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WINTER WHEAT YIELD DEPENDING ON DIFFERENT SOIL TILLAGE SYSTEMS IN SHORT-TERM CROP ROTATIONS UNDER BLACK SEA REGION CONDITIONS

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ABSTRACT. A crop rotation system with optimal placement and saturation of leading agricultural crops can improve the environmental conditions of the surrounding environment and increase the agricultural efficiency. Therefore, solving this task is relevant both scientifically and practically, especially in the current conditions of deteriorating environmental conditions in Ukraine. The development of environmentally safe technologies for the competitive production of high-quality crop products in the Black Sea Steppe. The primary method was fieldwork, supplemented by analytical studies, measurements, calculations, and observations according to generally accepted methodologies and guidelines in agriculture and crop production. This study focused on crop rotation systems and primary soil tillage systems. This study examined the impact of different primary soil tillage systems on the yield of winter wheat and oats in a short-rotation system. For the 1st and 4th crops, the most favourable conditions for winter wheat yield formation were observed when it was planted after black fallow and green manure fallow with winter vetch. In these cases, almost identical grain yields were recorded, averaging 3.98 and 4.08 t/ha for the 1st crop and 3.29 and 3.16 t/ha for the 4th crop. The differences in yield were not significant. For the 2nd crop, when comparing yield with the control (black fallow), an increase in yield was observed in the background of green manure fallow with winter vetch. The increase of 6.9% was statistically significant. The no-till system of primary soil cultivation provided the best conditions for the formation of winter wheat grain yield in the 1st, 2nd, and

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4th crops, with increases of 10.4, 6.9, and 5.4%, respectively, compared to conventional tillage. In the experimental variants, for the 1st and 4th crops, green manure fallow with winter vetch affected winter wheat yield, almost at the level of black fallow. For the 2nd crop, green manure fallow with winter vetch showed a clear advantage. Across all winter wheat crops, a positive impact on yield formation was observed with the no-till system. This system resulted in the highest yield compared to other soil tillage systems.

Keywords: black fallow; green manure fallow; oats; soil tillage systems.

INTRODUCTION

Currently, in the development of agricultural cultivation technologies, special attention is given to practices that ensure energy and resource savings and promote the production of environmentally friendly products. There is a trend towards transitioning from traditional soil tillage methods to minimum and soil-conserving methods to reduce the harmful impact of soil cultivation machinery and tools and decrease labour and fuel costs.

In recent years, there has been debate in the scientific community regarding soil tillage. This issue is very relevant for Ukrainian agriculture, which has diverse soil and climatic conditions, an insufficient material-technical base, and a wide range of tested soil tillage methods. In Ukraine, over 2/3 of the land is located in areas with insufficient moisture, where ploughing is preferred. However, in recent years, farmers have begun to use surface tillage, which reducing soil erosion and compaction as well as energy consumption. However, long-term studies have shown that under insufficient moisture conditions, especially in dry years, surface tillage results in lower yields of field crops compared to ploughing. To prevent yield losses and reduce risks, some scientists propose variable-depth soil tillage (Maslo, 2001).

Increasing the yield of agricultural crops requires constant attention to the implementation, improvement, and optimisation of crop rotations. Scientific research and the practical improvement of crop rotation systems in modern agriculture remains relevant and dynamic. The effectiveness of crop rotations has been demonstrated in a selection of crops and justified rotations at a high level of agronomy. All of this directly impacts the productivity of crop rotations and the technologically rational distribution of work throughout the entire growing season of agricultural crops.

According to Kovalenko (1999), for the central and southern zones of the Odessa region, the most acceptable proportion of cropped areas in field crop rotations is as follows: 8-10% in fallow, 20-25% in winter wheat, 5-6% in barley, 10% in green manure fallow, 10% in silage maize, 15-20% in grain maize, 5-6% in peas, and 8-10% in sunflower (one field in crop rotation).

At the current stage of agricultural development, special attention has been given to the application of soil tillage systems in the context of different predecessors in crop rotations, which play an important role in increasing the yield of winter wheat. However, in the context of climate change towards warming, the application of traditional soil tillage systems in short-term crop rotations sometimes yields negative results. Therefore, studying the impact of different soil tillage systems in the context of short-term crop rotations will continue to be a relevant issue of scientific and practical interest. Providing favourable conditions for the growth and development of winter cereals, which contribute to high yields in various soil and climatic zones, is only possible with appropriate agronomy (Makarov *et al.*, 1985).

The mechanical tillage of soil changes its physicochemical properties, regulates the water-air, thermal, and nutrient regimes, and influences biological processes while eliminating weeds. As a result, conditions for a more complete realisation of the natural fertility of soils and the genetic potential of winter cereal crop varieties grown in the experiment are created. It has been noted (Zhyvotkov *et al.*, 1992) that alternating conventional tillage, no-till, and shallow surface tillage in crop rotation creates the most favourable conditions for obtaining high cereal crop yields. This rotation promotes the accumulation and rational use of water, improves soil quality, increases fertility, and provides effective weed, pest, and disease control. Such measures improve agroecological conditions, which are especially important for growing winter wheat and other cereal crops.

Boyko *et al.* (2012) suggested that a differentiated primary soil tillage system could fully meet the modern requirements of agriculture. It considers soil and climatic conditions as well as the biological characteristics of field crops, allowing for the optimal combination of various tillage methods in crop rotation. Alternating conventional and no-till methods at different depths allows for better adaptation of agrotechnical measures to specific growing conditions. This, in turn, increases the efficiency of farming, creates favourable conditions for crop development, and promotes the rational use of natural resources.

Based on many years of comprehensive research by the Department of Agriculture of the V. Yuriev Institute of Crop Husbandry and the Department of Agronomy of V. Dokuchayev Kharkiv State Agricultural University for the conditions of the Kharkiv region, a differentiated, multi-depth, soil-conserving, and resource-saving primary tillage system for field crop rotations has been developed and widely implemented for the conditions of the Kharkiv region (Salo, 2001).

Shikula favoured no-till soil cultivation over conventional tillage and suggested that this method creates better conditions for uniform germination of the sown crop and initial plant growth, which subsequently affects yield (Shikula *et al.*, 2003).

According to Bischoff (2013) and Büsching and Wollenweber (2015), combined conventional no-till soil cultivation ensures an intermediate, temporally heterogeneous-homogeneous type of soil profile. This approach positively impacts the localisation of soil fertility elements, which contributes to better growth and development of most agricultural crops (Bischoff, 2013; Büsching and Wollenweber, 2015).

At the same time, the results of many studies have demonstrated that minimal tillage allows for the same and sometimes even higher yields of cereal crops as with traditional tillage systems. Conversely, flat-cut tillage leads to a decrease in crop yield (Shikitka *et al.*, 2003).

Leading scientists of the Institute of Grain Farming of the Ukrainian Academy of Agrarian Sciences hold different opinions. Based on the results of many years of research, the scientists concluded that ‘under the conditions of the Southern Steppe, ploughing remains the only viable primary soil tillage method on fields infested with rhizome and root-sprouting weeds' (Tsykov and Matiukha, 2003). Mechanical measures in addition to the use of chemical means are recommended to control unwanted vegetation (Tsyuk *et al.*, 2021).

According to Wang and Xing (2016) and Wahbi *et al.* (2016), reducing the ploughing depth to 10-12 cm as well as combining ploughing with flat-cut, surface, and rotary tillage, can lead to a decrease in crop yield. This is because insufficient tillage depth can limit the access of the plant root system to essential nutrients and water. As a result, this can negatively affect the productivity of agricultural crop rotation, thereby reducing yield and overall production efficiency.

Research Objective: The development of environmentally safe technologies for the competitive production of high-quality crop products in the Black Sea Steppe.

MATERIALS AND METHODS

The Odesa region is located in the south-west of Ukraine in the steppe zone, which is characterised by a warm climate, snowless and relatively mild winter, a hot summer and frequent dry winds. The average annual temperature in this region is 9.0-11.0°C. The average annual precipitation is 491 mm, of which approximately 70% falls in the warm period of the year. Depending on the year, the amount of precipitation can vary from 263 to 766 mm.

Changes in weather conditions during the years of the study and across the entire territory of Ukraine have become more noticeable and significantly affect agricultural practices. The years of research were characterised by different temperature regimes, the amount of precipitation, and its uneven distribution across various stages of the growing season.

The increase in precipitation during the autumn-winter period and the rise in temperatures in the winter months, observed during the years of the study, have both positive and negative effects on winter wheat cultivation. On the one hand, increased precipitation can contribute to moisture accumulation in the soil, potentially improving conditions for plant growth. On the other hand, the challenge lies in retaining moisture. The inability to retain the necessary amount of moisture leads to crop loss and soil water erosion, which degrades its quality and fertility. An adequate moisture supply for winter crops throughout the growing season is a crucial condition for achieving high yields (*Table 1*).

The soil water regime and uniform moisture content throughout the root zone are crucial for the successful cultivation of agricultural crops. The amount of moisture reserves and their distribution in the soil profile depend on the crop preceding winter wheat. Productive moisture reserves in the last meter of soil and soil and the presence of dry winds, which are threat values and criteria for hazardous phenomena, were of particular importance. These factors collectively affect plant growth and development as well as the yield and quality of winter wheat grain throughout the growing season.

In 2021, at the beginning of winter wheat regrowth, the reserves of productive moisture were 31.0-38.0 mm in the plough layer (0-20 cm) and 138.0-139.9 mm in the metre layer and maintained at a satisfactory level (60 mm) in the experimental plots until the end of May (*Table 2*). In 2023, the reserves of productive moisture in the 0-20 and 0-100 cm soil layers were at a satisfactory level, both at the beginning of regrowth and during the flowering phase. At the beginning of the summer period in 2021 and 2023, moisture reserves remained at a satisfactory level after all preceding crops. The year 2022 was very dry.

Table 1 - Amount of precipitation during the years of research compared to the long-term average (mm)

Month	Monthly precipitation total (mm)			Long-term average (mm)
	Research year			
	2020/2021	2021/2022	2022/2023	
September	31.0	18.0	45.0	31.8
October	7.5	26.0	18.5	23.1
November	32.0	28.0	37.0	41.8
December	34.0	50.1	47.5	32.0
January	24.0	10.8	19.0	25.0
February	39.8	5.0	6.0	22.0
March	41.0	12.0	36.0	32.1
April	84.0	8.1	85.5	33.3
May	77.2	26.0	45.0	36.6
June	62.6	28.0	32.0	55.0
The amount for the agricultural year	434.1	211.6	375.5	332.7

Source: Data from the Odessa SAES meteorological station

Table 2 - Reserves of productive moisture in the metre soil layer by year (mm)

Sowing Date	Development Phase	Soil Layer (cm)					
		0-20			0-100		
		2021	2022	2023	2021	2022	2023
Black Fallow	Regrowth Phase	32.8	13.9	38.2	139.9	96.6	123.5
	Flowering Phase	32.0	3.6	34.5	131.9	29.6	138.5
Winter Vetch	Regrowth Phase	32.6	13.7	36.8	140.2	96.9	116.3
	Flowering Phase	32.9	3.9	32.8	132.4	30.4	140.8
White Mustard	Regrowth Phase	32.6	13.6	33.4	139.0	96.3	110.5
	Flowering Phase	32.4	3.3	29.6	131.7	29.4	134.3
Field Peas	Regrowth Phase	31.8	13.2	31.9	138.0	96.0	105.3
	Flowering Phase	31.7	3.0	28.3	130.0	28.8	128.6

The reserves of productive moisture in the 1-metre soil layer were at a very low level, even during the regrowth phase, and by flowering, they had decreased to 28.8-29.6 mm after all preceding crops.

The increase in precipitation during the autumn-winter period and the rise in temperatures in the winter months, observed during the research years, have both positive and negative consequences for winter wheat cultivation.

On the one hand, increased precipitation can promote moisture accumulation in the soil, potentially improving growing conditions for plants. On the other hand, the challenge lies in retaining moisture. The inability to retain the necessary amount of moisture leads to crop losses and soil erosion, which degrades its quality and fertility.

Hydrothermal indicators of weather conditions (air temperature and precipitation) were analysed based on data from the Odessa State Agricultural Experimental Station (ICSA NAAS).

The research was conducted from 2021 to 2023 in the fields of the Odessa State Agricultural Experimental Station (ICSA NAAS). The primary method was field-based, supplemented by analytical research, measurements, calculations, and observations according to generally accepted methodologies and guidelines in agriculture and crop production.

The experimental field where the research was carried out is located on typical zonal soils - southern unwashed heavy loam chernozems. The thickness of the humus horizon is 50-55 cm, and the humus content is 3.71%. The plough layer (25 cm) has the following agrochemical characteristics: easily hydrolysable nitrogen content of 113-138 mg/kg soil; mobile phosphorus content (DSTU (USS) 4115:2002, 2002) of 114-131 mg/kg soil; exchangeable potassium content (DSTU (USS) 4115:2002, 2002) of 161-184 mg/kg soil (high and increased levels); sum of exchangeable bases of 300-341 mg/kg soil; nitrification capacity according to Kurakov and Popov (1995) of 11.4 mg/kg; and soil reaction, pH in water of 7.8.

This study examined crop rotation systems (*Table 3*) and primary soil tillage systems (*Table 4*). The total area of 1 field was 3.6 ha, and the experimental area was 18 ha. Plot sizes were 2025 m² (22.5 × 90 m) for soil tillage, 2025 m² (22.5 × 90 m) for preceding crops, and 44.7 m² (20.3 × 2.2 m) for plots. There were four repetitions. The arrangement of variants was performed using the split-plot method (Dospekhov, 1985; Wahbi *et al.*, 2016).

Plots with soil tillage were oriented in the north-south direction, while plots with preceding crops were oriented in the east-west direction, meaning the preceding crop was laid crosswise to the soil tillage.

The experimental part of the research was conducted with four crop rotations, differing only by the first field: the first rotation began with black fallow; the second rotation started with a green fallow with winter vetch; the third rotation began with a mixture of peas and white mustard used as green manure; and the fourth rotation started with field peas. All other fields in the rotations were planted with the same crops. This was done to adhere to the principle of a single difference to assess the residual effects of fallows and non-fallow predecessors on subsequent crops. Oats were used as phytosanitary crops.

The green mass of green manure crops was not ploughed but was instead shredded and partially mixed with the soil using a heavy disc harrow (such as BDT-7 or AGD-2.5). To determine the impact of different fallows and non-fallow predecessors on the winter wheat yield (according to the principle of a single difference), the wheat was left on the field for a second time and sown after oats (at the end of the rotation). This approach allowed for a detailed evaluation of how different predecessors and soil tillage methods affected winter wheat productivit, as well as an understanding of the residual effects of crops in the rotation. The rotations were applied to four main soil tillage systems: plough-based plough (PSSPS), non-plough (DSSDS), shallow (SSSSSS), and differentiated (SSSSPS, alternating plough and shallow-reduced).

Table 3 - Crop rotation scheme

Field	Crop rotation numbers			
	1	2	3	4
5	Black fallow	Green manure fallow (winter vetch)	Peas + white mustard as a green manure	Peas for grain
4	Winter wheat	Winter wheat	Winter wheat	Winter wheat
3	Winter wheat	Winter wheat	Winter wheat	Winter wheat
2	Oat	Oat	Oat	Oat
1	Winter wheat	Winter wheat	Winter wheat	Winter wheat

Table 4 - Scheme of the primary soil tillage system in crop rotation fields

Conventional symbols for primary soil tillage systems	Field number, crop, and fallow rotation pairs				
	5	4	3	2	1
	Black fallow, green manure fallow pairs	Winter wheat	Winter wheat	Oat	Winter wheat
PSSPS (1 variant)	Plough deep tillage, 22-24 cm (P)	Shallow non-plough, 8-10 cm (S)	Shallow non-plough, 8-10 cm (S)	Plough deep tillage, 22-24 cm (P)	Shallow non-plough, 8-10 cm (S)
SSSPS (2 variants)	Shallow non-plough, 8-10 cm (S)	Shallow non-plough, 8-10 cm (S)	Shallow non-plough, 8-10 cm plough (S)	Plough deep tillage, 22-24 cm (P)	Shallow non-plough, 8-10 cm (S)
DSSDS (3 variants)	Deep non-plough, 22-24 cm (D)	Shallow non-plough, 8-10 cm (S)	Shallow non-plough, 8-10 cm (S)	Deep non-plough, 22-24 cm (D)	Shallow non-plough, 8-10 cm (S)
SSSSS (4 variants)	Shallow non-plough, 8-10 cm (S)	Shallow non-plough, 8-10 cm (S)	Shallow non-plough, 8-10 cm (S)	Shallow non-plough, 8-10 cm (S)	Shallow non-plough, 8-10 cm (S)

Note: P - plough deep tillage (22-24 cm), S - shallow non-plough (8-10 cm), D - deep non-plough (22-24 cm).

The protection system in the study was standard according to the cultivation technology of the studied crops. This means that all agrotechnical measures for plant protection were carried out according to standard recommendations and requirements for each crop, including weed, pest, and disease control.

This approach ensured an adequate level of plant protection, which is a crucial component for obtaining reliable results when comparing different soil tillage systems and predecessors in crop rotation.

In this study, different soil tillage systems were applied under black fallow, as follows:

Option 1 (PSSPS): Ploughing was performed to a depth of 22-24 cm using ploughs of the PLH-5-35 type. This method involved the complete turning of the soil layer to improve the enrichment of the upper layer with nutrients.

Option 2 (SSSPS): Combined (differentiated) ploughing was used, which involved alternating plough and shallow reduced tillage. This approach combined the advantages of both methods, optimising tillage according to the conditions of a specific field.

Option 3 (DSSDS): Non-plough deep soil tillage to a depth of 22-24 cm was performed using a plough of the PRN 5-35 type, which was equivalent to the "Paraplow". This method avoids the turning of the soil layer and preserves the soil structure.

Option 4 (SSSSS): Shallow soil tillage to a depth of 8-10 cm was carried out using heavy discs of the BDT-7 type and a cultivator of the KRU-3 type. This method limits the depth of tillage, which can be effective for certain soil types but may also restrict root access to deeper layers with nutrients.

Each of these methods has its own advantages and disadvantages, which need to be considered depending on specific conditions and agricultural goals.

Harvesting was done using direct combine harvesting in the full maturity phase with a SAMPO 500 combine. The criterion for determining the maturity phase was grain moisture at the time of harvest. The winter wheat yield was determined by plot harvesting and weighing, with subsequent adjustments to standard moisture (14%) and purity (100%).

During harvesting, the combine's threshing mechanism was turned off after processing each plot when all the grain had been fully collected in the sack. The sack was then weighed, and samples were collected to determine moisture, purity, 1000-seed weight, test weight, and other grain and seed quality indicators. The grain yield was weighed to an accuracy of 0.1 kg, ensuring the high measurement precision and reliability of the obtained results.

The calculation to adjust to the base moisture content (14%) was carried out using the following *Equation* (1):

$$\mathrm{Yp} = \mathrm{Ya} \times \frac{(100 - \mathrm{Ma})}{(100 - \mathrm{Mb})} \quad (1)$$

where:

Y_p - yield of grain at base moisture (14%), t/ha;

Y_a - yield of grain at actual moisture, t/ha;

M_a - moisture content of grain at harvest, %;

M_b - the yield from the bunker of each plot was weighed in labelled bags. The yield from each plot was adjusted to

14% moisture and 100% purity and converted to tonnes per hectare (t/ha) (DSTU (USS) 4117:2007, 2007).

The statistical and mathematical processing of the obtained analytical data was carried out using Microsoft Excel and the software information system "Agrostat". Methods of variation, correlation, and dispersion analyses were employed to evaluate and interpret the data. This allowed for accurate and reliable results, which are important for scientific research and practical application in agriculture (Ushkarenko *et al.*, 2008).

RESULTS

Analysis of the data obtained over the 3 years showed that in the 1st crop, the most favourable conditions for winter wheat yield occurred when it followed black fallow and sideral fallow with winter vetch (*Table 5*).

The recorded grain yield was nearly the same, averaging between 3.98 and 4.08 t/ha. The difference in yield was not significant, although there was a trend toward increased yield after winter vetch, with a 2.5% increase compared to black fallow. The lowest yield was obtained after pea for grain, which was 3.36 t/ha, representing a 15.6% decrease compared to black fallow.

When examining the data by year, the highest yield occurred in 2021 (4.60 t/ha). This year, the moisture conditions were the most favourable. During the 2021 growing season, precipitation was 84.0 mm in April, 77.2 mm in May, and 67.6 mm in June, which exceeded the average multi-year values of 50.7 mm in April, 40.6 mm in May, and 7.6 mm in June. The reserves of productive moisture in the top metre of soil were also the highest in this year (130.0 mm). The year 2023 was also favourable for winter wheat yield formation, although the reserves of productive moisture in the top metre of soil were lower (128.6 mm) compared to 2021. The year 2022 was very dry, which resulted in the lowest yield (2.92 t/ha). In this year, precipitation was 8.1 mm in April, 26.0 mm in May, and 28.0 mm in June, which was significantly below the average multi-year values of 27.5 mm in April, 10.0 mm in May, and 27.0 mm in June. The lowest amount of productive moisture (28.8 mm) in the top metre of soil was observed. Weather conditions impacted the yield of winter wheat and oat crops.

DSSDS again provided the best conditions for winter wheat yield formation in the first crop, averaging 4.35 t/ha over the 3 years of research. This was 10.4% higher compared to the shear tillage system (*Table 6*).

With this tillage scheme, the winter wheat yield was 3.35 t/ha, which was 14.0% lower than with the shear tillage system. The yield of the second wheat crop after fallow and peas was influenced by the residual effects of the previous crop and tillage system, as the second-year winter wheat was sown only under shallow tillage conditions. In the second crop, the same pattern was observed as in the first crop (*Table 7*).

When comparing grain yields to the control (black fallow), an increase in yield (6.9%) was observed in the case of sideral fallow with winter vetch. The grain yield following sideral fallow with a mixture of peas and mustard was at the same level as the yield following black fallow (3.35 and 3.32 t/ha); this difference in yield was not statistically significant. The yield following peas for grain was 9.6% lower compared to black fallow. Depending on the tillage system, the yields were similar with ploughing (3.32 t/ha) and shallow tillage (3.25 t/ha), as the difference between these options was not significant (*Table 8*).

A significantly higher yield was obtained with the soil treatment scheme PSSPS, which amounted to 3.63 t/ha, representing a 9.3% increase compared to PSSPS. The lowest yield was obtained with SSSPS, averaging 3.02 t/ha. This was 9.0% less than the mouldboard ploughing soil treatment. The oat yield assessment (*Table 9*) indicated that almost identical yields were obtained after black fallow and fallow with winter rape and black fallow with a mixture, which amounted to 2.60 and 2.71 t/ha as well as 2.60 and 2.55 t/ha, respectively.

Table 5 - Grain yield of winter wheat depending on the predecessor (t/ha, average for 2021-2023), 1st crop after fallow, and peas

Predecessor	Year			Average of the predecessor	
	2021	2022	2023	t/ha	%
Black fallow	4.76	3.12	4.05	3.98	100.0
Green manure fallow (winter vetch)	4.85	3.24	4.14	4.08	102.5
Green manure fallow (pea + mustard)	4.63	2.81	4.02	3.82	96.0
Peas for grain	4.14	2.52	3.43	3.36	84.4
Average over the years	4.60	2.92	3.91	3.81	-
LSD_{05}	0.21	0.11	0.13	0.15	-

Table 6 - Winter wheat grain yield depending on the tillage system (t/ha, average for 2021-2023), 1st crop after fallow, and peas

Soil tillage system	Year			Average by tillage system	
	2021	2022	2023	t/ha	%
PSSPS (plough-based)	4.80	2.91	4.11	3.94	100.0
SSSPS (differentiated)	4.09	2.57	3.38	3.35	86.0
DSSDS (plough-less)	5.21	3.33	4.50	4.35	110.4
SSSSS (shallow)	4.28	2.88	3.65	3.60	91.4
Average over the years	4.60	2.92	3.91	3.81	96.7
LSD_{05}	0.21	0.11	0.13	0.15	-

Table 7 - Grain yield of winter wheat depending on the predecessor (t/ha, average for 2021-2023), 2nd crop after fallow and peas

Predecessor	Year			Average of the predecessor	
	2021	2022	2023	t/ha	%
Black fallow	3.95	2.65	3.36	3.32	100.0
Green manure fallow (winter vetch)	4.31	2.65	3.68	3.55	106.9
Green manure fallow (pea + mustard)	3.98	2.54	3.53	3.35	100.9
Peas for grain	3.63	2.34	3.02	3.00	90.4
Average over the years	3.96	2.55	3.40	3.31	-
LSD_{05}	0.17	0.10	0.15	0.14	-

Table 8 - Grain yield of winter wheat depending on the main soil tillage (t/ha, average for 2021-2023), 2nd crop after fallow, and peas for grain

Soil tillage system	Year			Average by tillage system	
	2021	2022	2021	t/ha	%
PSSPS (plough-based)	4.00	2.48	3.48	3.32	100.0
SSSPS (differentiated)	3.72	2.19	3.14	3.02	91.0
DSSDS (plough-less)	4.27	2.89	3.74	3.63	109.3
SSSSS (shallow)	3.86	2.64	3.25	3.25	97.3
Average over the years	3.96	2.55	3.40	3.31	-
LSD_{05}	0.17	0.10	0.15	0.14	-

Table 9 - Oat grain yield depending on the predecessor (t/ha, average for 2021-2023), 3rd crop after fallow, and peas

Predecessor	Year			Average of the predecessor	
	2021	2022	2023	t/ha	%
Black fallow	2.68	2.01	3.12	2.60	100.0
Green manure fallow (winter vetch)	3.00	2.07	3.06	2.71	104.2
Green manure fallow (pea + mustard)	2.71	1.92	3.01	2.55	98.0
Peas for grain	2.40	1.75	2.61	2.25	86.5
Average over the years	2.69	1.94	2.95	2.53	-
LSD_{05}	0.15	0.12	0.15	0.14	-

Here, the difference in yield was not significant. However, there was a significant difference between the yield in the background of winter rape and the mixture of peas with mustard (2.71 t/ha compared to 2.55 t/ha). The lowest yield (2.25 t/ha) was observed in the background of fallow with peas for grain, which was 13.5% less than in the background of black fallow.

The mouldboard plough system of primary tillage provided the best conditions for oat yield formation, reaching 2.93 t/ha (*Table 10*).

All variants with soil tillage schemes SSSPS (differentiated), DSSDS (no-tillage), and SSSSS (shallow) reduced the yield by 27.6, 7.2, and 20.5%, respectively. Yield data for the 4th crop following fallow and peas for grain (winter wheat after oats) indicated (*Table 11*) that the highest average grain yield was obtained on black fallow (3.29 t/ha).

An almost identical result to that after black fallow was obtained after sideral fallow with winter vetch (3.16 t/ha), but the difference was not statistically significant. In this case, the lowest yield was also observed after peas for grain (2.85 t/ha). Different soil cultivation schemes had a positive impact on winter wheat grain yield in the 4th crop (*Table 12*).

The most effective method of soil cultivation, on average for the 3 years of research, was the no-till cultivation (DSSDS), as it resulted in the highest yield (3.29 tons per hectare) compared to other soil cultivation methods. Under plough cultivation (PSSPS), the winter wheat yield (3.12 t/ha) significantly differed from the yield under no-till cultivation (DSSDS).

The variant with differentiated soil cultivation (SSSPS) showed the worst performance (2.82 t/ha). Aggregated data over 3 years for different predecessors indicated that the average grain yield per rotation after fallow with winter catch crops and after fallow was almost the same (*Table 13*). There was a tendency toward increased grain yield in fallow (101.7%). Grain yield was reduced by 4.3% in the pea and mustard mix variant and by 12.8% in the pea for grain variant.

Table 10 - Oat grain yield depending on the soil tillage system (t/ha, average for 2021-2023), 3rd crop after fallow, and pea

Soil tillage system	Year			Average by tillage system	
	2021	2022	2023	t/ha	%
PSSPS (plough-based)	3.14	2.34	3.31	2.93	100.0
SSSPS (differentiated)	2.30	1.51	2.56	2.12	72.4
DSSDS (plough-less)	2.84	2.17	3.15	2.72	92.8
SSSSS (shallow)	2.47	1.73	2.78	2.33	79.5
Average over the years	2.69	1.94	2.95	2.53	-
LSD_{05}	0.15	0.12	0.15	0.14	-

Table 11 - Grain yield of winter wheat depending on the predecessor (t/ha, average for 2021-2023), 4th crop after fallow, and peas for grain

Predecessor	Year			Average of the predecessor	
	2021	2022	2023	t/ha	%
Black fallow	4.07	2.35	3.45	3.29	100.0
Green manure fallow (winter vetch)	3.89	2.24	3.34	3.16	96.0
Green manure fallow (pea + mustard)	3.72	2.12	3.10	2.98	90.6
Peas for grain	3.66	1.90	2.99	2.85	86.6
Average over the years	3.84	2.15	3.24	3.08	-
LSD_{05}	0.16	0.11	0.16	0.14	-

Table 12 - Winter wheat grain yield depending on the primary soil cultivation (t/ha, average for 2021-2023), 4th crop after fallow, and peas

Soil tillage system	Year			Average by tillage system	
	2021	2022	2023	t/ha	%
PSSPS (plough-based)	3.92	2.15	3.28	3.12	100
SSSPS (differentiated)	3.62	1.80	3.03	2.82	90.3
DSSDS (plough-less)	4.09	2.30	3.47	3.29	10.4
SSSSS (shallow)	3.71	1.92	3.11	2.91	93.3
Average over the years	3.84	2.04	3.24	3.04	-
LSD_{05}	0.16	0.11	0.16	0.14	-

Table 13 - Grain yield in crop rotation depending on different soil tillage systems and the predecessor (t/ha, at 14% grain moisture, average for 2021-2023)

Soil Tillage System	Crop after fallow	Predecessors				Average by tillage system	
		black fallow	green manure fallow		peas for grain		
			winter vetch	pea + mustard		t/ha	%
PSSPS (plough-based)	1	4.11	4.20	4.01	3.44	3.94	100.0
	2	3.41	3.60	3.35	2.92	3.32	84.3
	4	3.42	3.21	2.93	2.90	3.12	79.2
average		**3.65**	**3.67**	**3.43**	**3.09**	**3.46**	**-**
SSSPS (differentiated)	1	3.53	3.68	3.30	2.85	3.35	100.0
	2	3.03	3.15	3.11	2.75	3.02	89.1
	4	2.99	2.86	2.73	2.68	2.82	84.2
average		**3.18**	**3.23**	**3.05**	**2.76**	**3.06**	**-**
DSSDS (plough-less)	1	4.47	4.67	4.29	3.96	4.35	100.0
	2	3.70	3.97	3.58	3.29	3.63	83.4
	4	3.47	3.40	3.21	3.04	3.29	75.6
average		**3.88**	**4.01**	**3.69**	**3.43**	**3.76**	**-**
SSSSS (shallow)	1	3.80	3.75	3.67	3.19	3.60	100.0
	2	3.14	3.47	3.35	3.04	3.25	90.3
	4	3.15	3.05	2.86	2.75	2.96	82.2
average		**3.36**	**3.42**	**3.29**	**2.99**	**3.27**	**-**
Average to predecessors	t/ha	3.52	3.58	3.37	3.07	3.39	-
	%	100.0	101.7	95.7	87.2	-	-

Non-mouldboard tillage had the most effective influence on the collection of grain units in crop rotation. On average, 3.76 t/ha were obtained, which was 0.30 t/ha more compared to mouldboard tillage.

DISCUSSION

Our study results do not fully align with data from other research (Andrusenko, 1989), which suggests that black fallow is the best treatment to precede winter wheat. In our experiments, the variant with winter vetch performed best.

Andrusenko (1989) noted that black fallow yielded 100% grain, followed by vetch-oat mixtures at 95%, peas at 90%, rapeseed at 82%, and wheat (repeated) at 76%.

Tsandur emphasiseds that winter soft wheat produces similar yields on black and green manure fallows. Green manure fallow increases wheat quality, with gluten content rising by 2-5% and crude protein by 0.6-1.5% (Tsandur *et al.*, 2000).

Polupan, Solovey, and Velychko suggested that although black fallow resulted in the highest winter wheat yield, this outcome requires two years of land use.

However, when calculating yield per year, black fallow was less effective than other predecessors, raising questions about its annual efficiency advantage. In the Southern Steppe zone, the average agropotential yield of winter wheat on black and occupied fallows was 27.5-29.0 c/ha under natural soil fertility conditions (Bondarenko *et al.*, 2005). Therefore, innovative approaches to fallow usage will be meaningful only if they ensure higher yields per hectare of rotation area or achieve at least the agropotential level for winter cereals. Dzhulai *et al.* (2012) emphasised that “reducing the share of black fallow from 25.0% to 10% or completely excluding it leads to decreased cereal yields”.

Numerous studies have suggested that leguminous crops should be used as precursors to enhance production efficiency and winter wheat competitiveness (Vorobiev, 1983; Edwards, 1987). Legumes positively affect soil by enriching it with eco-friendly nitrogen, an economically viable resource. Crops, such as peas, soybeans, and vetch, leave behind significant nitrogen quantities (50-100 kg/ha); quantities of 80, 65, and 89 kg/ha have been observed pea, soybean, and vetch, respectively. In addition to nitrogen, legume residue contains biologically active substances (antibiotics, vitamins, enzymes, and amino acids), providing additional nutrition for subsequent crops. It is estimated that 30-70% of the nitrogen in these residues is utilised by grain crops in rotation (Antonii and Pylov, 1980).

In addition, the developed root systems of legumes, reaching depths of 1.5-2.0 m, absorb nutrients from deeper layers, which are inaccessible to many other crops (Mylto, 1982). Data on high nitrogen fixation are available in some cases: up to 257 kg/ha by vetch, 259 kg/ha by peas, and 453 kg/ha by *Lathyrus sativus* (Shatokhina *et al.*, 2000; Smaglii *et al.*, 2006). This highlights legumes’ significant agronomic potential as precursors to enhance the yield and quality of winter wheat.

Regarding soil tillage, there are conflicting conclusions in the literature, some of which our experiments support. For example, some authors (Popov, 1969; Sdobnikov, 1980) argue that ploughing after non-fallow precursors improves soil residue conditions, water physical properties, and weed, pest, and disease control, underscoring ploughing’s benefits in maintaining favourable soil conditions and reducing harmful organisms. In our experiments, ploughing positively impacted oat yield (2.93 t/ha). However, ploughing remains the most expensive agrotechnical measure compared to other tillage methods (Krut, 1976).

Meanwhile, Krut *et al.* (1986) highlighted the benefits of non-plough and surface tillage for growing winter wheat after non-fallow precursors. According to Tsandur, “Plow and non-plow tillage at a depth of 25-27 cm offer no advantages over shallow tillage when preparing fallows” (Tsandur, 2006). In the Mykolaiv region, using Maltsev’s tillage method in a nine-field rotation significantly increased grain yield. In two rotations, this method increased grain yield by 1.4 c/ha in the first rotation and 9.3 c/ha in the second rotation compared to traditional ploughing (Musich, 1983), demonstrating the benefits of non-plough tillage for yield increase in this region.

According to Druziak (2001) and Druziak *et al.* (1992) in the steppe zone, different tillage systems-plough, non-plough, chisel, combined, and minimum-result in similar winter wheat yields.

Additionally, crop weed levels remain below the economic harm threshold, demonstrating that these methods are effective in maintaining crop cleanliness and yield stability in the steppe. Yarovenko noted that "non-plow tillage may promote the growth of weeds, pests, and crop diseases without pesticide use" (Yarovenko *et al.*, 1997).

Many scientists consider non-plough and minimal tillage promising approaches under intensified farming conditions, as they help avoid issues such as plough layer differentiation and increased field weed levels. Unlike plough tillage, the non-plough method reduces humus mineralisation, decreases soil erosion vulnerability, and improves the water regime. Non-plough tillage also aids moisture retention, which is essential for yield stability under water deficit conditions (Lebid *et al.*, 1997; Lebid *et al.*, 1993; Nazarenko and Tymynskyi, 1990).

Traditional ploughing should be replaced by shallow tillage (Demydenko, 1997; Hordiienko *et al.*, 1998; Hrabak, 2001, 2003; Tykhonov *et al.*, 1988). Shallow tillage forms a plough layer that better meets winter wheat's biological needs, conserves moisture, improves seed-soil contact, and ensures timely seedling emergence. The research from the Agricultural Institute in Nitra (Demo *et al.*, 1985) found no yield advantage of plough tillage over minimal tillage for winter wheat, suggesting that minimal tillage could be effective, economically viable, and environmentally sustainable. Romanian scientists (Popa and Popa, 1979) reported that replacing ploughing with other tillage types led to slight compaction in the 0-30 cm layer but did not hinder wheat or corn growth.

Furthermore, minimal tillage significantly reduced soil erosion losses by 37.6-81.5% compared to traditional ploughing.

Novacek, Hrbacek, Vanek, and Ridky concluded that minimal tillage was most advantageous for winter wheat after all precursors, while direct sowing suited all annuals except cereals (Novacek *et al.*, 1978). An Austrian study compared minimal and traditional tillage systems (Tykhonov, 1979) and showed that chisel and flat-cut tools reduced erosion risk and increased soil moisture, positively impacting wheat yield (Kovalenko, 1979) and demonstrating the effectiveness of these methods for improving soil moisture and yield stability.

From an agronomic science perspective, both positive and negative results often carry conflicting and debatable elements, leading to various interpretations and approaches. However, despite this, such findings play an essential role in expanding our understanding of agrosystem processes, enhancing knowledge, and supporting better-adapted crop-growing technologies.

Considering factors such as climate change, crop variety traits, and soil type helps develop effective and sustainable agrotechnical practices, ensuring stable and high yields even under variable conditions.

The results of the analysis of variance showed that weather conditions had the greatest impact on the yield of winter wheat. Specifically, the share of this factor's influence was 48% (*Figure 1*).

The impact of crop rotation and soil treatment was significantly lower, with shares of 26% and 23%, respectively. Other factors influenced only 3%. This indicates that although agronomic practices are important, weather conditions remain the decisive factor in determining winter wheat yield.

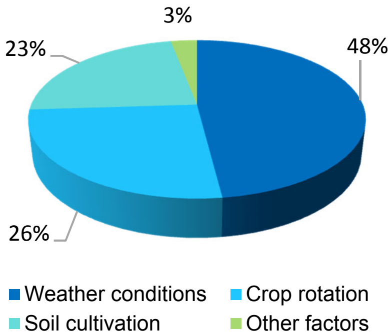

Figure 1 – Share of factors affecting winter wheat yield (average for 2021-2023)

CONCLUSIONS

The introduction and implementation of short crop rotations in the field (5 fields) with green manure fallow contribute to the accumulation of nutrients and moisture in the soil and facilitate the adaptation of winter wheat to drought when using a non-mouldboard soil tillage system throughout the entire crop rotation.

For all winter wheat crops in the short grain-fallow crop rotation, non-inversion tillage had a positive impact on yield. The use of green manure fallow with winter vetch provided a slightly higher winter wheat yield than the variant with black fallow. Considering the improved soil condition with green manuring, this variant should be considered a priority.

In the experimental variants, for the 1st and 4th crops, green manure fallow with winter vetch affected winter wheat yield nearly on par with black fallow: in the first crop, winter wheat sowing was 4.08 and 3.98 t/ha, respectively; in the fourth crop, winter wheat sowing was 3.16 and 3.29 t/ha, respectively. In the second winter wheat sowing, green manure fallow with winter vetch had an advantage compared to black fallow: 3.55 vs. 3.32 t/ha, respectively. For all winter wheat crops, a positive impact on yield was observed with non-mouldboard tillage. The average yield was highest compared to other tillage systems, specifically 3.76 t/ha compared to 3.46 t/ha (PSSPS), 3.06 t/ha (SSSPS), and 3.27 t/ha (SSSSS). Based on this crop rotation, depending on the level of weed infestation in the fields, one-time ploughing under fallow may be recommended for non-inversion tillage. The authors plan to investigate this aspect further in more detail.

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