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Assessment of the tillage impact on soybean productivity

Abstract. Modern crop production technologies depend on the intensity of soil cultivation. Traditional cultivation methods increase production costs and harm the environment. The research relevance is determined by the need to find effective and environmentally friendly alternative tillage technologies that will reduce the cost of agricultural production and have a positive impact on the environment. The research aims to determine the influence of the soil tillage system on the formation of soybean plant productivity. Research methods: long-term stationary experiment, laboratory determination of soil agrophysical properties, statistical data processing. The field research was carried out at the Agronomic Research Station, a separate subdivision of the National University of Life and Environmental Sciences of Ukraine, in a stationary experiment of the Department of Agriculture and Herbology. Soybean yields under the No-till system were found to be 22.7% higher than under the conventional system, which in absolute terms was 2.81 t/ha under the No-till system and 2.29 t/ha under the conventional system. No-till provided higher soil moisture content and the share of agronomically valuable aggregates at a higher soil density than the traditional system. In general, the efficiency of moisture use by soybean plants under the shelf tillage system was 16.0% lower compared to the no-till system. The use of the conventional tillage system on average in 2020-2022 led to a decrease in the structural structure of the 0-30 cm soil layer studied by 8-33%. The amount of agronomically valuable aggregates (0.25-10 mm) depended on the tillage system. The No-till system increased the agronomically valuable structure in the 0-10 cm soil layer by 15.5%, the 10-20 cm layer by 10.3% and the 20-30 cm layer by 9.1% compared to the conventional tillage system at the beginning of the growing season and by 4.2%, 7.3% and 4.7%, respectively, at the end of the growing season. The practical significance of the obtained research results is to determine the optimal soil cultivation system for the realisation of the genetic potential of soybean to form its stable productivity

Keywords: density; soil structure; water consumption; cultivation; crop; plant

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INTRODUCTION

Soybeans are a unique protein and oilseed crop that is in high demand. Ukraine has significant potential to increase its soybean production and generate higher profits from its sales. Current technologies do not fully realise their yield potential due to the parity of fuel prices, crop protection products and fertilisers, which increases technological costs and prompts the search for new soybean growing technologies. Soil cultivation is a fundamental factor in terms of its impact on soil quality and, consequently, on sustainable crop productivity (Vozhehova *et al.*, 2021). Among the measures to increase soybean productivity is the effective use of the basic tillage system. Therefore, it is important to improve existing and develop new tillage measures and systems, considering the soil and climatic conditions of the region.

Variability in climatic conditions, especially temperature and precipitation during the growing season, are factors that limit soybean productivity (Nendel *et al.*, 2023; Elmerich *et al.*, 2023). Adapting crop production technologies to climate change is particularly important for pulses, which are characterised by low productivity stability (Reckling *et al.*, 2018; Zong-Sheng *et al.*, 2023). When there is insufficient moisture, it is important to prepare the soil in such a way as to ensure that the maximum possible amount of precipitation is retained. In particular, the study by V. Kyryliuk *et al.* (2020) shows that no-till works best in dry conditions, with yields often equal to or higher than those obtained with conventional tillage.

The priority task of modern agricultural production is not only to produce high-quality products but also to increase the level of soil fertility (Litvinova *et al.*, 2019). Conservation tillage technologies are considered to be one of the most effective methods of managing soil fertility, as well as reducing the energy and economic costs of tillage (Mondal *et al.*, 2020; Achankeng & Cornelis, 2023). However, it is necessary to point out the problematic issues of obtaining stable crop productivity and soil fertility indicators when using conservation tillage in crop production technology. F. Tshuma *et al.* (2021) noted that No-till leads to a layered placement of nutrients in the soil, with a predominant amount in the upper horizon. This can hurt the supply of nutrients to crops, especially in the dry season. Y. Shen *et al.* (2021) reported that No-till improved soil structure compared to conventional tillage, with the content of macro-aggregates increasing by 4.8%, the AOS (cultivating sowing unit) by 8.3%, and the AMWS (minimum moisture sowing unit) by 18.3%, but conventional tillage provided higher crop yields compared to No-till. J.C. Calonego *et al.* (2017) indicate that the No-till system has a favourable effect on soil quality, improving its structure and increasing biological activity, water retention capacity and water use efficiency.

The research relevance is determined by the need to reduce the negative impact of agricultural activities on the environment and optimise production costs. The introduction of the No-till system can help preserve soil cover, reduce erosion and pollution, and reduce energy and labour consumption, which will help increase agricultural production efficiency (Page *et al.*, 2020; Bulygin *et al.*, 2021). The research aims to determine changes in the agrophysical parameters of typical chernozem, the efficiency of moisture used by plants and their impact on soybean yields depending on the tillage system.

MATERIALS AND METHODS

The determination of soil tillage efficiency for high soybean yields and improvement of soil agrophysical properties was carried out over three years, from 2020 to 2022. To evaluate the effectiveness of different tillage systems, agricultural and physical soil parameters, crop water consumption, and yield formation were studied. An integral indicator of the efficiency of a tillage system is the level of crop productivity. The field research was carried out at the stationary experimental plot of the Department of Agriculture and Herbology, which is located at the Separate Subdivision "Agricultural Research Station" of the National University of Life and Environmental Sciences of Ukraine. The experimental plot was in crop rotation and included the following crop rotations:

1. Soy;
2. Spring barley;
3. Grain corn.

Two tillage systems were chosen for the study: No-till – a no-tillage system in which no plough or disc is applied after harvesting the previous crops, and the remains of plant mass are retained on the soil surface; traditional system – involving disking at a depth of 8-10 cm after harvesting the previous crop (corn for grain), ploughing to a depth of 23-25 cm, early spring moisture closure, and pre-sowing cultivation to a depth of 6-8 cm. The area of the town plot was 52 m^2, and the accounting plot was 22 m^2.

The studied soil was a typical low-humus chernozem and had the following characteristics: granulometric composition: coarse-dust light loam and contained 37% physical clay and 63% sand; equilibrium bulk density of the soil was 1.16-1.30 g/cm^3; stable wilting moisture (SWM) was 10.8%. The thermostat-weight method was used to determine the total reserves and available moisture in the soil to a depth of 1 m. The average sample was dried in a thermostat at 105°C by DSTU ISO 16586:2005 (2008). Soil samples were taken with a drill from layers 0-10, 10-20, 20-30, 30-50, 50-70, and 70-100 cm. In each variant, the total moisture reserve and the moisture reserves available to plants were calculated. The structural-aggregate state of the soil was determined by the Savvinov method according to DSTU 4744:2007 (2008), and the density of soil composition was determined by the cutting ring method according to DSTU ISO 11272-2001 (2003).

To account for the soybean harvest, the researchers used the method of continuous threshing, which involved threshing the entire area of the accounting plot without dividing it into separate parts. After harvesting all replications of each variant, the harvested plants were threshed to separate the seeds from the rest of the plant mass. To obtain accurate results, the researchers brought the harvest to 100% purity, i.e., eliminated all impurities and unnecessary elements from the harvested material. They also standardised the moisture content of the harvested crop for each variant to eliminate the effect of moisture on seed weight. Soybean harvesting was carried out at the stage of full plant maturity, which means that the plants had reached the maximum level of development and were ready for seed harvesting. This allowed to obtain the most accurate data on the crop yield.

The researchers also considered the requirements of the Convention on Biological Diversity (1992) when conducting their research. This convention aims to conserve biological diversity and sustainable use of nature's components. These requirements helped to ensure the ecological adaptation of the studied tillage systems and allowed the research to be carried out with due regard for environmental aspects.

RESULTS AND DISCUSSION

According to the results of the research for the period from 2020 to 2022, the highest average yield of soybean plants, which amounted to 2.81 tonnes per hectare, was obtained using the no-till tillage system. On the other hand, the traditional tillage system, which involved ploughing to a depth of 23-25 cm, yielded 2.29 tonnes per hectare (Fig. 1).

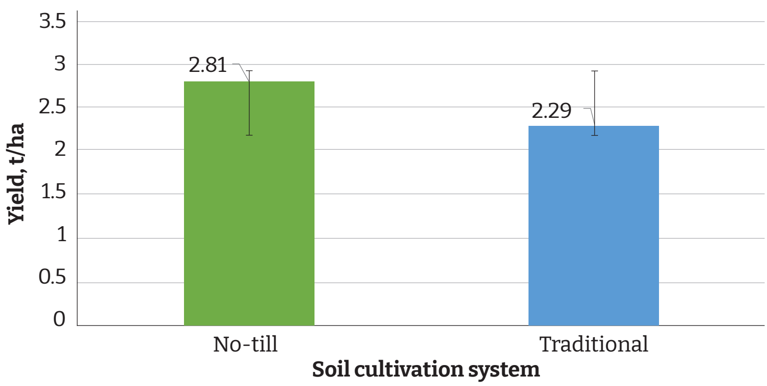

Figure 1. Soybean productivity under different tillage systems, average for 2020-2022
Source: compiled by the authors

However, D. Gawęda *et al.* (2020) found that soybeans produced higher yields (by 10.3%) under conventional tillage (ploughing), although soybean grain grown under No-till had a higher protein content (by 1.4%). J. Singh *et al.* (2021) indicated that long-term use of No-till reduced corn yields, but increased soybean yields under a two-year rotation compared to the traditional tillage system. S. Adamič & R. Leskovšek (2021), despite significant differences in plant condition and individual plant productivity, no significant differences in grain yield were observed between conventional and no-till cultivation systems. Yields for conventional and No-till systems were 4.54 and 4.48 t ha, respectively, with only a slight decrease in yield for the no-till system.

The results of the effective soil fertility study suggested that the use of different tillage systems causes changes in potential soil fertility, which determine the level of soybean yields. To substantiate the yield data in detail, the impact of different tillage systems on agrophysical parameters and crop moisture consumption was analysed. An important and urgent issue not only in the context of modern agricultural development, but also in the context of climate change is to study and determine the impact of various agrotechnical measures on the accumulation of available moisture in the soil and, as a result, obtaining stable crop yields. Considering the climatic conditions of the region, biological characteristics of crops in terms of water consumption and, accordingly, the water regime of the soil under crops, it is possible to identify ways to rationally use soil moisture and precipitation by crops in the process of growing them. An important measure to manage the use of water by plants is to optimise tillage. The processes of dry matter accumulation in the vegetative mass of agricultural plants are most active when there are sufficient reserves of available moisture in the soil.

According to the results of the research conducted in 2020-2022, on average, during the years of research, during the period of soybean sowing, the reserves of available moisture in the 0-100 cm soil layer under the No-till system were 160.4 mm, while under the traditional system – 134.3 mm. During the growing season, soil moisture was mostly used for the formation of soybean crops and partially for physical evaporation from the soil surface. At the time of soybean harvesting, the soil moisture reserves in the No-till system were 66.1 mm, and in the conventional system – 53.8 mm. This indicates a more efficient use of moisture by plants when implementing the No-till system, which affects the increase in soybean yields.

Studies of the efficiency of moisture consumption by soybean plants depending on soil tillage showed that the total moisture consumption from the soil during the growing season of soybean plants, depending on the tillage system, ranged from 319.1 to 332.9 mm, with higher values obtained with the No-till technology (Fig. 2). This means that the No-till system provides more efficient use of moisture by soybean plants compared to conventional tillage. The increase in moisture consumption in the No-till system may be due to the preservation of soil cover and its structure, which contributes to the preservation of moisture and its efficient use by plants. The No-till system allows to achieve optimal use of moisture from the soil under soybean plants, which in turn can have a positive impact on crop yields and lead to higher performance in growing this crop.

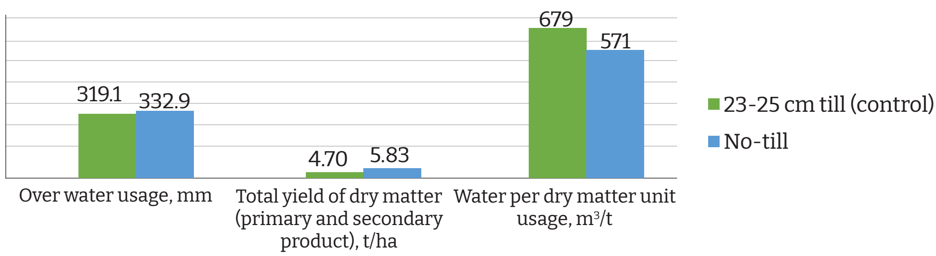

Figure 2. Total soybean water consumption depending on tillage, average for 2020-2022
Source: compiled by the authors

The calculations of the total moisture consumption for the formation of a unit of dry matter of the crop showed that in the variant with the traditional tillage system (ploughing at 23-25 cm), higher rates of total moisture consumption for the creation of a unit of dry matter of the crop were obtained, which amounted to 679 m^3/t, while in the No-till tillage system, they were 571 m^3/t. The opposite results were obtained in the studies of V.V. Sinchenko *et al.* (2019), who found that on typical black soil, the total moisture consumption for the formation of a unit of dry matter of soybean crop when placed after corn for grain was 475 m^3/t in the variant with ploughing and 623 m^3/t under No-till.

It is known that the most favourable conditions for growing soybeans are created when the soil density is in the range of 1.1-1.3 g/cm^3. M.T. Moraes *et al.* (2020) point out that soil density has always been a problem for agricultural productivity, mainly with minimum tillage technologies, in particular No-till. The determination of this indicator shows that in the No-till system, it was higher compared to conventional tillage (ploughing at 23-25 cm), where the soil density was 121-1.32 g/cm^3, while in the traditional tillage, it was in the range of 0.95-1.23 g cm^3 (Table 1).

Table 1. The density of soil layer 0-30 cm in soybean crops under different tillage systems (average for 2020-2022), g/cm^3

Soil layer, cm	vegetation beginning		vegetation ending	
	ploughing by 23-25 cm (control)	No-till	ploughing by 23-25 cm (control)	No-till
0-10	0.95	1.21	1.22	1.41
10-20	1.17	1.30	1.35	1.44
20-30	1.23	1.32	1.37	1.35
HiP_{05}	0.04	0.02	0.04	0.03

Source: compiled by the authors

During the growing season, soil compaction is observed in all variants of the experiment. It is natural that in the variant with deep shelf tillage, the density of soil compaction increased to 1.35 g/cm^3, or 28.4%, while in the No-till technology, it increased by 16.5%. It should also be noted that both in the top (0-10 cm) and in the 10-20 and 20-30 cm horizons, the soil texture density indicators had critical limits and significantly exceeded the optimal parameters for soybeans. Similar results were obtained by R.A. Vozhehova *et al.* (2021), who found that the lowest level of soil density (1.23 g/cm^3) was formed under chisel tillage to a depth of 28-30 cm of soil, which is 1.6% lower than the control (ploughing at 28-30 cm), and the highest (1.29 g/cm^3) was obtained under the No-till system, which is 3.2% higher than the control. However, S.R. Silva *et al.* (2023) found that the No-till system had a better effect on soybean productivity and was less harmful to soil physical quality.

Soil structure is crucial for the formation of air, water, nutrient and other regimes, and ultimately for obtaining high and sustainable crop yields. Structural and aggregate composition, as a complex factor in the formation of crop productivity, can be regulated within certain limits by basic tillage measures and generally contributes to better preservation of the structure of the cultivated layer. The study of seasonal changes in the structural state of typical chernozem in soybean crops depending on the tillage system was carried out at the beginning and end of the growing season (Table 2).

Table 2. Influence of primary tillage on the distribution of structural features in the 0-30 cm soil layer (average for 2020-2022)

Soil layer, cm	Ploughing by 23-25 cm (control)				No-till			
	number of units, %			structure coefficient	number of units, %			structure coefficient
	>10 mm	10-0.25 mm	<0.25 mm		>10 mm	10-0.25 mm	<0.25 mm	
Vegetation beginning								
0-10	22.3	63.8	14.3	2.86	19.6	79.3	6.9	2.99

Table 2. Continued

Soil layer, cm	Ploughing by 23-25 cm (control)				No-till			
	number of units, %			structure coefficient	number of units, %			structure coefficient
	>10 mm	10-0.25 mm	<0.25 mm		>10 mm	10-0.25 mm	<0.25 mm	
10-20	23.6	70.2	7.8	2.97	20.8	80.5	4.5	3.18
20-30	23.8	69.6	7.3	2.92	18.7	78.7	4.7	3.36
HiP_{05}	0.04	0.10	0.18		0.05	0.11	0.21	
Vegetation ending								
0-10	19.2	71.3	9.5	2.48	18.1	75.5	6.4	3.08
10-20	21.4	72.0	6.6	2.57	16.5	79.3	4.2	3.83
20-30	20.5	72.7	6.8	2.66	18.2	77.4	4.4	3.42
HiP_{05}	0.03	0.15	0.20		0.1	0.17	0.21	

Source: compiled by the authors

It was established that the highest content of agronomically valuable aggregates (10-0.25 mm in size) was formed in soybean crops under No-till technology. At the beginning of the growing season, the content of aggregates in the 0-10 cm layer was 79.3% in the 0-10 cm soil layer under this technology. In the soil layer 10-20 cm and 20-30 cm, respectively, it was 80.5 and 78.7%. Under shelf cultivation (ploughing at 23-25 cm), their share was 63.8%, 70.2% and 69.9%, respectively, 64.54-66.70%. The results obtained are confirmed by L. Gao *et al.* (2019), found that in the soil layers of 0-10 cm and 10-20 cm, the No-till system and deep soil loosening showed a significantly higher proportion of aggregates >250 μm (macroaggregates) compared to the traditional tillage system, and the proportion of aggregates <53 μm (microaggregates) was significantly higher in the traditional system compared to No-till and deep soil loosening. The opposite results were obtained by V. Kyryliuk *et al.* (2020), who found that minimising tillage, namely surface mouldboard tillage, worsened the soil structure compared to ploughing, especially in the 0-20 cm soil layer.

The highest coefficient of topsoil structure (0-10 cm) at the beginning of soybean vegetation was recorded in the No-till variant – 2.99, while in the ploughing variant, it was 2.86. In the horizons 10-20 and 20-30, the structural coefficient prevailed in No-till compared to ploughing, respectively, 3.18 vs. 2.97 and 3.36 vs. 2.92. It was determined that during the growing season of the crop, there was an increase in the share of agronomically valuable fractions due to a decrease in the dusty and cloddy fractions. When ploughing at 23-25 cm, the share of soil fraction (10-0.25 mm) was 71.3-72.7%, No-till – 75.5-79.3%. At the time of harvesting the crop, the structural coefficient increased in all variants regardless of the factors studied. Thus, optimisation of the soil tillage system has a significant impact on soil fertility and soybean yields on typical black soil.

CONCLUSIONS

Studies conducted on typical chernozem of the Right-Bank Forest-Steppe of Ukraine have established the positive impact of the No-till system on the management of soil agrophysical parameters and the formation of soybean plant productivity. It was found that the use of the No-till system ensures efficient (by 15.9%) use of moisture by soybean plants during the growing season, compared to the traditional tillage system.

Using No-till, an increase in the density of soil composition of 0-20 cm of the soil layer was observed compared to the traditional tillage system. At the beginning of the growing season, the density of the 0-20 cm soil layer under No-till exceeded the control variant (conventional tillage system) by 19.2%, and at the end of the soybean growing season by 11.1%.

It was found that the use of the traditional tillage system led to a decrease in the structure of the cultivated soil layer by 8.9-33.0% compared to the No-till system. At the beginning of the soybean growing season, the highest content of agronomically valuable aggregates in the 0-10 cm soil layer was formed in the No-till system (79.3%), while in the traditional system, the share of agronomically valuable aggregates decreased to 63.8%. During the growing season of soybean plants, an increase in the share of the agronomically valuable fraction was observed due to a decrease in the dusty and clumpy fraction. It was determined that due to the compaction of the cultivated soil layer and as a result of stronger contact of individual particles, the highest coefficient of the structural structure of the upper (0-10 cm) soil layer at the beginning of the soybean growing season was noted in the variant of the No-till system – 2.99, in the lower soil layers (10-20 and 20-30 cm) the coefficient was 3.18 and 3.36, respectively.

The tillage system influenced the density of the soil, the structural aggregate composition of the soil, and the moisture consumption of the crop, providing different conditions for the formation of soybean productivity. The use of the No-till system provided an increase in soybean yield by 22.7%, which in absolute terms was 0.52 t/ha compared to the traditional tillage system. A promising area for further research is the indicators of soil nutrition and the cycle of organic matter and nutrients.

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CONFLICT OF INTEREST

None.

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Оцінка впливу обробітку ґрунту на продуктивність сої

Анотація. Сучасні технології вирощування сільськогосподарських культур залежать від інтенсивності обробітку ґрунту. Традиційні методи обробітку збільшують собівартість виробництва та негативно впливають на навколишнє середовище. Актуальність дослідження полягає в необхідності знаходження ефективних та екологічно чистих альтернативних технологій обробітку ґрунту, які зменшать собівартість сільськогосподарського виробництва і мають позитивний вплив на стан навколишнього середовища. Метою досліджень було встановлення впливу системи обробітку ґрунту на формування продуктивності рослин сої. Методи досліджень: довготривалий стаціонарний дослід, лабораторне визначення агрофізичних властивостей ґрунту, статистична обробка даних. Польові дослідження виконано у Відокремлений підрозділ Національного університету біоресурсів і природокористування України «Агрономічна дослідна станція» у стаціонарному досліді кафедри землеробства та гербології. Встановлено, що урожайність сої за системи обробітку No-till була вищою на 22,7 % порівняно з традиційною системою, що у абсолютному значенні становило (2,81 т/га) за системи обробітку No-till, і 2,29 т/га за традиційної системи обробітку. No-till забезпечував більш високий уміст вологи в ґрунті, та частку агрономічно цінних агрегатів за вищого показника щільності складення ґрунту відносно традиційної системи. У цілому ефективність використання вологи рослинами сої за системи полицевого обробітку ґрунту була нижчою на 16,0 % порівняно з системою No-till. Застосування традиційної системи обробітку ґрунту у середньому за 2020-2022 рр. призвело до зниження структурності досліджуваного 0-30 см шару ґрунту на 8-33 %. Кількість агрономічно цінних агрегатів (0,25-10 мм) залежала від системи обробітку ґрунту. За системи No-till збільшувалась агрономічно цінна структура у шарі ґрунту 0-10 см на 15,5 %, 10-20 см шарі – на 10,3 % і 20-30 см – на 9,1 % порівняно з традиційною системою обробітку на початку вегетації і відповідно на 4,2 %, 7,3 % і 4,7 % у кінці вегетації. Практичне значення одержаних результатів досліджень полягає у визначення оптимальної системи обробітку ґрунту для реалізації генетичного потенціалу сої з метою формування стабільної її продуктивності

Ключові слова: щільність складення; структура ґрунту; водоспоживання; вирощування; сільськогосподарська культура; рослина