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RESEARCH ARTICLE

Yields of major grain crops depending on tillage system in semi-arid agroecological zone

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Abstract

No-till is a new trend in modern agriculture. As far as most farmers and researchers believe that no-till farming provides benefits both for sustainability of agroecosystems, climate change mitigation and economics of crop production, mass transfer to zero tillage is observed worldwide. However, it is quite debatable that no-till is always beneficial for the yields of crops. The main goal of this study is to establish the direction and strength of short and long-term no-till influence on the yields of major grain crops, cultivated in the south of Ukraine, namely, winter wheat, winter barley, and soybeans, within the irrigated short grain crop rotation. The study was carried out on dark-chestnut and chernozem soils within the semi-arid cold climate zone. Short- and long-term no-till effects on the yields of the mentioned crops were evaluated through direct harvesting and standardization of grain yields to basic conditions. It was established that conventional differentiated tillage provided higher yields of winter barley and soybean with the peak values 6.06 and 3.77 t/ha, respectively. No-till is effective mainly in the long run, and only under the use of green manure intercropping. The best yields of winter wheat were harvested under continuous no-till on the background of phacelia intercropping -7.02 t/ha. Regression analysis revealed that fertilization system is of greater influence and importance for yield formation of studied crops (R=0.77-0.86), while tillage plays less role or even becomes insignificant in some cases (R=0.31-0.32). Introduction of no-till in short grain crop rotations provides long-term benefits for winter wheat, while other crops demonstrate negative reaction. Green manure intercropping is of great importance to increase crop production efficiency at both conventional and no-till systems of agriculture

Keywords: Differentiated tillage, Green manure, Irrigation, No-till, Soybean, Winter barley, Winter wheat

Introduction

Modern agriculture is developing within the paradigm of resource conservation and minimization of environmental impact. In this regard, conventional tillage practices that are mainly associated with heavy environmental pressure and negative climate effects, are gradually replaced with minimal or zero tillage options. No-till adoption as a primary strategy in crop cultivation has recently become a new established trend. Considering strong support by recent ecological studies, claiming about beneficial effects on carbon sequestration and climate change mitigation, no-till transforms from a niche agricultural technique to a mainstream agrotechnology worldwide (Jayaraman and Dalal, 2022). Recent advances in biologized agriculture are another driving force to adopt no-till as more biologically friendly way of soil management (Zhuikov, et al. 2025). The most recent claims that no-till adoption not only decreases greenhouse gas emissions, but also provides benefits for crop yields, are one of the major driving forces to massive adoption of zero tillage (Yue, et al. 2023). However, is it always the case that no-till has no drawbacks or pitfalls? Does the influence of continuous no-till remain positive at any agro-industrial conditions of crop production? The question is quite debatable.

A brief revision of academic papers, published in recent decades, points out that there are not only songs of praise for no-till, but some opposite evidence could be found. General pattern is that no-till does not always lower yields or raise them. The effects of zero tillage on crop production and environment are strongly conditional. The main regularity is that at early adoption the yields tend to decrease, but if everything goes well, in the long run harvest raise up. It is quite surprising to mention that dry, rainfed systems in case of rational moisture management, soil mulching and reasonable crop rotations recover their productivity much better and faster, than irrigated agroecosystems or those located in humid climates (Pittelkow, et al. 2015ab). Besides, effects of no-till depend on crops. In general, winter wheat is the staple crop with the most positive reaction to no-till adoption worldwide. Recent American analysis found that average wheat yields are greater under no-till on some loamy-soil regions of the country, while an Asian meta-analysis established slight wheat yield gains or no overall difference compared to conventional tillage practices (Morrison, et al. 2017, Hashimi, et al. 2023). As for corn, this crop is more susceptible to no-till farming. The global meta-analysis put this crop among the largest cereal penalties, especially when cultivated on sandy soils, and long-term Canadian data found conventional tillage to provide 20% higher grain output than no-till in a humid climate (Toliver, et al. 2012, Morrison, et al. 2017). Soybean reaction to tillage minimization is mixed. The study performed in Canada found no difference between tillage systems for soybean productivity, while Brazilian study revealed a slight (6.5%) gain under no-till (Morrison, et al. 2017, Silva, et al. 2023). Among major staple crops, rice demonstrated the clearest negative reaction to no-till adoption and provided the best yield output under conventional tillage practices (Hashimi, et al. 2023). According to the results of most recent global meta-analysis, rice yield losses under no-till average to 4.8% compared to conventional farming systems (Godbey, et al. 2026). All these facts support the idea that no-till cannot be considered as a universal solution, and targeted research must be conducted in every case of this farming system adoption.

Therefore, the main goal of this study is to establish the direction and strength of short- and long-term no-till influence on the yields of major grain crops, cultivated in the south of Ukraine, namely, winter wheat, winter barley, and soybeans, within the irrigated short grain crop rotation.

Materials and Methods

Field trials were conducted within the period 2021-2025 on the irrigated stationary experimental plots, located in Kherson, Mykolaiv, and Odesa region. The locations of the experiment represent typical semi-arid cold climate zone (BSk) according to modern climate classification (Beck, et al. 2018). The soil of the plots was represented by dark-chestnut and chernozem soil. Average soil organic matter content in the soils was 2.5-4.3%. The content of nitrogen fluctuated within 3.0-3.2 mg/kg; mobile phosphorus content averaged to 4.5-11.8 mg/kg; exchangeable potassium content was within 45-305 mg/kg. Therefore, soil fertility is characterized with high variation that makes the trials more representable for the whole Steppe zone conditions. Meteorological conditions in the years of the study conduction were quite versatile, but within typical range of indicators for the agroecological zone of the Steppe of Ukraine.

Three tillage systems were studied: I-conventional differentiated (shallow disk tillage on 12-14 cm under cereals and moldboard plowing on 28-30 cm under soybean); II-no-till in the first year of adoption against the background of long-term (12 years) multi-depth (23-28 cm) chisel tillage; III-long-term (12 years in a row) pure no-till system. The study was conducted against the background of different fertilization approaches, including conventional mineral fertilization in the recommended rates, and green manure intercropping with such crops as phacelia, white melilot and buckwheat. The study design was systematic, with three replications.

The agrotechnology, employed in this study, was compliant with established regional guidelines for irrigated agriculture in the south of Ukraine, except for the studied parameters. Soil moisture content in the 0-50 cm layer was maintained at 75-80% of the field capacity. During the 2021-2022 period, irrigation was provided via the "Zimmatik" sprinkler system utilizing water from the Kakhovka irrigation network. Following the relocation of experimental sites to the Odesa and Mykolaiv regions, irrigation was performed using water from artificial wells. Phytosanitary protection against pathogens, pests, and weeds was conducted using a self-propelled "John Deere" sprayer, utilizing approved chemical agents in accordance with local integrated pest management standards. Annual white melilot (*Melilotus albus*), phacelia (*Phacelia tanacetifolia*), and common buckwheat (*Fagopyrum esculentum*) were selected as green manure intercrops due to their short growth periods, high biomass production in post-harvest cultivation, and documented positive effects on soil phytosanitary and hydro-physical properties. White melilot, as a leguminous crop, serves primarily as a nitrogen-fixing donor, significantly enhancing soil fertility. Its deep taproot system facilitates soil aeration and structure improvement across various soil types. Furthermore, *M. albus* exhibits strong phytosanitary potential, acting as an antagonist to soil-borne pathogens, specifically root rot (Cereal root rot) of barley, as well as suppressing populations of stem nematodes and wireworms (Elateridae), making it a valuable component in organic and biological farming systems. Phacelia is characterized by its high drought tolerance and resistance to common agricultural pests and diseases. Its low soil fertility requirements allow it to thrive in nutrient-depleted substrates, where it actively mobilizes and assimilates sparingly soluble mineral nutrients, thereby increasing their bioavailability for subsequent crops. Common buckwheat as a thermophilic species with a short growing season, is highly suitable for intercropping. The root system of *F. esculentum* actively produces organic acids (formic, oxalic, citric, and acetic acids), which promote the solubilization of recalcitrant phosphorus and potassium compounds, significantly enhancing nutrient availability in the rhizosphere. Therefore, the selected green manure crops were mainly aimed to improving soil health, fertility, and enhance productivity of the main staples in the crop rotation. The yields of winter wheat, winter barley and soybean were harvested using "Sampo-130" harvester. The grain yields were standardized to 14% moisture and 100% purity. To establish significance of differences between the variants, Fisher's least significant difference test at 95% confidence interval was performed (Williams and Abdi, 2010). Mathematical modeling of yields depending on agrotechnology was performed after inputs pre-processing into dummy format using ordinary least squares regression analysis (Burton, 2021). Statistical significance of the developed models was evaluated using F-test (Sureiman and Mangera, 2020).

Results and Discussion

The studied factors of agrotechnology significantly affected the yields of staple crops. The highest yields of winter barley (6.06 t/ha) were recorded under conventional tillage system with green manuring (Tab. 1). Decrease in the crop yield by 0.30-0.85 t/ha was recorded for no-till option. Yields under continuous no-till were somewhat higher than at the first year of adoption. Green manuring of the fore-crop also resulted in higher winter barley productivity (raise by 0.81-1.01 t/ha).

Table 1. Winter barley yields depending on tillage and fertilization system*, t/ha.

Tillage (Factor A)	Fertilization (Factor B)	Yield	± Residuals	
			(A)	(B)
Conventional differentiated	$N_{120}P_{40}$ after $N_{180}P_{40}$+green manure	6.06	-	1.01
	$N_{120}P_{40}$ after $N_{180}P_{40}$	5.05	-	-
No-till (1st year)	$N_{120}P_{40}$ after $N_{180}P_{40}$+green manure	5.21	-0.85	0.81
	$N_{120}P_{40}$ after $N_{180}P_{40}$	4.4	-0.65	-
No-till (12 years)	$N_{120}P_{40}$ after $N_{180}P_{40}$+green manure	5.61	-0.45	0.86
	$N_{120}P_{40}$ after $N_{180}P_{40}$	4.75	-0.3	-

***Note:** LSD_{05}: Factor A-0.42 t/ha; Factor B-0.41 t/ha.

Winter wheat yields in the variants without green manuring and disk tillage on the depth 12-14 cm averaged to 5.85 t/ha (Tab. 2). Under short-term no-till without green manure crops, the yields of crop decreased by 0.32 t/ha. Continuous no-till resulted in even greater yield losses-0.39 t/ha. Green manure intercropping increased winter wheat yields at all the studied tillage systems: By 0.27-0.47 t/ha under conventional tillage; 0.16-1.03 t/ha under short-term no-till; 0.56-1.56 t/ha under long-term zero tillage, respectively. The highest yield of crop (7.02 t/ha) was recorded in the variant with phacelia green manuring against the long-term no-till agriculture system.

Table 2. Winter wheat yields depending on tillage and fertilization system*, t/ha.

Tillage (Factor A)	Fertilization (Factor B)	Yield	± Residuals	
			(A)	(B)
Conventional differentiated	$N_{60}P_{40}$+buckwheat	6.20		0.35
	$N_{60}P_{40}$+melilot	6.11		0.27
	$N_{60}P_{40}$+phacelia	6.32		0.47
	$N_{60}P_{40}$	5.85		
No-till (1st year)	$N_{60}P_{40}$+buckwheat	6.19	-0.01	0.67
	$N_{60}P_{40}$+melilot	5.68	-0.43	0.16
	$N_{60}P_{40}$+phacelia	6.56	0.24	1.03
	$N_{60}P_{40}$	5.52	-0.32	
No-till (12 years)	$N_{60}P_{40}$+buckwheat	6.02	-0.18	0.56
	$N_{60}P_{40}$+melilot	6.27	0.16	0.82
	$N_{60}P_{40}$+phacelia	7.02	0.70	1.56
	$N_{60}P_{40}$	5.46	-0.39	

***Note:** LSD_{05}: Factor A-0.35 t/ha; Factor B-0.34 t/ha.

Soybean yields against conventional tillage system reached 3.20-3.77 t/ha (Tab. 3). No-till decreased the yield of crop by 0.09-0.42 t/ha in all the options of fertilization. Green manure crops resulted in higher soybean yields regardless tillage system. Buckwheat intercropping increased yields by 0.24-0.57 t/ha, white melilot-by 0.06-0.23 t/ha, and phacelia-by 0.29-0.34 t/ha. Phacelia was the best green manure crop against no-till background, while buckwheat-against conventional plowing. The greatest yields were recorded for conventional tillage system with the combined mineral and green manure fertilization (buckwheat option)-3.77 t/ha.

Table 3. Soybean yields depending on tillage and fertilization system*, t/ha.

Tillage (Factor A)	Fertilization (Factor B)	Yield	± Residuals	
			(A)	(B)
Conventional differentiated	$N_{60}P_{40}$+buckwheat	3.77		0.57
	$N_{60}P_{40}$+melilot	3.43		0.23
	$N_{60}P_{40}$+phacelia	3.54		0.34
	$N_{60}P_{40}$	3.2		
No-till (12 years)	$N_{60}P_{40}$+buckwheat	3.35	-0.42	0.24
	$N_{60}P_{40}$+melilot	3.18	-0.25	0.06
	$N_{60}P_{40}$+phacelia	3.40	-0.14	0.29
	$N_{60}P_{40}$	3.11	-0.09	

***Note:** LSD_{05}: Factor A-0.25 t/ha; Factor B-0.18 t/ha.

Regression modeling revealed that fertilizers had greater effect on the yields of the studied crops regardless tillage system (Tab. 4). The coefficient of determination fluctuated within 0.59-0.74 for fertilizers-based models, while reached only 0.31-0.32 for statistically significant tillage-based models. Therefore, fertilizer-based models provide moderate-to-strong fitting quality, while tillage-based models provide weak-to-moderate fitting quality (Akoglu, 2018). As for winter wheat, tillage-based model is statistically unacceptable: F criterion value is less than Fcritical value. In terms of accuracy, all the models demonstrated good precision levels with MAPE within 3-10% (Moreno, et al. 2013). The best accuracy of prediction was recorded in the fertilizers-based winter wheat model. Tillage-based model of winter barley productivity prediction showed the lowest accuracy, while the worst fitting quality was observed in the tillage-based soybean model. In general, regression analysis results demonstrate the inferior influence of tillage system on the productivity of studied crops. Therefore, mineral nutrition and green manuring are of much greater importance for sustainable crop production and food security. Our findings are supported by recent scientific reports that claim about significant yield gains in soybean (up to 59%) and corn (up to 250%) under better plant nutrition options, while tillage, though provided significant effect, was inferior in its influence on crops' productivity (Buah, et al. 2017, Pendke, et al. 2025). Besides, optimal organo-mineral fertilization improves soil health and fertility, enhances water use efficiency, and provides long-term benefits for agroecosystems, significantly outweighing the impacts of tillage (Vozhehova, et al. 2019, Kyryliuk, et al. 2025). It should be stressed that efficiency of fertilization systems should be evaluated in the context of tillage, because it is established that soil treatment must correspond to nutrition system, though the share of variance explained by fertilization is typically higher (up to 62.5% for soybean) compared to tillage (Kyryliuk, et al. 2025). The explanation of stronger effects of fertilizers on the yield of crop is explained by the fact that direct improvement of plant nutrition inevitably results in productivity gain, while soil tillage just creates favorable conditions for nutrients and water uptake providing no direct impact on plants vigor. Tillage cannot compensate substantial nutrients or water deficit and plays indirect role in the improvement of plant growth and development, therefore, it has less pronounced effects compared to fertilization-the factor with direct influence on plants (You, et al. 2023). But at the same time, even the best fertilization systems will fail under inappropriate tillage (Allam, et al. 2022).

Table 3. Soybean yields depending on tillage and fertilization system*, t/ha.

Metrics	Winter wheat-fertilizers	Winter wheat-tillage	Winter barley-fertilizers	Winter barley-tillage	Soybean-fertilizers	Soybean-tillage
R	0.86	0.2	0.82	0.56	0.77	0.56
R2	0.74	0.04	0.68	0.32	0.59	0.31
SE, t/ha	0.26	0.48	0.38	0.63	0.18	0.19
F	7.77	0.19	8.35	0.7	1.93	2.7
Fcritical	0.01	0.9	0.06	0.63	0.31	0.16
MAE, t/ha	0.18	0.33	0.26	0.45	0.11	0.14
MAPE, %	2.96	5.36	4.93	8.62	3.33	4.22
RMSE, t/ha	0.21	0.41	0.31	0.45	0.13	0.17

***Notes:** R-Pearson's correlation coefficient; R2-coefficient of determination; SE-Standard Error; F-Fisher's criterion of significance; MAE-Mean Average Error; MAPE-Mean Average Percentage Error; RMSE-Root Mean Square Error.

Conclusion

Efficiency of tillage systems has pronounced specificity. No-till demonstrates better results for winter wheat, while conventional differentiated tillage system-for winter barley and soybean. Zero tillage leads to decrease in crops productivity by 0.09-0.85 t/ha in the first years of implementation, but the yields tend to improve with a prolonged no-till adoption. Green manure causes significant yield improvement under all the systems of tillage, and it is a main droving force of agriculture intensification within the system of conservative crop production. No-till may be potentially beneficial for winter cereals in the Steppe zone of Ukraine in the conditions of continuous technology adoption and simultaneous use of green manure crops.

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