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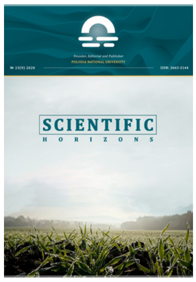

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Tillage influence on agrophysical soil properties and crop productivity in the irrigated conditions of the steppe zone of Ukraine

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Abstract. The main goal of the study was to establish the influence of various tillage systems on the agrophysical properties of dark-chestnut soil under short-grain crop rotation in the irrigated conditions of southern Ukraine. The research was carried out during 2021-2022 in a stationary experiment on a four-field crop rotation: grain maize – winter rapeseed – winter wheat – soybeans. The experimental field was in the

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semi-arid steppe climate zone at the Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine. Three tillage systems were studied for their influence on soil bulk density, porosity, and water permeability, namely: mouldboard-differentiated ploughing tillage; differentiated chisel tillage; and differentiated ploughless tillage with soil slitting. Soil bulk density was determined using the core method. Soil porosity was calculated as the ratio of total bulk density to solid fraction bulk density. Water infiltration rates, established through the water absorption test method, were used to measure soil water permeability. The results of the study were statistically analysed using the common ANOVA procedure with Fisher's least significant difference test at P<0.05. In addition to the agrophysical parameters of the soil, the energy output of the crop rotation was assessed. It was established that mouldboard tillage did not provide significant benefits in terms of bulk density and soil porosity. However, ploughing showed the best results for soil water permeability across all crops in the rotation. The highest energy output of crop rotation (119.1 GJ/ha) was recorded for the ploughless-differentiated tillage system with soil slitting, whereas the mouldboard ploughing and chisel tillage systems produced somewhat lower energy yields of 112.0 and 108.6 GJ/ha, respectively. Therefore, ploughless-differentiated tillage with soil slitting is the most effective option for short-grain crop rotations in irrigated conditions of southern Ukraine, in terms of creating optimal soil agrophysical properties and achieving the highest crop productivity

Keywords: mouldboard ploughing; ploughless tillage; soil bulk density; soil porosity; water permeability; yield

INTRODUCTION

Tillage is a farming technique that uses mechanical manipulation to alter soil properties and improve conditions for crop growth and development. Tillage significantly affects the physical characteristics and functions of soil, which can influence its health and overall fertility. Enhancing soil properties and increasing crop yields through proper soil tillage is crucial, but ensuring sustainability requires careful soil tillage management. Tillage is vital for maintaining the sustainability and quality of soil as it modifies its physical, chemical, and biological properties.

The physical characteristics of soil and the viability of agriculture are greatly impacted by tillage, an essential soil management practice. Tillage affects the bulk density, porosity, and hydraulic properties of soil, which in turn influence water infiltration and retention (Steponavičienė *et al.*, 2023). Although tillage can improve soil conditions for crop emergence and yield, it also has potential drawbacks. Excessive tillage can lead to erosion and soil degradation, which harm long-term productivity (Nweke, 2018). Conservation tillage techniques have emerged as alternatives to address these challenges, balancing productivity, profitability, and environmental protection. By reducing degradation, promoting sustainable food production, and preserving soil health, these methods minimise negative environmental impacts. Selecting the appropriate tillage system is critical, as it affects not only the soil's physical health but also plant growth and the broader environment. Suitable tillage practices must be implemented to safeguard soil quality, environmental integrity, and food security (Ramzan *et al.,* 2019). Implementing scientifically proven optimal tillage practices is particularly important in regions with unstable natural humidification, such as southern Ukraine, where frequent and severe droughts, erosion, freshwater shortages, and increased aridity exacerbate soil degradation (Lykhovyd, 2021). Furthermore, tillage practices must account for the specifics of crop rotations, which to some extent determine the required parameters of agrophysical soil properties.

It was established that tillage systems in crop rotations significantly impact not only soil properties but also the overall productivity of crop rotations and the efficiency of water use. Different types of crop rotation in varying growing conditions require distinct approaches to tillage. For example, H. Sharifnasab *et al.* (2024) reported that tillage minimisation was found to be essential for improving soil water retention under wheat crops, as demonstrated by the results of a meta-analysis. No-tillage and minimal-tillage methods enhanced soil organic carbon content, total nitrogen levels, and beneficial earthworm populations when compared to standard mouldboard tillage. However, long-term studies revealed that no-till farming greatly increased weed populations and that population and that crop rotations had no effect on weed infestation. The study by A. Woźniak and M. Soroka (2018) demonstrated that in a semi-arid climate, reduced tillage (rototiller and chisel) could boost the economic profitability of crop production and decrease weed infestation compared to traditional mouldboard ploughing. M. Maliarchuk *et al.* (2021) concluded that the best agrophysical properties of dark-chestnut soil in the irrigated conditions of southern Ukraine were achieved under differentiated ploughless tillage. Moreover, this option also provided the best economic return for crop cultivation in a four-field grain crop rotation involving grain maize, sorghum, soybeans, and winter wheat. The differentiated tillage system with disc tillage at a depth of 8-10 cm was also found to be the most efficient in terms of water use (Vozhehova *et al.,* 2019). However, it is difficult to disagree with S. Khursheed *et al.* (2019) that adaptive tillage systems in Ukraine are currently insufficiently studied and, as a result, inefficient and irrational practices are still implemented, leading to the loss of organic matter, erosion, deterioration of agrophysical properties, and, consequently, a general decline in fertility. O. Menshov and O. Kruglov (2023) stressed that one of the most prominent reasons for soil degradation in Ukraine is irrational tillage, particularly, excessive ploughing. Therefore, current research must provide robust evidence in support of alternative tillage methods that are less harmful to soil health. It should also be emphasised that tillage systems should be studied in close relation to soil and climate conditions, which are changing nowadays rapidly and must take into account the water supply and the range of cultivated crops. Novel studies and approaches to soil tillage should be based on the principles of sustainability and climate-smart agricultural technologies.

Thus, the primary objective of this study was to determine the ideal tillage strategy under current climate change conditions in southern Ukraine, to optimise the agrophysical properties of dark-chestnut soil under irrigated short four-field grain crop rotation.

MATERIALS AND METHODS

The study was conducted during 2021-2022 as part of a stationary field experiment on the experimental plots of the Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences, located in the village of Naddniprianske, Kherson Region. The location of the experiment was 46°44’34.9”N, 32°42’20.1”E. The scheme of the short grain crop rotation and the studied tillage options are presented in Table 1.

***Table 1**. Experimental scheme of the study on tillage effects on agrophysical soil properties and crop productivity in the irrigated conditions of southern Ukraine*

No.	Tillage system	Crop rotation and tillage depth, cm			
		Grain maize	Winter rapeseed	Winter wheat	Soybeans
1	Mouldboard-differentiated (standard control option)	28-30 (p)	14-16 (p)	20-22 (p)	23-25 (p)
2	Ploughless-differentiated	28-30 (c)	14-16 (c)	20-22 (c)	23-25 (c)
3	Ploughless-differentiated with slitting on 38-40 cm	10-12 (d) + 38-40 (s)	12-14 (d) + slitting aftereffect	14-16 (d) + slitting aftereffect	10-12 (d) + slitting aftereffect

***Note:** p – ploughing; c – chisel tillage; d – disc tillage; s – soil slitting*
***Source:** prepared based on the authors’ research*

The study was carried out on dark-chestnut, middle loamy soil with a humus horizon depth of 40 cm, humus content of 2.3%, total nitrogen content of 0.17%, gross phosphorus content of 0.09%, and a pH of the soil ranging from 6.8 to 7.3. The climate of the zone is characterised as semi-arid steppe, and the region is considered risky for rainfed agriculture (Beck *et al.,* 2018). The study was conducted in four replications using a systematic plot distribution design. The sown area was 450 m^2, while the accounted area was 50 m^2.

Tillage was conducted using standard manufactured machines. The plant genotypes used in the study were: the variety Skadovskyi for grain maize, with a sowing rate of 80,000 pcs./ha; the variety Diona for soybeans, a sowing rate of 10 kg/ha; the variety Konka for winter wheat, with a sowing rate of 220 kg/ha (5 million pcs./ha); the variety Chornyi Veleten for winter rapeseed, with a sowing rate of 8 kg/ha (800,000 pcs./ha). Irrigation was conducted using a DDA-100-MA overhead sprinkler machine. Irrigation occurred when soil moisture dropped to 70% of the field water-holding capacity in the root zone. In general, the cultivation technology of the studied crops within the crop rotation was standard for southern Ukraine, except for the tillage options. The depth of tillage was controlled using a furrow meter, and at least 50 measurements were taken on each experimental plot. The bulk density of the soil was established using the core method in layers of 0-10, 10-20, 20-30, and 30-40 cm at the beginning of the growing season and after harvesting (Al-Shammary *et al.,* 2018). Soil porosity was determined by the equation (1):

$$P = (1 - d/dsf), \qquad (1)$$

where P is porosity; d – soil bulk density, g/cm^3; dsf – bulk density of the solid fraction of the soil, g/cm^3.

Water permeability was measured using the water absorption test after three hours of exposure (Nagy *et al.,* 2013). Soil moisture was determined by the gravimetric method (Reynolds, 1970). The yield of the studied crops was established through direct harvesting using a combined harvester. The energy output of the crop rotation was calculated based on the standardised energy income from crop products (Konieczna *et al.,* 2020). Statistical data processing was performed at $P < 0.05$ using the common ANOVA procedure, with Fisher’s least significant difference test (Williams & Abdi, 2010). The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

The study's findings showed that, for the majority of the crops examined, traditional mouldboard tillage had no impact on the bulk density of the soil – with soybeans being the exception. Mouldboard ploughing resulted in noticeably improved soil loosening under soybeans at the start of the crop growing season, but this difference was negated after harvest (Table 2).

***Table 2**. Soil bulk density (g/cm$_3$) in the 0-40 cm layer under the studied crops depending on the tillage system*

No.	Tillage system	Method and depth (cm)	Crops			
			Grain maize	Winter rapeseed	Winter wheat	Soybeans
			At the beginning of the growing season			
1	Mouldboard	28-30 (p)	1.28a	1.25a	1.27a	1.25a
2	Ploughless	28-30 (c)	1.29a	1.29b	1.28a	1.29b
3	Ploughless-differentiated	10-12 (c) + 38-40 (s)	1.25a	1.27ab	1.26a	1.27ab
			After harvesting			
1	Mouldboard	28-30 (p)	1.29a	1.27a	1.28a	1.31a
2	Ploughless	28-30 (c)	1.31a	1.31a	1.30a	1.31a
3	Ploughless-differentiated	10-12 (c) + 38-40 (s)	1.27a	1.29a	1.28a	1.35a

***Note:** different letters indicate that the difference between the experimental variants is significant according to Fisher's least significant difference test at $P < 0.05$*
***Source:** prepared based on the authors' research*

This was also true for soil porosity, which did not significantly differ between the variants of the tillage system. Generally, soil porosity was somewhat higher under mouldboard ploughing, but this difference was insignificant and could not be attributed to the effect of the tillage system itself (Table 3).

***Table 3**. Soil porosity (%) in the 0-40 cm layer under the studied crops depending on the tillage system*

No.	Tillage system	Method and depth (cm)	Crops			
			Grain maize	Winter rapeseed	Winter wheat	Soybeans
			At the beginning of the growing season			
1.	Mouldboard	28-30 (p)	51.1ab	52.0a	51.5a	52.0a
2.	Ploughless	28-30 (c)	50.6a	50.7a	50.9a	50.7a
3.	Ploughless-differentiated	10-12 (c) + 38-40 (s)	52.0c	51.3a	51.6a	51.2a
			After harvesting			
1.	Mouldboard	28-30 (p)	50.7ab	51.2a	50.9a	51.3a
2.	Ploughless	28-30 (c)	49.9b	49.9a	50.4a	50.0a
3.	Ploughless-differentiated	10-12 (c) + 38-40 (s)	51.2a	50.6a	50.8a	50.3a

***Note:** different letters indicate that the difference between the experimental variants is significant according to Fisher's least significant difference test at $P < 0.05$*
***Source:** prepared based on the authors' research*

Another trend was observed regarding soil water permeability. It was established that mouldboard ploughing and the ploughless-differentiated tillage system with soil slitting provided significantly better water permeability compared to ploughless chisel tillage under grain maize. Under soybeans and winter rapeseed, mouldboard ploughing was significantly superior to both ploughless tillage systems, while ploughless-differentiated tillage with soil slitting performed better than chisel loosening. As for soil water permeability under winter wheat, mouldboard ploughing outperformed all other systems at the beginning of crop growth. However, after harvesting, it was no longer superior to the differentiated system of ploughless tillage with soil slitting. In general, it can be concluded that conventional tillage with mouldboard machines creates better conditions for water absorption in dark-chestnut soil in the semi-arid climate of southern Ukraine (Table 4).

***Table 4**. Soil water permeability (infiltration rates in mm/min) under the crops of the studied four-field crop rotation depending on tillage options*

No.	Tillage system	Method and depth (cm)	Time of measurement	
			Beginning of growing	After harvesting
Under grain maize				
1	Mouldboard	28-30 (p)	4.4a	4.0a
2	Ploughless	28-30 (c)	3.9b	3.4b
3	Ploughless-differentiated	10-12 (d) + 38-40 (s)	4.6a	4.3a
Under soybeans				
1	Mouldboard	28-30 (p)	4.9a	4.3a
2	Ploughless	28-30 (c)	3.7b	3.0b
3	Ploughless-differentiated	10-12 (d) + 38-40 (s)	4.2c	3.6c
Under winter wheat				
1	Mouldboard	28-30 (p)	4.2a	3.6a
2	Ploughless	28-30 (c)	3.0b	2.3b
3	Ploughless-differentiated	10-12 (d) + 38-40 (s)	3.6c	3.0a
Under winter rapeseed				
1	Mouldboard	28-30 (p)	3.8a	3.4a
2	Ploughless	28-30 (c)	2.6b	2.2b
3	Ploughless-differentiated	10-12 (d) + 38-40 (s)	3.2c	2.7c

***Note:** different letters indicate that the difference between the experimental variants is significant according to Fisher's least significant difference test at $P < 0.05$*
***Source:** prepared based on the authors' research*

In terms of the crop rotation's productivity and energy output, it was found that the ploughless-differentiated tillage with soil slitting produced the highest yields across all the crops studied. This also applies to the energy output of the crop rotation, which was the highest in this variant and reached 119.1 GJ/ha, while the lowest energy output was recorded under the chisel ploughless tillage – 108.6 GJ/ha. Conventional mouldboard ploughing tillage occupied an intermediate position in terms of both crop productivity and energy production (Table 5).

***Table 5**. Productivity of the crop rotation depending on tillage options*

No.	Tillage system	Indicators	Crops				
			Grain maize	Winter rapeseed	Winter wheat	Soybeans	Average for the crop rotation
1	Mouldboard-differentiated	yield, t/ha	12.69	2.62	6.51	3.56	-
		GJ/ha	209.4	52.4	116.9	69.3	112.0
2	Ploughless-differentiated	yield, t/ha	12.27	2.55	6.37	3.41	-
		GJ/ha	202.6	51.0	114.3	66.4	108.6
3	Ploughless-differentiated with slitting on 38-40 cm	yield, t/ha	13.70	2.70	6.76	3.85	-
		GJ/ha	226.2	53.9	121.3	74.9	119.1

***Source:** prepared based on the authors' research*

To summarise the results of the current study, it was established that the agrophysical properties of the soil, and soil water permeability in particular, are to some extent dependent on the tillage options, especially how the layers are mixed and turned. Tillage effects vary across different crops, which could be attributed to differences in their root systems, as it is a well-established fact that plant roots play a crucial role in the formation of physical traits in soil (Wang *et al.*, 2023). Additionally, tillage greatly affects crop productivity and energy production; therefore, it is essential to consider these impacts of soil cultivation on the final results of crop production.

Tillage is one of the major factors affecting soil agrophysical and hydraulic indicators, especially those such as soil bulk density, porosity, and water permeability. Its effects on the soil are strongly dependent not only on the machinery used but also on soil type, climate conditions, and the overall level of agricultural practice. Therefore, considerable variations in results are obtained in studies conducted under different agro-industrial conditions. Most studies claim that tillage systems significantly impact soil bulk density and related properties, such as porosity and hardness. Conventional tillage, usually involving mouldboard ploughing, generally decreases soil bulk density compared to minimal or no-till systems, particularly in the arable soil layer. For example, R. Hashimi *et al.* (2023) determined that although soil compaction occurs to some extent under zero tillage, it generally improves soil structure and increases the proportion of beneficial agrophysical aggregates in the soil. However, excessive soil compaction in some cases can pose significant hazards to normal crop growth and development, resulting in decreased yields and yield quality due to impediments to plant roots accessing water and nutrients. It was found that compacted soils reduced barley, wheat, maize, and soybean yields by 15.1%, 4.1%, 37.7%, and 27.7%, respectively, providing evidence that maize crops are the most susceptible to soil compaction (Zhang *et al.,* 2024).

Several studies have claimed that chisel ploughing can be even more effective than mouldboard ploughing in reducing soil bulk density. In this regard, disc ploughless tillage is inferior to both mouldboard and chisel ploughing, but the aspects of soil bulk density formation under the influence of tillage are also dependent on the speed of tillage machinery, which was not considered as a factor in this study (Isaak *et al.,* 2024). However, in this study, a very subtle difference was found between mouldboard and ploughless tillage options in terms of soil bulk density. Reports on the influence of tillage on crop yields are inconsistent and sometimes even contradictory. In this research, the most productive tillage option was differentiated disc ploughless tillage with soil slitting. However, D. Burger *et al.* (2023) reported different results, confirming improved yields under ploughing during dry years in Northern Germany. The difference in the study results could be due to the fact that although this research was conducted in a more arid climatic zone than Northern Germany, irrigation was applied to mitigate the effects of drought on the crops studied. The authors' hypothesis is supported by the study conducted by B. Zhang *et al.* (2023), who claimed that crop productivity under deficit irrigation could be significantly improved through deeper tillage, which provides better water-retention capacity. In this case, there was no need for the creation of water-saving storage in the soil; thus, the highest yield and energy output were obtained in the variants with conservation ploughless tillage.

As for soil water permeability, this study showed that tillage provided the best water penetration rates under all the studied crops except for maize. In general, it can be concluded that deeper tillage with soil layer rotation is the best practice to increase soil water filtration rates while minimising tillage and neglecting soil rotation results in slower infiltration rates. This theory is supported by the study conducted by Y. Qian *et al.* (2024), who compared soil permeability under conventional and no-till systems. However, no-till systems seem to be the better option for soil health in irrigated conditions, as zero tillage results in better water flux and a more beneficial soil structure in the long-term (Talukder *et al.,* 2023). As this study covered a relatively short period of two years, it is difficult to support or refute this statement.

Another important question is the effect of tillage options on overall crop productivity. A meta-analysis of European studies determined that tillage minimisation (through ridge and strip tillage methods) increased the yields of major crops by 5% compared to conventional mouldboard ploughing, while no-till systems reduced yields by 5.1% (Achankeng & Cornelis, 2023). In the US Corn Belt, satellite data analysis revealed a subtle (3.3%) increase in grain maize yields and a 0.74% increase in soybean yields under a long-term conservation (ploughless) tillage system (Deines *et al.,* 2019). These results align with the findings of the authors of this article, but it should be stressed that the ploughless tillage system with chisel ploughing was inferior to the differentiated system with disc cultivation and soil slitting.

In addition, it should be acknowledged that studying tillage must consider soil wind and water erosion hazards. Tillage-related erosion on slopes can reduce wheat and maize yields over time, and current climate change potentially exacerbates this effect (Quinton *et al.,* 2022). Conservation tillage practices, which mainly include ploughless and no-till options, provide benefits such as improved soil health, reduced erosion, and generally better soil structure, which can contribute to sustainable crop production (Kumar *et al.,* 2022). However, this statement is not universally applicable to all agro-industrial conditions, as this study demonstrated that a significantly better water infiltration capacity of the dark-chestnut soil under irrigated conditions is achieved with conventional mouldboard ploughing. However, no erosion effects were studied; therefore, it cannot be established whether ploughless tillage is superior or inferior to mouldboard ploughing.

At the same time, it must be acknowledged that in this study deep ploughing does not provide significant benefits in terms of soil agrophysical properties; therefore, excessive ploughing should be avoided. The future of agriculture lies in the rational combination of differentiated tillage systems within short- to moderate-length crop rotations, especially in the so-called bio-tillage. Consequently, experimental and theoretical research into the efficiency of tillage systems and their impact on soil agrophysical, agrochemical, agromeliorative, biological, and fertility properties should be conducted under different agroclimatic conditions in Ukraine to ensure a rational transition to innovative tillage systems in the context of the current food crisis and climate change (Lykhovyd, 2024; Pavlova & Litvinov, 2024).

To sum up, the current study demonstrates that, in general, the ploughless-differentiated tillage system with disc cultivation and soil slitting provides the best balance between the formation of optimal soil agrophysical properties and crop productivity of the irrigated steppe zone of southern Ukraine.

CONCLUSIONS

Soil bulk density was insignificantly influenced by tillage systems and fluctuated between 1.25-1.29 g/cm^3 at the beginning and 1.27-1.35 g/cm^3 at the end of the growing season for the studied grain crops. The same is true for soil porosity, which was approximately 50.0% across all the studied tillage variants. As for soil water permeability, it was established that mouldboard ploughing resulted in a significantly higher rate both at the beginning of the growing season and after harvesting under soybeans and winter rapeseed, averaging between 3.8-4.9 and 3.4-4.3 mm/min, respectively. However, in grain maize, mouldboard tillage did not statistically outperform the ploughless-differentiated tillage system, and in winter wheat crops, it performed significantly better only at the beginning of the growing season. Regarding the productivity of the crop rotation, it was established that mouldboard tillage performed better than the ploughless chisel tillage system, but was still inferior to disc tillage with soil slitting, as evidenced by the energy output of the crop rotation – 119.1 vs. 112.0 GJ/ha. Thus, there is no scientifically sound evidence supporting conventional mouldboard ploughing over the studied ploughless tillage systems on irrigated dark-chestnut soil in the short grain crop rotation. Therefore, a ploughless-differentiated tillage system with disc tillage to a depth of 10-12 cm, accompanied by soil slitting to a depth of 38-40 cm once per crop rotation, should be preferred over conventional mouldboard ploughing systems on the irrigated lands of the semi-arid zone of southern Ukraine to provide the best ratio between soil health and crop yields. Further investigations will focus on studying no-till systems in irrigated short grain crop rotations, regarding their influence on agrophysical and agrochemical soil properties and overall fertility, as well as the impact of no-till practices on crop productivity.

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CONFLICT OF INTEREST

None.

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Вплив обробітку на агрофізичні властивості ґрунту та продуктивність сільськогосподарських культур в зрошуваних умовах степу України

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Анотація. Основною метою дослідження було встановити вплив різних систем обробітку ґрунту на агрофізичні властивості темно-каштанового ґрунту в короткоротаційній зернопросапній сівозміні в зрошуваних умовах півдня України. Дослідження проводили протягом 2021-2022 рр. у стаціонарному досліді в чотирипільній сівозміні: кукурудза на зерно – ріпак озимий – пшениця озима – соя. Дослідне поле знаходилося в напівпосушливій степовій кліматичній зоні Інституту кліматично орієнтованого землеробства НААН. Досліджували три системи обробітку ґрунту з точки зору їх впливу на насипну щільність, пористість та водопроникність ґрунту, а саме: відвальний диференційований обробіток; диференційований чизельний обробіток; диференційований безполицевий обробіток з щілюванням ґрунту. Об'ємну масу ґрунту визначали за допомогою кернового методу. Пористість ґрунту розраховували як відношення загальної об'ємної маси до об'ємної маси суцільного зламу. Швидкість інфільтрації води, встановлена за допомогою методу водопоглинання, була використана як міра водопроникності ґрунту. Результати дослідження були статистично оброблені за допомогою загальноприйнятої процедури ANOVA з використанням критерію найменшої значущої різниці Фішера при $P < 0{,}05$. Крім агрофізичних параметрів ґрунту, оцінювали енергетичну продуктивність сівозміни. Встановлено, що відвальний обробіток ґрунту не має суттєвої переваги за показниками насипної щільності та пористості ґрунту. В той же час, оранка показала найкращі результати за водопроникністю ґрунту під всіма культурами сівозміни. Проте найвищий вихід енергії в сівозміні (119,1 ГДж/га) був зафіксований за безполицевої системи диференційованого обробітку ґрунту з щілюванням, тоді як відвальна оранка та чизельний обробіток забезпечили дещо нижчий вихід енергії – 112,0 та 108,6 ГДж/га відповідно. Таким чином, безполицевий диференційований обробіток ґрунту з щілюванням є найкращим варіантом для короткоротаційних зернових сівозмін в зрошуваних умовах півдня України з точки зору створення оптимальних агрофізичних властивостей ґрунту та отримання найвищої продуктивності сільськогосподарських культур

Ключові слова: полицева оранка; безполицевий обробіток; щільність складення ґрунту; пористість ґрунту; водопроникність; урожай