methods, there arises a need for further research in this area. The goal is to de-

termine the optimal soil loosening method for the technology of grain crop cultivation that ensures favourable conditions for soil biological activity, which is closely linked to water and nutrient regimes, and contributes to maximising seed yield with minimal production costs and high profitability.

The aim of our research was to establish the impact of various methods of shallow mulch tillage and fertilization under high levels of post-harvest residues in crop rotation on soil biological activity, productivity, and economic efficiency in sunflower cultivation under the conditions of the Northern Steppe of Ukraine.

Materials and Methods

The research was conducted at the experimental farm "Dnipro", of the State Institution Institute of Agriculture, of the Steppe Zone of the NAAS of Ukraine (now the Institute of Grain Crops of the NAAS of Ukraine), in a stationary field experiment at the laboratory of crop rotation and environmentally safe soil tillage systems. The experiment was carried out within a five-field crop rotation: fallow – winter wheat – sunflower – spring barley – maize, in accordance with generally accepted research methodologies, from 2021 to 2024.

The experimental design included the application of plough tillage (ploughing with the LEMKEN TERRION Euro Diamant plough at a depth of 20–22 cm, control), and various types of non-plough mulching soil tillage (chisel ploughing with a heavy Chisel Plow cultivator at a depth of 14–16 cm, flat-cut loosening with a combined unit AKSH3.6 at 12–14 cm, and disking with an AGM-4.2 harrow at 10–12 cm). The straw mass of the predecessor crop (winter wheat) was chopped and evenly distributed across the field during harvest. Soil tillage and incorporation of chopped straw were carried out under three agrochemical backgrounds: 1 – after-harvest residues (no fertilizers); 2 – after-harvest residues + $N_{30}P_{30}K_{30}$; 3 – after-harvest residues + $N_{60}P_{30}K_{30}$. To control weeds, the soil herbicide Harness (acetochlor, 900 g/l) was applied at 2.5 l/ha, and inter-row cultivation was performed. Other agronomic practices were in line with the general standards for the Steppe zone. Soil biological activity was assessed using the flax cloth application method as a homogeneous source of fibre with a known chemical composition.

The soil of the experimental plot is typical Chernozem heavy loam, with the following content in the arable layer: humus – 4.2%, nitrate nitrogen – 13.2 mg/kg, and mobile phosphorus and potassium compounds (according to Chirikov) of 145 and 115 mg/kg, respectively (DSTU 4115-2002, 2003). The number of soil microorganisms was determined using the method of soil particle overgrowth and on Ashby's medium (Tsyliuryk et al., 2018). Soil biological activity was determined using linen cloth measuring 10 × 30 cm, with an exposure duration of 30 days during June, the period of highest biological activity in the soil. The intensity of CO_2 emission per 1 m² per hour was determined using the Shtatnov method (Ushkarenko et al., 2008).

The data analysis was performed using Statistica 12.0 software (StatSoft Inc.). Results were presented as the mean ($\bar{x}$) ± standard deviation (SD). Crop capacity was determined using mathematical statistics (dispersion method) (Ushkarenko et al., 2008).

Results and Discussion

The intensity of cellulose decomposition of flax fiber fabrics in the arable layer (0–30 cm, exposure – 30 days) differed across soil treatment methods and fertilization backgrounds in the crop rotation fields. On plots without mineral fertilizers, the highest decomposition rate was observed in plowing (16.0%), while the lowest was found in disking (13.0%). The chisel and ploughless tillage treatments took intermediate positions. The enhanced microbiological processes under plowing can be explained by better soil aeration, while the reduced decomposition under disking is attributed to the compacted structure of the arable layer and the localized environment with a large amount of post-harvest residue (Table 1).

Table 1. The intensity of flax fabric decomposition in the 0–30 cm soil layer, % (average for 2021–2024, x ± SD)

Fertilization	Soil tillage method			
	ploughing 20–22 cm	chisel ploughing 14–16 cm	ploughless tillage 12–14 cm	discing 10–12 cm
1. Residual crop matter (no fertilizers)	16.0 ± 1.0	14.3 ± 0.9	13.9 ± 0.9	13.0 ± 0.9
2. Residual crop matter+ $N_{30}P_{30}K_{30}$	20.8 ± 1.1	21.4 ± 1.1	20.3 ± 1.1	18.7 ± 1.0
3. Residual crop matter+ $N_{60}P_{30}K_{30}$	24.9 ± 1.2	25.0 ± 1.2	23.8 ± 1.2	20.7 ± 1.1

Source: Authors' own elaboration

In the presence of mineral fertilizers combined with post-harvest residues (wheat, barley, corn, sunflower), conditions for soil microorganisms' activity significantly improved under chisel and ploughless tillage. This was most evident in 2022 and 2023, likely due to the favourable combination of hydrometeorological elements, sufficient energy material reserves, and the gradual increase in microbial mass turnover speed over time. On average, during the study period, the cellulose decomposition intensity here ranged from 20.3% to 25.0%, compared to 20.8% to 24.9% in plowing and 18.7% to 20.7% in disking.

The biological activity of the Chernozem in the experiment, correlated with the nitrate nitrogen ($N{-}NO_3$) content in the plough layer, and increased in an ascending order: the unfertilized background – 13.0–16.0%; $N_{30}P_{30}K_{30}$ – 18.7–21.4%; $N_{60}P_{30}K_{30}$ – 20.7–25.0%. The obtained data support the thesis regarding the unidirectionality of cellulose decomposition processes and indicate not only the activity of a particular group of microorganisms, but also the degree of nitrogen mobilization in the soil.

Maintaining the aforementioned patterns concerning the methods of primary tillage and fertilization backgrounds, in 2022 and 2023, the biological activity of the soil was significantly higher than in the abnormally dry 2024. In the latter case, this is explained by the significant deterioration of the internal soil microclimate during the experiment due to dry conditions, progressing dehydration, and compaction of the topsoil of the Chernozem (Figures 1 and 2).

The results of microbiological studies indicated that the total number of microorganisms at the beginning of the growing season of field crops was higher in the treatments with non-plough tillage (chisel ploughing, disking) compared to the ploughed variant (Table 2). Over the course of the growing season, their numbers tended to stabilize, yet by the end of the growing season, the total count remained higher in the chisel tillage treatment. It is also noteworthy that throughout the entire growing season of the field crops in the crop rotation, the total number of microorganisms under ploughing conditions was lower than in the other treatments.

The population of oligotrophic microorganisms in the plough layer slightly increased from sowing to the mass flowering of sunflower, then significantly decreased (Table 2). In July, the number of microorganisms increased in all studied treatments and was highest under chisel tillage. By the end of the growing season in August, no significant differences were observed between the soil tillage treatments.

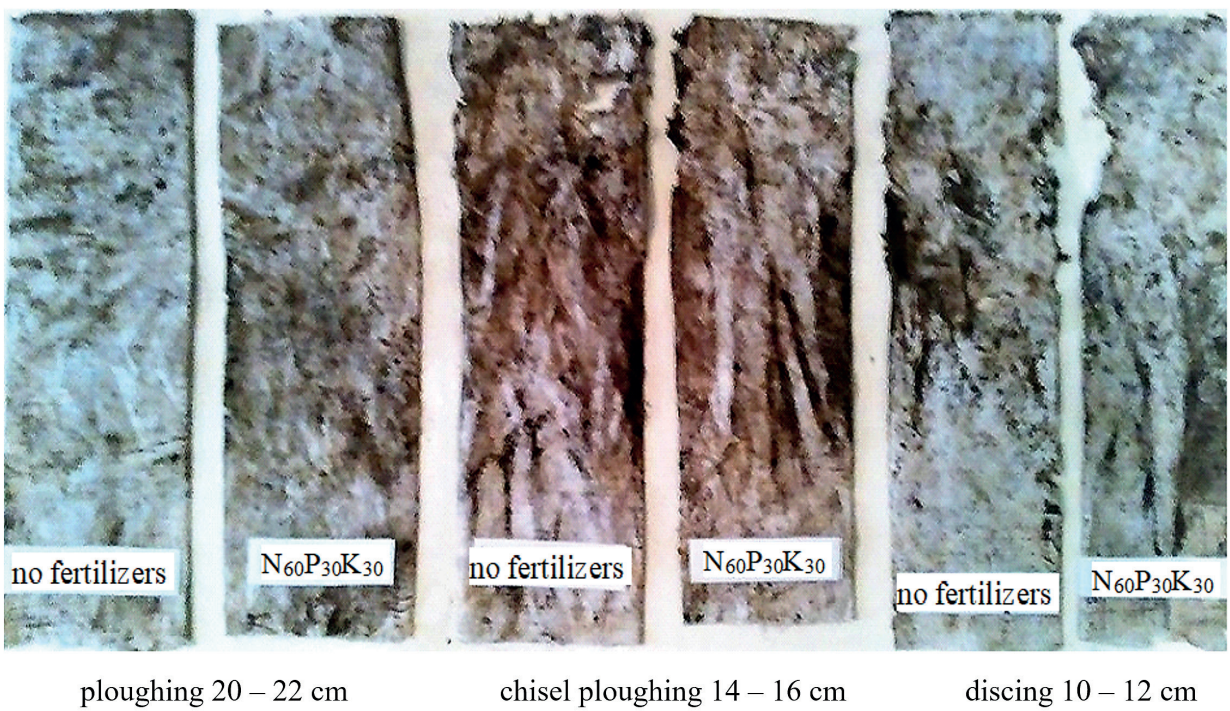


Fig. 1. Decomposition of linen fabric in the favorable humidity conditions of 2022 and 2023
Source: Authors' own elaboration

The number of ammonifying microorganisms in the soil increased during the first half of the growing season, and then decreased, likely due to the gradual reduction of available moisture in the upper soil layers. In June, the number of ammonifying microorganisms across the experimental treatments was almost identical, but in July and August, their population was significantly higher in the chisel ploughing and disking treatments.

A trend of increasing nitrifying microorganisms in the soil throughout the growing season was also observed, with higher populations under shallow tillage treatments (disking) compared to ploughing.

The intensity of organic matter decomposition in the soil is a heterogeneous process, primarily dependent on determining factors such as moisture, temperature, and the level of aeration in the cultivated layer of the Chernozem. The intensity of soil microorganisms' respiration allowed us to assess the overall biological activity of the soil, based on the amount of carbon dioxide released per unit area of the field surface under different tillage methods. As our studies have shown, the biological activity of the soil depended on the growth phases of field crops and exhibited a fairly wide amplitude of variation. For example, in the case of ploughing, insufficient soil heating under normal moisture levels during sowing was the cause of a decrease in biological activity to 31.8–37.2 mg CO_2/kg soil/day. The peak respiration intensity (41.0–50.4 mg CO_2/kg soil/day) occurred 30 days after sowing, when there was an optimal combination of temperature and soil moisture (Table 3).

Similar patterns and trends in CO_2 emissions from the soil at the beginning of the growing season of field crops in crop rotation were also noted under the differentiated and zero tillage systems, but with somewhat lower overall CO_2 emission levels, namely 30.3–34.8 mg CO_2/kg soil/day (10–12% lower compared to ploughing) and 28.3–32.1 mg CO_2/kg soil/day (12–22% lower). Similar results were also observed at the end of the growing season.

The observed trend occurred both at the maximum and minimum amplitudes of respiratory activity. That is, the overall biological activity of the soil was higher in the case of ploughing, surpassing other mechanical soil tillage systems (differentiated and zero tillage systems).

One of the reasons for the decrease in soil biological activity, depending on the primary tillage method, lies in the different vertical distribution of plant residues. That is, the availability of oxygen, moisture, optimal agro-physical prop-

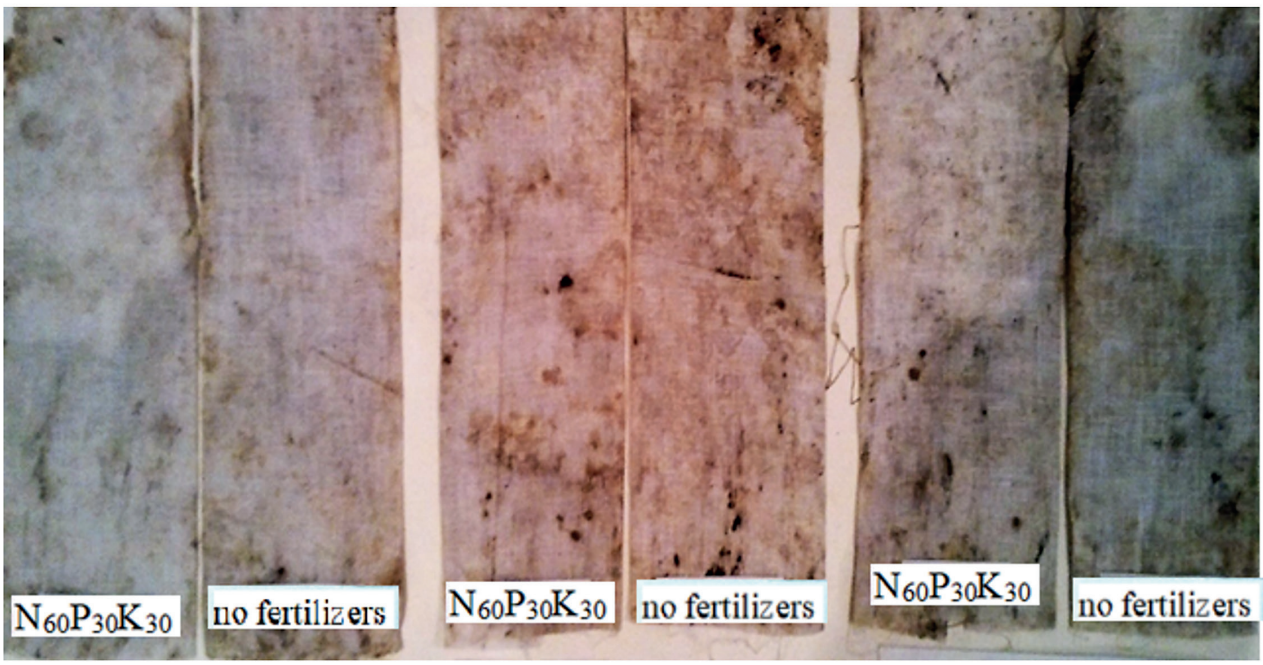


Fig. 2. Decomposition of linen fabric in the abnormally dry conditions of 2024
Source: Authors' own elaboration

Table 2. Dynamics of soil microorganism populations depending on tillage practices in sunflower crops, CFU × 10^6/g (average for 2021–2024, x ± SD)

Soil tillage method	Soil sample collection		
	June	July	August
Total microorganisms			
Ploughing (20–22 cm)	17.99 ± 1.35	20.24 ± 1.13	17.72 ± 1.65
Chisel ploughing (14–16 cm)	20.05 ± 1.40	21.09 ± 1.04	20.57 ± 2.61
Discing (10–12 cm)	18.53 ± 1.62	21.81 ± 1.01	19.19 ± 1.89
Oligonitrophilic microorganisms			
Ploughing (20–22 cm)	17.53 ± 0.70	19.61 ± 0.92	15.03 ± 1.10
Chisel ploughing (14–16 cm)	17.21 ± 0.98	22.33 ± 0.36	14.77 ± 0.83
Discing (10–12 cm)	18.39 ± 1.08	21.12 ± 0.19	14.95 ± 1.10
Amonifying microorganisms			
Ploughing (20–22 cm)	21.70 ± 2.34	23.46 ± 0.98	16.41 ± 0.44
Chisel ploughing (14–16 cm)	21.89 ± 2.14	24.30 ± 0.44	18.12 ± 0.95
Discing (10–12 cm)	20.09 ± 2.01	25.05 ± 0.86	19.94 ± 0.73
Nitrifying microorganisms			
Ploughing (20–22 cm)	7.09 ± 0.20	7.65 ± 0.40	9.63 ± 0.76
Chisel ploughing (14–16 cm)	8.02 ± 0.38	7.29 ± 0.31	9.62 ± 0.37
Discing (10–12 cm)	8.00 ± 0.39	8.93 ± 0.49	10.15 ± 0.36

Source: Authors' own elaboration

Table 3. Impact of crop rotation and soil tillage on total biological activity, mg CO_2/kg soil/day (average for 2021–2024, x ± SD)

Field crops of crop rotation	Sampling dates (day, month)	Soil tillage system		
		ploughing	Differentiated	zero tillage
Peas	01.05	37.2 ± 1.3	34.8 ± 1.3	32.1 ± 1.2
	01.06	50.4 ± 1.8	46.4 ± 1.4	40.6 ± 1.5
Winter wheat	01.05	31.8 ± 1.2	30.3 ± 1.2	29.0 ± 1.1
	01.06	41.0 ± 1.6	38.1 ± 1.5	35.2 ± 1.3
Sunflower	01.05	35.1 ± 1.3	34.8 ± 1.3	29.6 ± 1.2
	01.06	49.3 ± 1.5	44.0 ± 1.4	42.1 ± 1.4
Spring barley	01.05	32.9 ± 1.2	31.4 ± 1.2	29.7 ± 1.2
	01.06	43.4 ± 1.6	39.8 ± 1.5	36.1 ± 1.3
Corn	01.05	33.2 ± 1.2	31.5 ± 1.2	28.3 ± 1.2
	01.06	47.6 ± 1.4	45.9 ± 1.4	41.2 ± 1.5

Source: Authors' own elaboration

erties of the soil, and the presence of a significant amount of plant residues within the plough layer profile under the ploughing system creates the most favourable environment for microorganisms. On the other hand, under zero tillage, all plant residues are located on the soil surface and isolated from the zone of active soil biota activity.

The soil tillage system for agricultural crops in crop rotation is based on a combination of various methods aimed at creating optimal conditions for plant growth, preserving soil fertility, and efficiently utilizing moisture. Each crop requires an individual approach that takes into account its biological characteristics, preceding crops in the rotation, soil type, and climatic conditions. For winter wheat, deep ploughing at 20–25 cm is typically used, which helps to control weeds, accumulate moisture, and create a favourable soil structure. Prior to sowing, cultivation is performed to level the surface and ensure a fine-grain soil structure.

For maize, which requires significant moisture reserves, deep tillage or chiseling is often used, which helps to break up compacted soil layers and improve its permeability. In regions with insufficient moisture, it is advisable to use technologies that minimize soil disturbance, such as Strip-till. Sunflower requires deep ploughless tillage or chiseling to a depth of 20–30 cm to control weeds and create conditions for the formation of a strong root system. Pre-sowing treatment for this crop is limited to leveling the surface for precise sowing.

Spring barley is usually grown after surface tillage or ploughing to a depth of 20–22 cm, which ensures adequate aeration and optimal conditions for root system development.

The soil tillage system in crop rotation should take into account the alternation of crops with different biological requirements. Leguminous crops, for example, improve soil structure and enrich it with nitrogen, creating favourable conditions for subsequent crops. In arid regions, to conserve moisture, minimal or zero tillage is actively implemented, while on slopes, non-ploughing methods are used to prevent erosion. Thus, the soil tillage system is an important element

of agricultural technologies, ensuring efficient resource management, increased yield, and soil fertility preservation.

The productivity of the five-field grain-fallow-crop rotation was mainly determined by the applied mineral fertilizers, rather than the soil tillage method. The primary tillage systems on the plots fertilized with mineral fertilizers, along with post-harvest residues, were found to be equivalent in all productivity indicators: grain yield (2.81–2.91 t/ha), grain units (3.60–3.65 t/ha), feed units (3.93–4.00 t/ha), and digestible protein (0.42–0.45 t/ha) per hectare of rotational area, with a slight tendency for lower performance in the shallow mulching tillage system. On the variant with plant residues without mineral fertilizers, the ploughing and differentiated tillage systems showed superior results in all productivity indicators, due to a better nutritional regime (Table 4). For example, the grain yield with the ploughing tillage system was 0.21 t/ha (7.6%) higher, grain units 0.19 t/ha (5.5%) higher, feed units 0.23 t/ha (6.2%) higher, and digestible protein 0.04 t/ha (7.5%) higher compared to the shallow mulching system.

The applied mineral fertilizers in moderate doses ($N_{24}P_{18}K_{18}$, $N_{48}P_{18}K_{18}$, on average per 1 ha of the crop rotation area), together with plant residues, significantly increased the overall productivity of the crop rotation. The maximum increase in grain yield from applying $N_{60}P_{30}K_{30}$ under the ridge tillage system was 0.25 t/ha (8.7%), grain units – 0.36 t/ha (9.9%), fodder units – 0.41 t/ha (10.3%), digestible protein – 0.02 t/ha (5.0%) per hectare of crop rotation area. The use of $N_{48}P_{18}K_{18}$ under the differentiated tillage system increased grain yield by 0.34 t/ha (12.2%), grain units – 0.49 t/ha (13.5%), fodder units – 1.12 t/ha (28.0%), digestible protein – 0.06 t/ha (13.6%) per hectare of crop rotation area. The application of $N_{48}P_{18}K_{18}$ in the crop rotation under the shallow (mulching) tillage system resulted in an increase in grain yield by 0.38 t/ha (13.6%), grain units – 0.51 t/ha (14.2%), fodder units – 0.57 t/ha (14.5%), digestible protein – 0.07 t/ha (15.9%) per hectare of crop rotation area. According to the research results, the highest increases from mineral fertilizers in productivity indicators were observed for the shallow (mulching) background with a more

Table 4. Impact of primary soil tillage systems and fertilization on the productivity of short-rotation grain-fallow-crop rotation, t/ha (average for 2021–2024)

Crop rotation sequence	Soil cultivation and fertilization system in crop rotation								
	plowing system			differentiated system			mulching system		
	plant residues	plant residues + $N_{24}P_{18}K_{18}$	plant residues + $N_{48}P_{18}K_{18}$	plant residues	plant residues + $N_{24}P_{18}K_{18}$	plant residues + $N_{48}P_{18}K_{18}$	plant residues	plant residues + $N_{24}P_{18}K_{18}$	plant residues + $N_{48}P_{18}K_{18}$
Black fallow	–	–	–	–	–	–	–	–	–
Winter wheat	5.02	5.15	5.22	5.02	5.40	5.50	4.80	5.03	5.32
Sunflower	2.41	2.57	2.67	2.28	2.57	2.71	2.34	2.61	2.74
Spring barley	2.79	2.94	3.14	2.60	2.88	3.11	2.24	2.57	2.89
Corn	5.32	5.76	6.03	5.24	5.65	5.92	5.13	5.54	5.85
Yield from 1 ha of the crop rotation area (t)									
Total grain:	2.63	2.77	2.88	2.57	2.78	2.91	2.43	2.63	2.81
winter wheat grain	1.01	1.03	1.05	1.01	1.08	1.10	0.97	1.01	1.07
fodder grain	1.62	1.74	1.84	1.53	1.71	1.81	1.48	1.62	1.75
grain yield	4.37	4.61	4.79	4.28	4.64	4.84	4.05	4.38	4.68
Output: fodder units	3.58	3.81	4.00	2.88	3.80	4.00	3.36	3.66	3.93
digestible protein	0.41	0.43	0.45	0.39	0.43	0.45	0.38	0.42	0.45
grain units	3.27	3.48	3.63	3.16	3.47	3.65	3.09	3.38	3.60
Least significant difference (LSD), t/ha (p = 0.05) For factor A For factor B For interaction AB									 0.12 0.14 0.15

Source: Authors' own elaboration

rigid nutrient regime. The applied mineral fertilizers in moderate doses here increased the productivity of the crop rotation by more than 14% compared to the ridge tillage system with better initial mineral nutrition conditions.

Conclusion

Soil microbial activity is primarily directly proportional to the moisture conditions of the arable layer (0–30 cm), applied mineral fertilizers, and soil aeration. A tendency to increase microbial activity, flax canvas degradation, and CO_2 emissions was noted under ridge tillage, even in unfertilized variants, due to better aeration conditions and deeper incorporation of plant residues.

Use of by-products of the predecessor crop without mineral fertilizers resulted in a decrease in soil biological activity and nitrate nitrogen content in the 0 – 30 cm layer under mulching tillage compared to plowing, with an average reduction of 1.0–2.2 mg/kg. In the variant with straw incorporation combined with fertilizers ($N_{30}P_{30}K_{30}$, $N_{60}P_{30}K_{30}$), positive changes in the nitrogen regime of the black soil were recorded over time under chiseling and subsoiling tillage, associated with adequate soil moisture and the development of nitrate remobilization processes.

Different tillage systems (ridge, differentiated, shallow (mulching)) in a five-field crop rotation were found to be equivalent in terms of productivity indicators, except for the variants without mineral fertilizers, where the shallow (mulching) system lagged behind the differentiated and ridge systems by 5.5–7.6%. The application of mineral fertilizers in moderate doses significantly increased (5.0–13.6%) crop rotation productivity indicators, especially in the shallow (mulching) tillage system with more rigid initial mineral nutrition conditions, where they increased by more than 14%.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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