Agronomy Research **21**(X), xxx–ccc, 2023
https://doi.org/10.15159/AR.23.079

Efficiency of technology elements for growing winter wheat on typical chernozem

O. Litvinova[1], S. Dehodiuk[2], D. Litvinov[1], O. Havryliuk[1,*], A. Kyrychenko[2], N. Borys[3] and O. Dmytrenko[4]

[1]National University of Life and Environmental Sciences of Ukraine, Agrobiological faculty, 12A, 13 Heroiv Oborony Str., UA03041 Kyiv, Ukraine
[2]National Scientific Centre Institute of Agriculture of National Academy of Agricultural Scienses, 2-B Mashynobudivnykiv Str., UA08162 Chabany, Kyiv region, Ukraine
[3]National Academy of Agrarian Sciences of Ukraine, Scientific staff and post-graduate studies Department, 9 Omelyanovich-Pavlenko Str., UA01010 Kyiv, Ukraine
[4]State Institution Soils Protection Institute of Ukraine, 3 Babushkina lane, UA03190 Kyiv, Ukraine
[*]Correspondence: o.havryliuk@nubip.edu.ua

Received: March 15th, 2023; Accepted: July 17th, 2023; Published: September 1st, 2023

Abstract. The use of traditional tillage technologies in short-rotational crop rotations increases the cost of agricultural production and has a negative impact on the environment. The research was aimed at establishing and improving the ways winter wheat yield increase in short-rotational crop rotations depending on the efficiency of the main tillage system and fertilizing on typical chernozems s in conditions of unstable moisture in the Forest Steppe of Ukraine. The research was conducted at the Department of Agrochemistry National Scientific Centre Institute of Agriculture of National Academy of Agricultural Scienses at the Panfil Research Station of the National Scientific Center Institute of Agriculture of the National Academy of Agrarian Sciences in a stationary technological experiment, on typical low-humus chernozem in 2 short rotation crop rotations with the following crops rotation: crop rotation 1 - winter rape (*Brassica napus* L.), winter wheat (*Triticum aestivum* L), grain maize (*Zea mays*), spring barley (*Hordeum vulgare* L); crop rotation 2 - soybean (*Glycine max* (L.) *Merrill*), winter wheat (*Triticum aestivum* L), sunflower (*Helianthus annuus*), spring barley (*Hordeum vulgare* L). The article presents the results of research in two short-rotation crop rotations with the placement of winter wheat (*Triticum aestivum* L) after winter rape (*Brassica napus* L.) and soybean (*Glycine max* (L.) *Merrill*) against the background of two tillage systems: ploughing (25–27 cm) and no-till (direct sowing). The impact of different methods of soil cultivation and fertilizing systems on the humus content and nutrient regime of typical chernozems in the agrocenosis of winter wheat was determined. It was established that in winter wheat, placed after winter rapeseed and soybeans, there is a tendency to increase the humus content under zero tillage up to 15% relative to the control (without fertilizers) and from 5–14% relative to moldboard tillage (25–27 cm ploughing). The most effective in nutrient accumulation was fertilizing system $N_{(90)}P_2O_{5(90)}K_2O_{(90)}$ applied after rape and after soybean. Respectively, the content of mobile phosphorus compounds increased by 10–18% and potassium by 1.3–2.0 times compared to the control (without fertilizers) with the advantage of no-tillcultivation technology. The given comparative assessment of the yield formation of winter wheat when growing it after different pre-crops showed that the average yield of winter wheat grain in both cultivations on the control option for the soybean pre-crop was 3.55 t ha^{-1} and 4.00 t ha^{-1} for rape. The highest increases in grain yield on average over the years of research were provided by the fertilizing system of 50–54% ($N_{(90)}P_2O_{5(90)}K_2O_{(90)}$) for growing winter wheat after soybeans and 39–47% ($N_{(90)}P_2O_{5(90)}$ $K_2O_{(90)}$) on the winter rape pre-crop with the advantage of moldboard tillage (ploughing) in crop cultivation technologies. The fertilizing system with the introduction of $N_{(16)}P_2O_{(16)}K_2O_{(16)}$ has the prospect of spreading because, in terms of the formation of typical indicators of chernozem fertility and the yield of winter wheat grain, it approaches technologies with the introduction of $N_{(120)}P_2O_{5(90–60)}K_2O_{(100–90)}$ with significant cost savings for mineral fertilizers.

Keywords: tillage system, fertilizing system, short-rotational crop rotations, soil nutrient regime, winter wheat, productivity.

INTRODUCTION

Crop rotation is an integral part of any farming system. Cultivation methods, fertilizing, and protection systems are changing. Still, a scientifically based rotation of crops in time, which brings the functioning of agrocenoses closer to natural conditions, is a mandatory condition. The correct alternation of crops in crop rotation is ensured by observing the chemical, physical, and biological foundations of farming, as well as taking into account the adaptation of crops to climate changes (Litvinov et al., 2020). Under these conditions, selection of pre-crop with an optimal combination of crops of the same species and the permissible periodicity of their return to the same field is very important (Parkhuts, 2023). Due to the nitrogen fixation in crop rotations with peas 33–56% of nitrogen consumption from fertilizers and soil for crop yields were compensated. With soybeans - 57–62%, with perennial grasses - 89% (Tonkha et al., 2019, 2021; Tanchyk et al., 2021).

At the current stage of conducting energy-saving agriculture in many countries, the principle of minimizing soil cultivation is established. In Ukraine, this direction is being improved mainly in its depth reduction, the number of carried out deep loosening, and the use of beardless tools (beardless method of soil cultivation - without rotation of the arable layer), which reduce the specific resistance of the soil and increase labor productivity (Medvediev & Lyndina, 2001; Bai et al., 2020). Great importance in the growth and development of agrophytocenoses regulating is assigned to mechanical soil cultivation. Research by scientists has shown that agrophysical properties are extremely important in managing soil fertility (Shylina et al., 2006; Zakharchenko et al., 2013; Sobko et al., 2014). The study of soil nutrient regime and its optimization are an important part of the general problem of developing optimal parameters of the root-containing layer when studying the effectiveness of minimizing tillage (Martinenko et al., 2014; Yeromina & Soroka, 2014). According to Tsyuk et al. (2022), this technology not only contributes to the better reproduction of organic matter but also significantly changes the nitrogen regime of the soil. The total nitrogen content and accumulation, which is in the composition of organic compounds, significantly increases in soils using no-till cultivation (Soanea et al., 2012; Arvidsson et al., 2014), and the amount of easily hydrolyzable mineral and organic forms - sharply decreases (by 25–30%), which can lead to a deterioration of plants nitrogen nutrition, a decrease in the yield of crops and the need for additional application of nitrogen fertilizers. Some scientists believe that minimum tillage helps preserve soil fertility and increase the yield of cultivated crops (Li et al., 2020; Rieznik et al., 2021), while others prefer deep or differentiated tillage in crop rotation, which combines deep ploughing for row crops and shallow or surface tillage for cereals (Liu et al., 2022; Alexander et al., 2023; Balen et al., 2023). The goal of improving resource-saving cultivation technologies in specific soil and climatic conditions is to increase yields and reduce costs for growing crops (Prymak et al., 2012; Rustamova, 2016; Ivanova et al., 2022). Thus, replacing ploughing with no-till cultivation does not significantly affect the relative variability of winter wheat yields, as well as its repeated sowings. The coefficient of evenness for both processing methods was in the range of 71–76%. At the same time, the overall level of winter wheat yield under shallow tillage is higher than under ploughing, both in favorable and unfavorable years in terms of moisture (Saiko, 2007). According to Prymak et al. (2012) increased productivity of almost all crops under moldboard ploughing, rather than beardless, method of main cultivation was ensured due to better accumulation and preservation of soil moisture, as well as significantly less weediness of fields. Moreover, soil cultivation in crop rotation should be of various depths. This is due to economic and agrotechnical reasons (Somasundaram et al., 2020). With multi-depth tillage in crop rotation, segetal vegetation is more effectively controlled, plowed soil is better structured, and applied fertilizers are mixed with the soil.

Thus, soil cultivation in crop rotations should be carried out at different depths and combine various methods of moldboard and beardless cultivation methods. It should be noted that most scientists think that the differentiation of the arable soil layer due to the introduction of surface and tillage with the localization of nutrients in its upper 0–10 cm layer has a negative impact on the growth, development, and yield of crops. Long-term tillage increases the heterogeneity of the arable layer and worsens the phytosanitary condition of the soil environment. There are also known significant disadvantages of permanent main ploughing (intensive mineralization of organic matter, high energy intensity) (Tsvey & Boychuk, 2012; Tsentilo, 2019; Litvinova et al., 2019, 2023). It is worth noting that no country in the world where no-till cultivation applied to the entire area of arable land. It was most widespread in the grain provinces of the USA, Canada, Australia, and arid regions of Ukraine. In Western Europe, differentiated cultivation is widespread, due to the advantages of the moldboard method. No-moldboard, chisel tillage is used for winter and spring grain crops, which are sown after row crops (Momirović et al., 2011; Moraru & Rusu, 2013; Moitzi et al., 2013; Rusu, 2014; Spriazhka et al., 2022). In all countries of the world, where no-till cultivation is common, herbicides are used to control the abundance of weeds (Manko et al., 2003). But strict adherence to the technological process, rational selection of bladeless tools, and depth of tillage taking into account the biological requirements of crops and zonal features can provide significantly higher soil protection efficiency of mechanical tillage in crop rotation. It is undeniable that the minimization of soil cultivation is a product of a high crops of agriculture, an integral component of science-intensive technologies (Vasylenko et al., 2021; Havryliuk et al., 2022a, 2022b). Each of their elements not only solves its tasks but also functionally supports and reveals the potential of the next element of technology, thereby realizing the principle of a system approach in agriculture (Shykula & Dymedenko, 2005; Degodjuk et al., 2015; Litvinova et al., 2019).

Only long-term stationary field experiments can provide an objective assessment of the effectiveness of methods combination, depth, means and measures of the main tillage in crop rotation concerning specific soil and climatic conditions.

The purpose of the research is to establish and improve the ways of increasing winter wheat yield in short-course crop rotations depending on the efficiency of the main tillage system and the fertilizing on typical chernozems in the conditions of unstable moisture of the forest-steppe of Ukraine.

MATERIALS AND METHODS

Field research was carried out at the department of agrochemistry National Scientific Centre Institute of Agriculture of National Academy of Agricultural Scienses at the Panfil Research Station of the National Scientific Center Institute of Agriculture of the National Academy of Agrarian Sciences in a stationary technological experiment established in 2008 (the research was carried out during 2016–2019 years) on typical low-humus chernozem in 2 short-rotation crop rotations with the following crop shift:

Crop rotation 1 – winter rape, winter wheat, grain maize, spring barley;

Crop rotation 2 – soybean, winter wheat, sunflower, spring barley.

The total area of the experiment is 5.6 ha^{-1}, 4.3 ha^{-1} are occupied under the experimental plots. The size of the sowing plot is 25×6 = 150 m^2, the accounting plot is 100 m^2. The experiment is quadruple, the placement of options and repetitions is systematic. The research was carried out under the winter wheat crop after its pre-crop - winter rape and soybean. In field crop rotations, two tillage systems were studied:

1) Moldboard ploughing (ploughing at 25–27 cm);

2) No-till (direct sowing).

The scheme of the experiment consisted of four different fertilizing systems variants:

1) Control (without fertilizers);

2) $N_{(120)}P_2O_{5(90)}K_2O_{(100)}$ – after pre-crop rape and $N_{(120)}P_2O_{5(60)}K_2O_{(90)}$ – after pre-crop soybean;

3) $N_{(90)}P_2O_{5(90)}K_2O_{(90)}$, after pre-crop soybean - $N_{(90)}P_2O_{5(90)}K_2O_{(90)}$;

4) $N_{(16)}P_2O_{(16)}K_2O_{(16)}$ on two pre-crops.

By-products of the pre-crop were applied to all versions of fertilizers. In the experiment, the variety of winter (soft) wheat - 'Stolychna', entered in the State Register of Plant Varieties Suitable for Distribution in Ukraine is used.

In the conditions of the Panfil Research Station, soil samples under winter wheat were taken at the end of the growing season on typical chernozems.

The following were determined in the soil samples:

– humus - according to Tyurin (the method is based on the oxidation of the carbon of humus substances to CO_2 0.4 by the solution of potassium dichromate ($K_2Cr_2O_7$), prepared on sulfuric acid diluted in water 1:1. According to the amount of the chromium mixture that was used for the oxidation of organic carbon judging by its quantity) (DSTU 4289:2004, 2005);

– hydrolyzed nitrogen by alkaline - according to Kornfield (the method consists in hydrolyzing a weight of soil by 1H NaOH solution in a thermostat at 28 °C in a Conway cup) (DSTU 7863:2015, 2016);

– mobile phosphorus and potassium - by the Chirikov method (the method is based on the extraction of mobile compounds of phosphorus and potassium from one weight of soil by 0.5M solution of CH_3COOH at a ratio of soil: solution = 1:2.5 with the subsequent determination of phosphorus on a photoelectrocolorimeter) (DSTU 4115-2002, 2003).

According to the observations of Yahotyn Meteorological Station (Yahotyn), the average annual air temperature is 7.3 °C; the average long-term precipitation is 442 mm and it varies from 250 to 670 mm; the relative humidity is 78%; the average duration of the growing season is 202 days.

Weather conditions during the years of research were formed in accordance with the indicated agroclimatic region, but each year had its own specific features in the formation of the temperature regime and moisture supply (Tables 1–2).

In general, the most favorable for the formation of crop productivity were 2004–2006, 2008 and 2009 and 2011. Arid conditions of crop vegetation developed in 2010, which was characterized by the most significant and extreme deviation of air temperature during the growing season.

Table 1. Indicators of average monthly air temperature for 2016–2019 °C

Month	Amount of precipitation, mm					
	Norm	Actually				
		2016	2017	2018	2019	average
January	23	51	32	68	39	48
February	21	55	19.5	22	33	32
March	22	28	9.5	88	26	38
April	34	26	32	12,3	41	28
May	44	127	22	33	47	57
June	58	70	8	62	22	41
July	66	25	66	78	15	46
August	34	60	23	5	17	26
September	40	11	15	34	24	21
October	35	86	96	16	3	50
November	34	22	40	14	15	23
December	31	0	0	67	36	26
In a year	442	561	363	499	318	435

Table 2. The amount of precipitation per., mm

Month	The air temperature, °C					
	Norm	Actually				
		2016	2017	2018	2019	average
January	-6.5	-6.8	-6.0	-3.5	-5.5	-5.5
February	-5.2	1.5	-3.1	-4.6	-0.4	-1.7
March	-0.3	3.9	5.4	-2.8	3.9	2.6
April	8.3	12.4	10.1	12.3	10.3	11.3
May	15	15.3	14.9	17.4	21.2	17.2
June	18.1	20.1	20.1	19	23	20.6
July	19.4	22.1	20.6	21.2	19.8	20.9
August	18.6	20.9	22.3	21.9	20	21.3
September	13.6	14.7	16.5	16.8	15.5	15.9
October	7.5	4.0	8.2	10	10.5	8.2
November	1.5	2.4	2.9	-0.47	2.3	1.8
December	-3	0.0	0.0	-2.37	2.2	0.0

Crop protection system against harmful organisms. Modern recommended pesticides based on ecological and economic thresholds of harmfulness were used as chemical means of controlling weeds and other harmful organisms in winter wheat fields. The crop protection system provided for seed treatment before sowing with Vitavax 200 FF (2.5–3.0 L t^{-1}). Treatment of crops to protect against diseases with fungicide Impact 25% k.s. (0.5 L ha^{-1}) and Falcon (0.6 L t^{-1}). To protect against weeds - Granstar herbicide 75% vol. (20–25 g ha^{-1}). Nurel D 500 EC (1.0 L ha^{-1}) and Fastak (150 g ha^{-1}) were used to control pests.

Harvesting of winter wheat was carried out by direct combining with a combine harvester 'SAMPO 130' by the method of continuous threshing of each plot with subsequent conversion to 100% purity and 14% moisture.

Statistical analysis. Statistical differences between experimental and control results were tested by one-way analysis of variance (ANOVA) and the student-Newman-Keuls test. Values of $P < 0.05$ were considered statistically significant. Statistical processing was performed in Microsoft Excel 2016 values were estimated using mean and standard deviations and subsequently evaluated in the statistical program XL Stat. In hypothesis testing, if the p-value is lower than a significant level, in the case of XL Stat software by Addinsoft, it is 0.05, the null hypothesis was rejected and alternative hypothesis was confirmed.

RESULTS AND DISCUSSION

The indicator of soil-forming processes development is the content of total humus in the soil. The analysis of obtained results showed that the use of different fertilizing systems and methods of soil cultivation caused changes in the content of organic matter (humus). Determination of dynamics of total humus accumulation, on average over the years of research, showed a tendency for it to increase regardless of the fertilizing system relative to the control (without fertilizers), where it was 2.82% under the studied pre-crop. An increasing humus content was noted for the no-tillcultivation system compared to the control option (without fertilizer application) by 15% (Fig. 1).

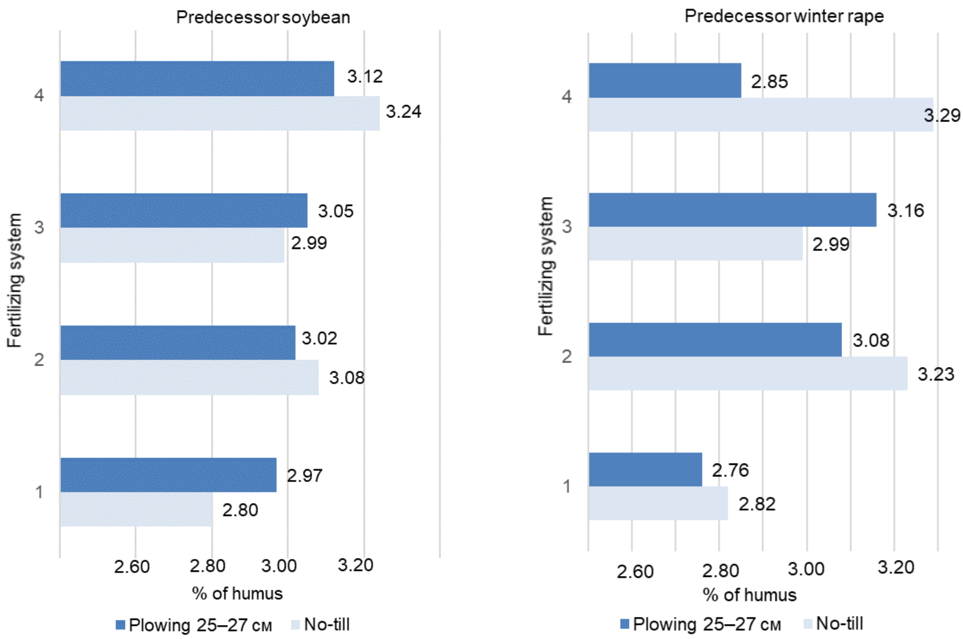

Figure 1. Total humus content in typical chernozems depending on fertilizing, systems, and methods of its tillage for growing winter wheat, soil layer 0–20 cm, the average for 2016–2019.

Note to the Figure. Fertilizing system: 1 – control (without fertilizers); 2 – $N_{(120)}P_2O_{5(90)}K_2O_{(100)}$ – after pre-crop rape and $N_{(120)}P_2O_{5(60)}K_2O_{(90)}$ – after pre-crop soybean; 3 – $N_{(90)}P_2O_{5(90)}K_2O_{(90)}$ – after pre-crop rape, $N_{(90)}P_2O_{5(90)}K_2O_{(90)}$ – after pre-crop soybean; 4 – $N_{(16)}P_2O_{(16)}K_2O_{(16)}$ for both pre-crops.

Depending on the humus content, it is effective to grow winter wheat under no-till systems and place it after winter rape and soybeans, while under the traditional moldboard tillage system (ploughing at 25–27 cm), only after soybeans. It was determined that the highest value of this indicator was formed under the resource-saving fertilizing system, which is associated with the presence of a sufficient amount of plant residues and indicates their significant role in humification processes. The use of low rates of mineral fertilizers was significantly inferior to fertilizing systems with increased backgrounds, this trend was characteristic of both soil treatments and did not depend on the pre-crop (winter rape, soybean), which indicates that the possibilities of humus accumulation in the soil due to fertilizers are limited and the use of fertilizers in optimal in doses that do not exceed the nutrient requirements of plants, does not significantly increase the humus content of the soil. Moldboard processing under such conditions balances the processes of synthesis and mineralization towards the accumulation of organic components relative to zero technologies.

The obtained average data on the content of easily hydrolyzed nitrogen, mobile forms of phosphorus and potassium are clearly differentiated depending on the tillage and fertilizing systems. Thus, in the crop rotation for winter wheat after rape, a significant number of by-products accumulates. The by-products accumulated in the soil, as a result of homogenization in the plow layer, provide 5% less easily hydrolyzed form of nitrogen in the control than in the variant with the no-till system. In option 2 – by 4%, and option 4, with introduction of $N_{(16)}P_2O_{(16)}K_2O_{(16)}$ – by 10% (Fig. 2).

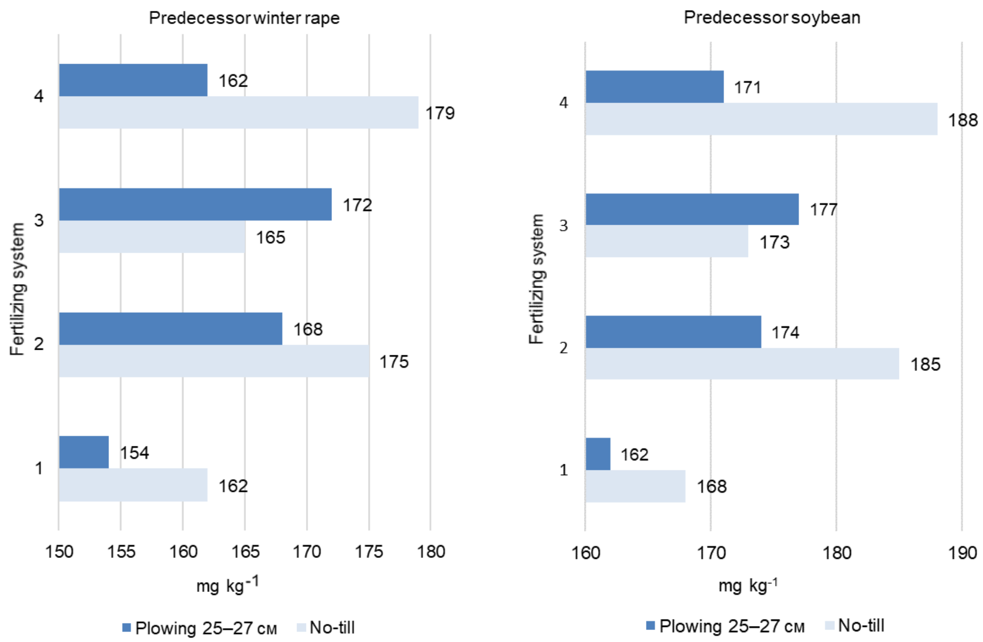

Figure 2. Easily hydrolyzed nitrogen content in typical chernozems , depending on fertilizing systems and methods of its tillage for growing winter wheat, soil layer 0–20.

Note to the Figure. Fertilizing system: 1 – control (without fertilizers); 2 – $N_{(120)}P_2O_{5(90)}K_2O_{(100)}$ – after pre-crop rape and $N_{(120)}P_2O_{5(60)}K_2O_{(90)}$ – after pre-crop soybean; 3 –$N_{(90)}P_2O_{5(90)}K_2O_{(90)}$ – after pre-crop rape, $N_{(90)}P_2O_{5(90)}K_2O_{(90)}$ – after pre-crop soybean; 4 – $N_{(16)}P_2O_{(16)}K_2O_{(16)}$ for both pre-crops.

An advantage in 5% of option 3 with the moldboard system of soil cultivation (ploughing at 25–27 cm) was noted. Similar regularities are confirmed in the works of scientists who claim that the influence of tillage methods on the nitrogen regime of the soil, affected by nitrogen content redistribution in the arable layer. On average, for crop rotation crops, reserves of easily hydrolyzed nitrogen for ploughing were 8–10% higher than for plowless tillage (Zvedeniuk, 2014).

The obtained data indicate that in the vast majority of cases, there are better conditions for the nitrogen transformation in the soil under zero tillage. Research by Kolos (2017) found that the content of easily hydrolyzable nitrogen over four years in tillage without a moldboard had a tendency to increase in the upper soil layer (0–10 cm) compared to control ploughing. Moreover, in the no-till variant, the indicator content increased by 11.0 mg kg^{-1} soil compared to ploughing. Thus, under the mulched layer of rape and soybean straw during the growing season, optimal conditions of temperature regime and moisture are formed for the translocation of organic matter into assimilated nitrogen compounds.

The mobile phosphorus content under different systems of cultivation and fertilizing did not undergo significant changes and was formed within the limits of control (without fertilizers). For fertilizing systems in variant 2 with a slight excess of up to 5%, and in variant 3 - by 12%, regardless of cultivation. For fertilizing systems with $N_{(16)}P_2O_{(16)}K_2O_{(16)}$, the advantage in the accumulation of this phosphorus form was revealed by the introduction of moldboard ploughing (ploughing at 25–27 cm) compared to no-till technology under both pre-crops within 6%. The decrease in the rate of mobile phosphorus compounds accumulation under intensive systems with increased fertilizing backgrounds is associated with the removal of the nutrient element by crop production and formation of higher crop yield levels under such conditions. Also, these non-productive losses are characterized by retrogradational processes that occur under high loads and are caused by the genetic features of soil subsidence (Fig. 3).

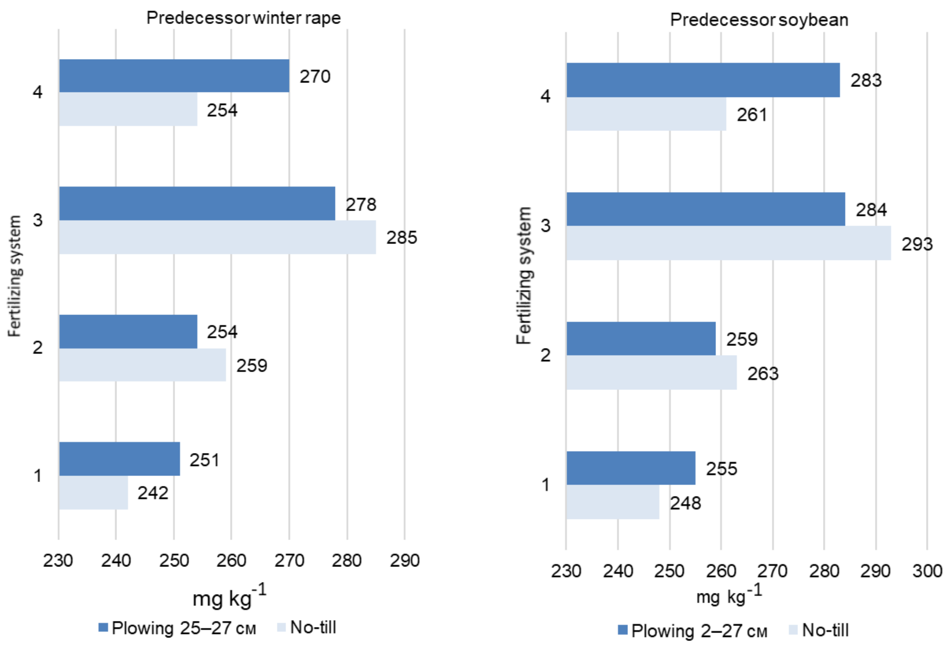

Figure 3. Mobile phosphorus content in typical chernozems, depending on fertilizing systems and methods of its tillage for growing winter wheat, soil layer 0–20 cm, the average for 2016–2019.

Note to the Figure. Fertilizing system: 1 – control (without fertilizers); 2 – $N_{(120)}P_2O_{5(90)}K_2O_{(100)}$ – after pre-crop rape and $N_{(120)}P_2O_{5(60)}K_2O_{(90)}$ – after pre-crop soybean; 3 –$N_{(90)}P_2O_{5(90)}K_2O_{(90)}$ – after pre-crop rape, $N_{(90)}P_2O_{5(90)}K_2O_{(90)}$ – after pre-crop soybean; 4 – $N_{(16)}P_2O_{(16)}K_2O_{(16)}$ for both pre-crops.

Due to the weak response of phosphorus compounds to agrotechnical measures, the mobile potassium content in the field crop rotation prevailed under no-till technology and placement of winter wheat after both pre-crops. As the load of agrochemicals in the fertilizing system increased potassium content in the soil increased. Compared to variant 4 ($N_{(16)}P_2O_{(16)}K_2O_{(16)}$ was from 10 to 15%. This process is associated with the growing mineralization of straw organic matter due to increased doses of nitrogen fertilizers. There is a marked advantage in the accumulation of this indicator in variant 2, which is obviously due to an increase in the removal of nutrients per unit of yield at high levels of fertilizer loading (Fig. 4).

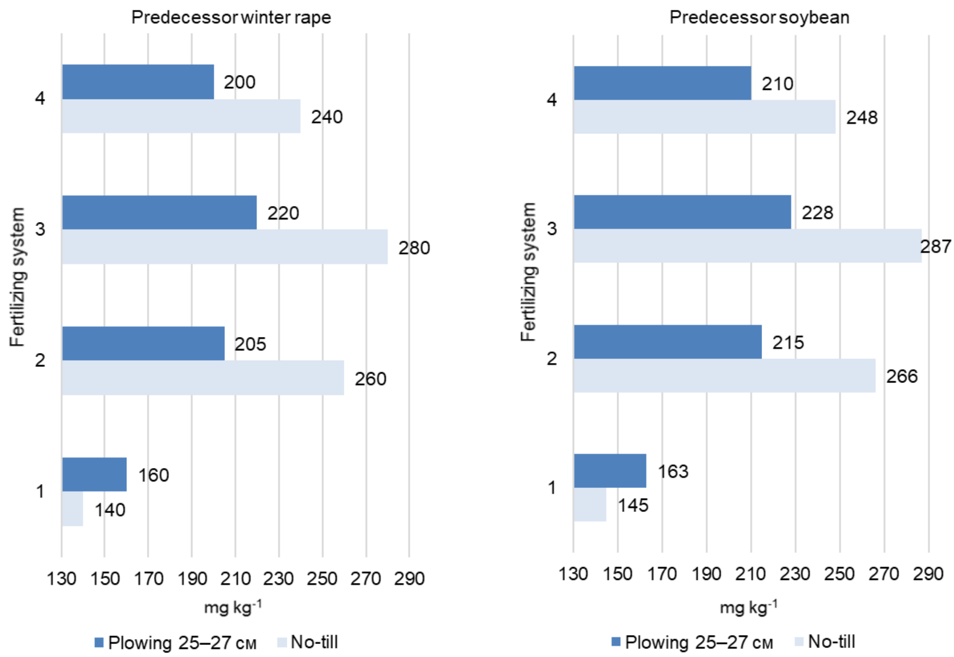

Figure 4. Mobile potassium content in typical chernozems depending on fertilizing systems and methods of its tillage for growing winter wheat, soil layer 0–20 cm, the average for 2016–2019.

Note to the Figure. Fertilizing system: 1 – control (without fertilizers); 2 – $N_{(120)}P_2O_{5(90)}K_2O_{(100)}$ – after pre-crop rape and $N_{(120)}P_2O_{5(60)}K_2O_{(90)}$ – after pre-crop soybean; 3 – $N_{(90)}P_2O_{5(90)}K_2O_{(90)}$ – after pre-crop rape, $N_{(90)}P_2O_{5(90)}K_2O_{(90)}$ – after pre-crop soybean; 4 – $N_{(16)}P_2O_{(16)}K_2O_{(16)}$ for both pre-crops.

It is known that the productivity of any crop is an objective assessment of various technologies. Obtaining appropriate levels of fertilizing in crop rotations after various pre-crops for the introduction of cultivation technologies had a corresponding effect on winter wheat grain yield formation. During crop rotation without fertilizers (control) on the pre-crop of soybeans, with zero tillage, the grain yield of winter wheat was 3.50 t ha^{-1}, with moldboard tillage (ploughing at 25–27 cm), it was 3% higher than no-till. When winter wheat was placed after winter rape in the variant without fertilizer application (control), the grain yield was 11% higher than after soybeans with zero tillage, which was inferior within the experimental margin of error to moldboard tillage (ploughing at 25–27 cm) (Table 3).

Table 3. The yield of winter wheat depending on the fertilizing system, pre-crop, and methods of soil cultivation in short-course crop rotation (the average for 2016–2019)

Fertilizing system	Tillage						
	No-till			Moaldboard (ploughing on 25–27 cm)			average for tillage,
	yield, $t\ ha^{-1}$	an increase		yield, $t\ ha^{-1}$	an increase		
		$t\ ha^{-1}$	%		$t\ ha^{-1}$	%	%
Pre-crop soybean							
Control (without fertilizers)	3.50	–	–	3.59	–	–	–
$N_{(120)}P_2O_{5(60)}K_2O_{(90)}$	5.39	1.89	54	5.23	1.64	46	50
$N_{(90)}P_2O_{5(90)}K_2O_{(90)}$	5.07	1.57	44	5.16	1.57	44	44
$N_{(16)}P_2O_{(16)}K_2O_{(16)}$	4.07	0.57	16	4.37	0.78	22	19
LSD_{05} for the tillage factor – 0.26; LSD_{05} for the fertilizer factor – 0.30; LSD_{05} overall – 0.52							
Pre-crop rape							
Control (without fertilizers)	3.93	–	–	4.26	–	–	
$N_{(120)}P_2O_{5(90)}K_2O_{(100)}$	5.77	1.84	47	5.92	1.66	39	43
$N_{(90)}P_2O_{5(90)}K_2O_{(90)}$	5.33	1.40	36	5.80	1.54	36	36
$N_{(16)}P_2O_{(16)}K_2O_{(16)}$	4.44	0.51	13	4.76	0.50	12	12
LSD_{05} for the tillage factor – 0.25; LSD_{05} for the fertilizer factor – 0.29; LSD_{05} overall – 0.51							

Note to Table 1. Fertilizing system: 1 – control (without fertilizers); 2 – $N_{(120)}P_2O_{5(90)}K_2O_{(100)}$ – after pre-crop rape and $N_{(120)}P_2O_{5(60)}K_2O_{(90)}$ – after pre-crop soybean; 3 – $N_{(90)}P_2O_{5(90)}K_2O_{(90)}$ – after pre-crop rape, $N_{(90)}P_2O_{5(90)}K_2O_{(90)}$ – after pre-crop soybean; 4 – $N_{(16)}P_2O_{(16)}K_2O_{(16)}$ for both pre-crops.

The average yield of winter wheat when using the fertilizing system, depending on the pre-crop, varied between 4.07–5.39 $t\ ha^{-1}$ for cultivation after soybean and from 4.44 to 5.92 $t\ ha^{-1}$ after winter rape. It has been established that no-till was carried out for the placement of winter wheat after its tillage (ploughing at 25–27 cm), while after the pre-crop of winter rape, it turned out to be more effective, which is connected with the creation of an available nutrients reserve for yield formation of this intensive crop. Liashenko et al. (2021) found that the influence of cultivation technology was manifested primarily on inferior predecessors. For example, the difference in the productivity of winter wheat between minimal and zero technologies on the background of the predecessor pure steam was 0.02 $t\ ha^{-1}$, and on the background of the predecessor soybean 0.36 $t\ ha^{-1}$, on the background of corn for silage – 0.22 $t\ ha^{-1}$. The difference in the last two predecessors is statistically significant. With the systematic fertilizers application, the yield parameters of winter wheat in crop rotation with rape are inferior to crop rotation with soybeans, especially under no-till, with an increase in option 2 up to 54% compared to the control (without fertilizers). So, a comparative assessment of winter wheat technology of growing according to two pre-crops showed that the use of moldboard tillage (ploughing at 25–27 cm) was inferior to growth indicators on high backgrounds by 4% for the placement of winter wheat after soybeans, while for the pre-crop of winter rape, the yield was balanced by increments regardless of the tillage system. Calculations carried out by Kucher & Kucher (2014) proved that the use of zero technology is more effective against the traditional one.

CONCLUSIONS

It was established that during winter wheat cultivation in short-course crop rotations on typical chernozem, the content of total humus had a noticeable tendency to increase under no-till systems and placement after winter rape and soybeans. It was determined that during winter wheat growing according to pre-crops, the content of hydrolyzed nitrogen, mobile phosphorus and potassium increased as the agrochemical load in fertilizing systems per unit area increased. The most favorable nutrient regime of the soil developed under no-till cultivation systems. The average grain yield of winter wheat without the use of fertilizers and placing it after winter rape and soybeans was 3.70 t ha^{-1}, moldbord (plowed at 25–27 cm) - 3.93 t ha^{-1}. The highest yield increases at the level of 47–54%, on average over the years of research, for both pre-crops were obtained under the fertilizing system $N_{(120)}P_2O_{5(90–60)}K_2O_{(100–90)}$ and zero tillage (no-till). The fertilizing system with input $N_{(16)}P_2O_{(16)}K_2O_{(16)}$ has the prospect of spreading. Since, in terms of typical chernozems fertility indicators and yield formation, it approaches intensive technologies with significant savings in mineral fertilizer costs.

REFERENCES

Alexander, J.R., Baker, J.M., Gamble, J.D., Venterea, R.T. & Spokas, K.A. 2023. Spatiotemporal distribution of roots in a Maize-Kura clover living mulch system: Impact of tillage and fertilizer N source. *Soil and Tillage Research* **227**, 105590. https://doi.org/10.1016/j.still.2022.105590

Arvidsson, J., Etana, A. & Rydberg, T. 2014. Crop yield in Swedish experiments with shallow tillage and no-tillage 1983–2012. *European journal of agronomy* **52**, 307–315. https://doi.org/10.1016/j.eja.2013.08.002

Bai, J., Qiu, S., Jin, L., Xu, X., Zhao, S., He, P., Wang, L., Christie., P & Zhou, W. 2020. Quantifying soil N pools and N_2O emissions after application of chemical fertilizer and straw to a typical chernozem soil. *Biol Fertil Soils* **56**, 319–329. https://doi.org/10.1007/s00374-019-01422-2

Balen, D., Cuperus, F., Haagsma, W., Haan, J., Berg, W. & Sukkel, W. 2023. Crop yield response to long-term reduced tillage in a conventional and organic farming system on a sandy loam soil. *Soil and Tillage Researc*h **225**, 105553. https://doi.org/10.1016/j.still.2022.105553

Degodjuk, S.E., Degodjuk, E.G. & Litvinova, E.A. 2015. Crop rotation factor in tilling and fertilizing systems. *Agriculture* **1**, 46–50 (in Ukraine). Available at http://nbuv.gov.ua/UJRN/Zemlerobstvo_2015_1_11

DSTU 4115-2002. 2003. Soils. Determination of mobile compounds of phosphorus and potassium by the modified Chirikov method. [Effective from 2003-01-01]. Kyiv. *State Committee of Ukraine for Technological Regulation and Consumer Policy*, 9 p. (in Ukraine).

DSTU 4289:2004. 2005. Soil quality. Methods for determining organic matter. [Effective from 2005-07-01]. Kiev, *State Consumer Standard of Ukraine*, 14 p. (in Ukraine).

DSTU 7863:2015. 2016. Soil quality. Determination of easily hydrolyzable nitrogen by the Kornfield method. [Effective from 2016-07-01]. Kyiv. *State Enterprise "UkrNDNC*". 5 p. (in Ukraine).

Havryliuk, O., Kondratenko, T., Mazur, B., Kutovenko, V., Mazurenko, B., Voitsekhivska, O. & Dmytrenko, Y. 2022a. Morphophysiological peculiarities of productivity formation in columnar apple varieties. *Agronomy research* **20**(1), 148–160. https://doi.org/10.15159/AR.22.007

Havryliuk, O., Kondratenko, T., Mazur, B., Tonkha, O., Andrusyk, Y., Kutovenko, V., Yakovlev, R., Kryvoshapka, V., Trokhymchuk, A. & Dmytrenko, Y. 2022b. Efficiency of productivity potential realization of different-age sites of a trunk of grades of columnar type apple-trees. *Agronomy research* **20**(2), 241–260. https://doi.org/10.15159/AR.22.031

Ivanova, I., Serdyuk, M., Malkina, V., Tonkha, O., Tsyz, O., Mazur, B., Shkinder-Barmina, A., Gerasko, T. & Havryliuk, O. 2022. Cultivar features of polyphenolic compounds and ascorbic acid accumulation in the cherry fruits (*Prunus cerasus* L.) in the Southern Steppe of Ukraine. *Agronomy research* **20**(3). https://doi.org/10.15159/AR.22.065

Kolos, M. 2017. Research of the nitrogen regime and humus state of ordinary chernozems depending on soil cultivation technologies. *Scientific Journal 'ScienceRise'* **12**(41), 26–29 (in Ukrainian). https://doi.org/10.15587/2313-8416.2017.118803

Kucher, A. & Kucher, L. 2014. Economic efficiency of using no-till technology during the cultivation of winter wheat. *Fodder and fodder production* **79**, 48–55 (in Ukrainian). Available at https://www.researchgate.net/profile/Lesia-Kucher/

Li, Y., Zhang, Q., Cai, Y., Yang, Q. & Chang, S.X. 2020. Minimum tillage and residue retention increase soil microbial population size and diversity: Implications for conservation tillage. *Science of the Total Environment* **716**, 137164. https://doi.org/10.1016/j.scitotenv.2020.137164

Liashenko, V.V., Karasenko, V.M. & Krakotets, S.I. 2021. The impact of soil tillage system and proceeding crops on winter wheat grain yield capacity and quality. *Bulletin of Poltava State Agrarian Academy* **4**, 64–70. https://doi.org/10.31210/visnyk2021.04.07

Litvinov, D., Litvinova, O., Borys, N., Butenko, A., Masyk, I., Onychko, V., Khomenko, L., Terokhina, N. & Kharchenko, S. 2020. The typicality of hydrothermal conditions of the forest steppe and their influence on the productivity of crops. *Journal of Environmental Research, Engineering and Management* **76**(3), 84–95. https://doi.org/10.5755/j01.erem.76.3.25365

Litvinova, E.A., Litvinov, D.V. & Bodnar, U.D. 2019. Content of the label organic substance in the blacksmith by individual depending on the methods of growth and the system of extraction wheat lines. *Plant and soil science* **10**(1), 48–53. http://dx.doi.org/10.31548/agr2019.02.048

Litvinova, O., Tonkha, O., Havryliuk, O., Litvinov, D., Symochko, L., Dehodiuk, S., Zhyla, R. 2023. Fertilizers and pesticides impact on surface-active substances accumulation in the dark gray podzolic soils. *Journal of Ecological Engineering* **24**(7), 119–127. doi: https://doi.org/10.12911/22998993/163480

Liu, W., Ma, K., Wang, X., Wang, Z. & Negrete-Yankelevich, S. 2022. Effects of no-tillage and biologically-based organic fertilizer on soil arbuscular mycorrhizal fungal communities in winter wheat field. *Applied Soil Ecology* **178**, 104564. https://doi.org/10.1016/j.apsoil.2022.104564

Manko, Yu.P., Tanchyk, S.P. & Ivaniuk, M.F. 2003. Effectiveness of the adapted crop weed control system in the Forest Steppe of Ukraine. *Biological sciences and problems of crop production* 637–640 (in Ukrainian).

Martinenko, V., Senchenko, N. & Sobko, N. 2014. Influence of fertilizers and methods for primary treatment agrochemical properties of typical chernozems. *Bulletin of the Sumy National Agrarian University* **3**(27), 51–56. (in Ukrainian). Available at http://repo.snau.edu.ua/xmlui/handle/123456789/1906?locale-attribute=en

Medvediev, V. & Lyndina, T. 2001. Scientific prerequisites for minimization of the main tillage and prospects for its implementation in Ukraine. *Bulletin of Agricultural Science* **7**, 5–8. (in Ukrainian).

Moitzi, G., Schueller, M., Szalay, T., Wagentristl, H., Refenner, K., Weingartmann, H., Boxberger, J. & Gronauer, A. 2013. Energy Consumption and Energy Efficiency of Different Tillage Systems in the Semi-Arid Region of Austria. *Agriculture Engineering* **4**, 25–33. Available at http://arhiva.nara.ac.rs/handle/123456789/567

Momirović, N., Dolijanović, Ž., Oljača, M.V. & Videnović, Ž. 2011. Long term effects of different tillage systems influencing yield and energy efficiency in maize (*Zea mays L.*). in Poljoprivredna tehnika. *Univerzitet u Beogradu - Poljoprivredni fakultet - Institut za poljoprivrednu tehniku* **36**(1), 97–104. Available at https://hdl.handle.net/21.15107/rcub_agrospace_2505

Moraru, P.I. & Rusu, T. 2013. No-tillage and minimum tillage systems with reduced energy consumption and soil conservation in the hilly areas of Romania. *Journal of Food, Agriculture & Environment* **11**(2), 1227–1231.

Parkhuts, B. 2023. Yield and oil content of winter rapeseed depending on fertilization on typical chernozem. *Collection of Scientific Papers «ΛΌΓΟΣ»*, (April 28, 2023; Seoul, South Korea), pp. 98–99. https://doi.org/10.36074/logos-28.04.2023.30

Prymak, I.D., Kupchyk, V.I. & Kolesnyk, T.V. 2012. Changes in agrochemical properties of typical chernozem under different systems of main tillage and fertilization in the Central Forest-Steppe of Ukraine. *Bulletin of the Poltava State Agrarian Academy* **3**, 26–30 (in Ukrainian).

Rieznik, S., Havva, D., Butenko, A. & Novosad, K. 2021. Biological activity of chernozems typical of different farming practices. Agraarteadus. *Journal of Agricultural Science* **32**(2), 307–313. https://doi.org/10.15159/jas.21.34

Rustamova, I. 2016. Economic Evaluation of the Resource-Saving Technologies in Non-irrigated Lands. *Journal of Agricultural Science and Technology A* 6, 211–219. https://doi.org/10.17265/2161-6256/2016.04.001

Rusu, T. 2014. Energy efficiency and soil conservation in conventional, minimum tillage and no-tillage. *International Soil and Water Conservation Research* **2**(4), 42–49. https://doi.org/10.1016/S2095-6339(15)30057-5

Saiko, V. 2007. Systems of soil cultivation in Ukraine. *Collection of scientific works of the National Scientific Center 'Institute of Agriculture of the National Academy of Sciences of Ukraine'* **1**, 3–10. (in Ukraine). Available at http://nbuv.gov.ua/UJRN/znpzeml_2007_1_3

Shykula, M.K. & Dymedenko, O.V. 2005. Cultivated soil formation with minimal cultivation of chernozem. *Scientific Bulletin of the National Agrarian University* **81**, 107–118 (in Ukrainian).

Shylina, L., Shapoval, I. & Yermolaiev, M. 2006. Changes in the structural and aggregate state of typical chernozem under the influence of agricultural factors. Agrochemistry and soil science. *Thematic scientific collection* Spec. issue **2**, 188–190 (in Ukrainian).

Soanea, B.D., Ballb, B.C., Arvidssonc, J., Baschd, G., Morenoe, F. & Roger-Estradef, J. 2012. No-till in northern, western and south-western Europe: A review of problems and opportunities for crop production and the environment. *Soil and Tillage Research* **118**, 66–87. https://doi.org/10.1016/j.still.2011.10.015

Sobko, M., Zakharchenko, E. & Sobko, O. 2014. Influence basic tillage of soil on its agrophysical properties and productivity of grain row crop rotation. *Bulletin of the Sumy National Agrarian University* **9**(28), 46–49. Available at http://nbuv.gov.ua/UJRN/Vsna_agro_2014_9_13

Somasundaram, J., Sinha, N.K., Dalal, R.C., Lal, R., Mohanty, M., Naorem, A.K., Hatia, K.M., Chaudhary, R.S., Biswas, A.K., Patra, A.K. & Chaudhari, S.K. 2020. No-till farming and conservation agriculture in South Asia–issues, challenges, prospects and benefits. *Critical Reviews in Plant Sciences* **39**(3), 236-279. https://doi.org/10.1080/07352689.2020.1782069

Spriazhka, R.O., Zhemoida, V.L., Makarchuk, O.S., Dmytrenko, Y.M. & Bahatchenko, V.V. 2022. Selection value of initial material according to the main biochemical parameters of grain in new maize hybrids creation. *Agronomy Research* **20**(S1). https://doi.org/10.15159/AR.22.037

Tanchyk, S., Litvinov, D., Butenko, A., Litvinova, O., Pavlov, O., Babenko, A., Shpyrka, N., Onychko, V., Masyk, I. & Onychko, T. 2021. Fixed nitrogen in agriculture and its role in agrocenoses. *Agronomy Research* **19**(2), 601–611. https://doi.org/10.15159/ar.21.086

Tonkha, O., Menshov, O., Pikovska, O., Karabach, K. & Bykova, O. (2021, November). Spatial heterogenity of exchangable potassium in the phaozems and chernozems of Ukraine. *In 15th International Conference Monitoring of Geological Processes and Ecological Condition of the Environment* (Vol. 2021, No. 1, pp. 1–5). EAGE Publications BV. https://doi.org/10.3997/2214-4609.20215K2103

Tonkha, O., Pikovska, O., Balaev, A., Kovalyshyna, G., Zavgorodniy, V. & Kovalenko, V. 2019. Monitoring of the microbiological condition of virgin chernozem under different management. *Monitoring 2019 Conference - Monitoring of Geological Processes and Ecological Condition of the Environment*, 2019, 1–5. doi: https://doi.org/10.3997/2214-4609.201903256

Tsentilo, L.V. 2019. Influence of different systems of basic soil and fertilizer treatment on moisture supply of winter wheat crops. *Scientific reports of NULES of Ukraine* **1**(77). (in Ukraine). https://doi.org/10.31548/dopovidi2019.01.021

Tsvey, Ya.P. & Boychuk, O.V. 2012. Soil cultivation and clogging of winter wheat crops. *Quarantine and plant protection* **8**, 4–6. (in Ukraine). Available at http://nbuv.gov.ua/UJRN/Kizr_2012_8_4

Tsyuk, O., Tkachenko, M., Butenko, A., Mishchenko, Y., Kondratiuk, I., Litvinov, D., Tsiuk, Y., Sleptsov, Y. 2022. Changes in the nitrogen compound transformation processes of typical chernozem depending on the tillage systems and fertilizers. *Agraarteadus* **33**(1), 192–198. https://doi.org/10.15159/jas.22.23

Vasylenko, O., Kondratenko, T., Havryliuk, O., Andrusyk, Y., Kutovenko, V., Dmytrenko, Y., Grevtseva, N. & Marchyshyna, Y. 2021. The study of the productivity potential of grape varieties according to the indicators of functional activity of leaves. *Potravinarstvo Slovak Journal of Food Sciences* **15**, 639–647. https://doi.org/10.5219/1638

Yeromina, T. & Soroka, Yu. 2014. Realization of the agro-resource potential of ordinary chernozem in the North-Central. *Bulletin of Agricultural Science* **8**, 57–51 (in Ukraine). Available at http://nbuv.gov.ua/UJRN/vaan_2014_8_16

Zakharchenko, E., Masyk, I. & Davydenko, H. 2013. Influence of different ways of the till of the soil on structural and modular structure at cultivation of winter wheat. *Bulletin of the Sumy National Agrarian University* **3**, 114–119 (in Ukraine). Available at http://nbuv.gov.ua/UJRN/Vsna_agro_2013_3_31

Zvedeniuk, T.B. 2014. Nitrogen balance in grain crop rotation under different methods of main soil cultivation and fertilization. *Bulletin of Agricultural Science* **1**, 69–71 (in Ukraine). http://nbuv.gov.ua/UJRN/vaan_2014_1_18