ECONOMIC AND ENERGETIC EFFICIENCY OF APPLICATION OF DIFFERENT SOIL TILLAGE SYSTEMS IN CROP ROTATION IN THE CONDITIONS OF NORTHERN STEPPE OF UKRAINE

ЕКОНОМІЧНА ТА ЕНЕРГЕТИЧНА ЕФЕКТИВНІСТЬ ЗАСТОСУВАННЯ РІЗНИХ СИСТЕМ ОБРОБІТКУ ГРУНТУ В СІВОЗМІНІ В УМОВАХ ПІВНІЧНОГО СТЕПУ УКРАЇНИ

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Shevchenko Mykhailo
Doctor of Agricultural Sciences, Professor,
Head of the Department of Arable Farming
The Institute of Grain Crops of
National Academy of Agrarian Sciences
of Ukraine
Kompaniets Viktoriya
Candidate of Economic Sciences,
Senior Research Fellow,
Head of the Laboratory of Economics
The Institute of Grain Crops of
National Academy of Agrarian Sciences
of Ukraine
Kulik Alla
Chief Specialist of the Laboratory of
Economics
The Institute of Grain Crops of
National Academy of Agrarian Sciences
of Ukraine

The article presents the evaluation results of the economic and energy efficiency of applying various tillage systems in crop rotation when growing winter wheat, spring barley, corn for grain and sunflower in the conditions of the northern Steppe of Ukraine. The experimental part of agrotechnological researches has been carried out on the basis of the SE "Experimental Farm "Dnipro" of the SE Institute of Grain Crops of National Academy of Agrarian Sciences of Ukraine. The variants of application of different tillage systems such as moldboard tillage (based on plowing), moldboardless soil protection tillage (based on flat-cut tillage) and No-till (zero tillage), depending on the nutrition background, have been studied. According to the evaluation results of the indicators of yield, cost and energy content of products, net income per 1 ha, profitability and energy efficiency coefficient, the variants of soil tillage that can be recommended for implementation into production are determined.

Keywords: tillage *system, moldboard tillage, moldboardless tillage, zero tillage, fertilizers, grain crops, sunflower, yield, cost, profitability, energy efficiency, protecting the soil from erosion.*

В статье представлены результаты оценки экономической и энергетической эффективности применения различных систем обработки почвы в севообороте при выращивании озимой пшеницы, ярого ячменя, кукурузы на зерно и подсолнечника в условиях северной Степи Украины. Экспериментальная часть агротехнологических исследований проводилась на базе ГП «Опытное хозяйство «Днепр» ГУ Института зерновых культур НААН Украины. Были изучены варианты применения разных систем обработки почвы: отвальной обработки (на основе вспашки), безотвальной почвозащитной (на основе плоскорезной обработки почвы) и No-till (нулевой обработки почвы) в зависимости от фона питания. По результатам оценки показателей урожайности, себестоимости и энергоемкости продукции, чистого дохода с 1 га, рентабельности и коэффициента энергетической эффективности определены варианты обработки почвы, которые могут быть рекомендованы для внедрения в производство.

Ключевые слова: *система обработки почвы, отвальная обработка почвы, безотвальная обработка почвы, нулевая обработка почвы, удобрения, зерновые культуры, подсолнечник, урожайность, себестоимость, рентабельность, энергетическая эффективность, защита почвы от эрозии.*

В сучасних умовах виробництво продукції рослинництва в системі АПК країни виконує роль стратегічно важливої галузі, оскільки від ефективного її функціонування залежить рівень продовольчої безпеки країни та формування потужної сировинної бази для переробної промисловості. В контексті підвищення врожайності сільськогосподарських культур та прибутковості їх вирощування провідна роль належить чинникам техніко-технологічного характеру. Одним з ключових факторів, дія яких спрямована на створення сприятливих умов для вирощування сільськогосподарських культур, є обробіток ґрунту. Спрямування новітніх адаптивних технологій на зниження ресурсо- та енергомісткості виробництва продукції рослинництва, а також забезпечення захисту ґрунту від ерозії спонукає до поглиблених досліджень щодо визначення найбільш ефективних систем обробітку ґрунту, рекомендованих для конкретних ґрунтово-кліматичних умов. В статті наведені результати оцінки економічної та енергетичної ефективності експериментальних досліджень з вивчення застосування різних систем обробітку ґрунту в польовій сівозміні зони північного Степу України, проведених на базі ДП «Дослідне господарство «Дніпро» ДУ Інститут зернових культур НААН України. Проаналізовані отримані показники врожайності озимої пшениці, ярого ячменю, кукурудзи на зерно та соняшнику, виробничих грошово-матеріальних витрат в розрахунку на 1 га посіву і на 1 т продукції, затрат сукупної енергії в розрахунку на 1 га посіву, енергоємності 1 т продукції, чистого доходу в розрахунку на 1 га, приросту валової енергії на 1 га, рівня рентабельності та коефіцієнта енергетичної ефективності для різних варіантів трьох систем обробітку ґрунту: полицевої (на основі оранки), ґрунтозахисної безполицевої (на основі плоскорізного обробітку ґрунту) і No-till (нульового обробітку ґрунту) для удобреного та неудобреного фонів живлення. Визначені найбільш ефективні з точки зору врожайності, економічної та енергетичної ефективності варіанти застосування систем обробітку ґрунту, що орієнтовані на захист ґрунту від ерозії та можуть бути рекомендовані для впровадження у виробництво.

Ключові слова: *система обробітку ґрунту, полицевий обробіток ґрунту, безполицевий обробіток ґрунту, нульовий обробіток ґрунту, добрива, зернові культури, соняшник, урожайність, собівартість, рентабельність, енергетична ефективність, захист ґрунту від ерозії.*

Problem statement. One of the priority areas of Ukraine's agricultural policy is the implementation of adaptive production technologies. The adaptive strategy of plant growing is aimed at sustainable growth of production while reducing energy expenditures and disturbances in the agricultural landscape.

Land is the main wealth of our state, but it is characterized by a high degree of in tillage (54 %), while in Europe this figure is 35 %. As of 01.01.2019, the area of agricultural land was 41.4 million hectares, of which 32.7 million hectares (79.0 %) were occupied by arable land. The remaining land was occupied by pastures (5.3 million hectares), hayfields (2.3 million hectares), perennial plantings (0.9 million hectares) and fallow areas (0.2 million hectares). The share of organic land was 422 thousand hectares [1].

The irrational use of land resources has led to the phenomenon of soil degradation, which can already be classified as catastrophic. According to the results of our previous researches, it was revealed that in the conditions of the Dnipropetrovsk region, which is geographically located in the northern Steppe zone

of Ukraine, eroded lands are actively used in agricultural turnover. So, the specific weight of plots with a slope steepness of more than 10 is 53.6 %. 47.2 % is accounted for by arable land with a slope steepness of 1–30, and the share of eroded land with a slope steepness of more than 30 is 6.4 %. This negatively affects the economic indicators of efficiency of production of plant growing products, and also leads to an increase in soil fertility losses. It was calculated that under the existing structure and location of sown areas of agricultural crops without taking into account the topography of the territory, the region loses about 4 million tons of chernozem annually due to black fallow, which is the most dangerous in terms of erosion. The washout of fertile soil from the arable land area exceeds 24 million tons per year. The washed-away soil contains about 783 thousand tons of humus, 1.24 thousand tons of active substance nitrogen, 2.22 thousand tons of phosphorus and 2.67 thousand tons of potassium.

Solving the issue of increasing the volume of production of plant growing products and the level of its efficiency, while minimizing the negative impact on the environment, does not lose its topicality. In this regard, the important point that requires frofound researches is the study of the effectiveness of applying various tillage systems, the use of which is designed not only to create favourable conditions for obtaining high yields of high-quality plant growing products, but also to protect the soil from erosion.

There are three main systems of tillage such as traditional (plowing), minimal (plowless cultivation with constant loosening of the soil) and No-till (zero tillage).

Plowing is the most effective mechanical measure of weed control. Its use helps to improve the physical properties of the soil (porosity, aeration, water permeability, etc.) and enhance the use of nutrients from the soil. However, on the other hand, plowing is the most resource- and energy-intensive method of tillage, as well as the least effective one from the point of view of protecting soils from erosion.

Market conditions force agricultural producers to reduce production expenditures. In this regard, the scientific researches aimed at developing and implementing various resource- and energy-saving technologies, including soil protection technologies based on the use of minimal and zero tillage, are becoming very topical.

The transition to the system of farming with the use of minimal and zero tillage requires in-depth researches. Based on their results, appropriate recommendations should be formed for production regarding the use of the most effective tillage systems for specific soil and weather-climatic conditions for growing agricultural crops.

Analysis of recent research and publications. The issue of the effectiveness of applying various tillage systems has been studied by such scientists as V.V. Adamchuk [2], V.M. Bulgakov [2], Ya. Gukov [6], V. Kravchuk [3], A.M. Malienko, M. Malyarchuk [4], V.V. Medvedev [5–6], V.T. Nadykto [2], M. Novokhatsky [7], I.A. Pabat [8], D. Primak, V. Pogorily [3], O. Rozhansky [3], V.G. Roshko, V.F. Saiko [9], S.P. Tanchik [2], Z.M. Tomashivsky [10], M.V. Shevchenko [11], L. V. Tsentilo [12], V.S. Tsikov [13], Yu.A. Tsova [14] and others. However, the study of economic and energy efficiency of the use of various (including soil protection) tillage systems in field crop rotation of the zone of the northern Steppe of Ukraine currently remains an urgent issue.

Statement of research purposes. The purpose of this article is to ground the directions for increasing economic and energy efficiency of production of plant growing products based on the use of the most efficient tillage systems.

Statement of the main research material. The assessment of the indicators of economic and energy efficiency of the use of various tillage systems depending on the background of nutrition was based on the use of experimental data obtained based on the results of the researches conducted during 2016–2020 on the basis of the SE “Experimental Farm “Dnipro” of the SE Institute of Grain Crops of NAAS, which is geographically located in the northern Steppe zone of Ukraine. The effectiveness of using three systems of tillage such as moldboard tillage (based on plowing to a depth of 20–22 cm), soil protection moldboardless tillage (based on flat-cut tillage to 12–14 cm) and No-till (zero tillage) has been studied by the program of scientific research of the laboratory of crop rotations and environmental systems of tillage.

The calculations of norms of expenses for the production of plant growing products (winter wheat, spring barley, corn for grain and sunflower seeds) and quantity of energy contained in the economically valuable part of the harvest and the indicators of energy efficiency have been carried out on the basis of composed technological maps of cultivation, as well as the prices for material and technical resources and products which were actual in the second-third quarters of 2020. The calculations have been performed for the natural climate conditions of the Northern Steppe zone of Ukraine with the use of existing methodical recommendations [15–19].

It is proved by science and practice that moldboard tillage creates the most favourable conditions for the growth and development of plants of agricultural crops, in particular winter wheat, which causes the formation of a higher biological level of productivity. The research results have shown that during 2016–2020, the moldboard tillage system in the technology of growing winter wheat, when it is grown on bare fallow against a background without application of fertilizers, not only provided the greatest yield increases in comparison

with the other two systems but also the formation of a higher quality of wheat grain. Thus, due to this factor the maximum level of cost payback (at the level of profitability of 212.7 %), as well as the maximum amount of net income from 1 ha (17.01 thousand UAH/ha) were achieved (table 1).

However, on the other hand, the advantages of a moldboardless tillage system should be acknowledged. They, in comparison with a moldboard system (1074 UAH/ha), involve not only saving 286 UAH of material, monetary and labour expenditures per 1 ha of sowing but also ensuring a higher degree of soil protection efficiency. In the context of solving the problem of loss of soil fertility, this factor can be of priority importance when choosing a tillage system. Moreover, in this variant, against the background without fertilization, cheaper grain has been obtained (1691 UAH/ton) that made it possible to ensure a high level of cost payback with a profitability level of 207.8 %.

Application of the No-till system took place with the use of a mighty plant protection system, which required an increase in production expenses to 8245 UAH/ha. Even with an average yield of 4.41 t/ha (at the level of a moldboardless tillage system), this naturally has led to an increase of unit product cost by 9.5–10.6 % (compared to the other two variants) as well as a decrease in the amount of net income per 1 ha (up to 14.22 thousand UAH/ha) and the level of profitability (up to 172.5 %) in the conditions of formation of low grain quality indicators.

Analysis of the results of growing winter wheat against the background of applying N45P45K45 has showed that the studied background of mineral nutrition

Table 1

Economic efficiency of tillage systems in crop rotation depending on the fertilizer background

Fertilizer background	Tillage system	Yield, tons per 1 ha	Production expenses, UAH per 1 ha	Cost of 1 ton of products, UAH	Net income from 1 ha, UAH	Level of profitability, %
Winter wheat						
Without fertilization	Moldboard	4,68	7995	1708	17006	212,7
	Soil protection moldboardless	4,41	7458	1691	15496	207,8
	No-till	4,41	8245	1870	14220	172,5
$N_{45}P_{45}K_{45}$	Moldboard	5,27	11362	2156	17976	158,2
	Soil protection moldboardless	5,05	10850	2149	17263	159,1
	No-till	4,91	11566	2356	15768	136,3
Sunflower						
Without fertilization	Moldboard	2,53	6530	2581	19410	297,2
	Soil protection moldboardless	2,36	6071	2573	18126	298,5
	No-till	2,24	6950	3103	16017	230,5
$N_{45}P_{45}K_{45}$	Moldboard	3,07	10021	3264	21456	214,1
	Soil protection moldboardless	2,75	9444	3434	18752	198,6
	No-till	2,60	10299	3961	16359	158,8
Spring barley						
Without fertilization	Moldboard	2,43	6530	2687	5062	77,5
	Soil protection moldboardless	2,25	6384	2837	4349	68,1
	No-till	2,12	7190	3392	2922	40,6
$N_{45}P_{45}K_{45}$	Moldboard	2,94	9922	3375	4102	41,3
	Soil protection moldboardless	2,71	9744	3596	3182	32,7
	No-till	2,52	10512	4171	1508	14,3
Corn for grain						
Without fertilization	Moldboard	5,48	8415	1536	17198	204,4
	Soil protection moldboardless	5,07	7937	1565	15760	198,6
	No-till	4,37	8458	1935	11967	141,5
$N_{45}P_{45}K_{45}$	Moldboard	6,55	11894	1816	18721	157,4
	Soil protection moldboardless	6,22	11447	1840	17625	154,0
	No-till	6,09	12188	2001	16277	133,5

made it possible to obtain 3rd class grain regardless of the applied tillage system. At the same time, the highest yield has been formed in the variant with a moldboard system (5.27 t/ha), and the lowest one has been formed when using zero tillage (4.91 t/ha). Only due to this factor, in the variant with the moldboard method of tillage, the maximum amount of net income per hectare of sowing (17.98 thousand UAH) has been obtained. However, due to saving expenses per unit of product at the lowest cost (2149 UAH/t), in the variant where a moldboardless tillage system was used the maximum level of cost payback has been achieved (with profitability of 159.1 %). The use of the No-till system, despite strengthening the system of plant protection measures, has ensured the formation of the lowest level of winter wheat yield (4.91 t/ha), which at the maximum expenditures per 1 ha of sowing (11.57 thousand UAH) caused an increase in the unit product cost by 9.3–9.6 %, a shortfall of 1.50–2.21 thousand UAH of net income per hectare of sowing and a decrease in the level of profitability by 21.9–22.8 percentage points.

According to the results of researches, it has been established that the economic indicators of production of spring barley grain were the best when using the moldboard system on both non-fertilized and fertilized backgrounds where there were obtained the yield of 2.43 and 2.94 t/ha, the cost production of 2687 and 3375 UAH/t, the net income of 5.06 and 4.10 thousand UAH/ha and the profitability level of 77.5 and 41.3 %, respectively. The use of the moldboardless tillage system has led to the shortage of 0.18 and 0.23 tons of grain per 1 ha, 0.71–0.92 thousand UAH/ha of net income and the reduction of profitability to 68.1 and 32.7 %, respectively.

It should be noted that when achieving the goals of protecting soil from erosion and loss of its fertility, the use of a soil protection moldboardless tillage system is the most attractive variant. In this case, the reduction in productivity, income per 1 ha and cost payback is insignificant compared to the variant of applying zero technology with high expenditures of plant protection means. This reduces its value from the point of view of ensuring the ecological purity of soil and products. It should be added that according to the results of the study, the highest income per 1 hectare of sowing and cost payback have been provided by the variants where fertilizers were not used, that obviously connected with their excessively high cost in conditions of disparity in prices for products of agro-industrial complex (AIC).

The study of the effectiveness of the use of various tillage systems has showed that when growing row crops, such as corn for grain, forming the best indicators of productivity, cost of 1 ton, net income per 1 ha and level of profitability was provided by the moldboard tillage system both against the background without fertilizers and when applying nitrogen-phosphorus-potassium fertilizer at a dose of 45 kg a. s. per 1 ha. Thus, on the unfertilized background, when using the moldboard system of tillage, 5.48 t/ha of corn grain and 17.2 thousand UAH/ha of net income were obtained. In the least efficient variant of use of "zero" technology it was obtained 4.37 t/ha of grain and 12.0 thousand UAH/ha of net income at the level of profitability of 204.4 and 141.5%, respectively. At the same time, although fertilizing at a dose of $N_{45}P_{45}K_{45}$ has provided an increase in corn yield to 6.09–6.55 t/ha, it led to increase in the cost of products and decrease in profitability to 133.5–157.4%. The yield growth factor has provided an increase in the amount of net income from 1 ha to 16.3–18.7 thousand UAH/ha.

However, it should be noted that the use of soil protection moldboardless tillage system can be recommended as the variant that provides a competitive level of corn yield (5.07–6.22 t/ha), as well as sufficiently high indicators of the net income per 1 hectare of sowing and the level of profitability (15.8–17.6 thousand UAH/ha and 154.0–198.6%, respectively). In addition, its main advantage is the prevention of losses of soil fertility, which is an extremely relevant issue when growing a low-efficiency row crop, which the corn is in terms of its ability to protect the soil from erosion.

Sunflower cultivation using traditional technology with application of plowing also has showed the best results both in terms of products yield per hectare of sowing and amount of net income, as well as cost payback on both studied fertilizer backgrounds. The worst indicators, as in other similar variants, have been formed in the case of using No-till technology. According to the results of the study, the moldboardless tillage technology have been recognized as the most appropriate one for growing sunflower from the point of view of combining its soil protection ability with economic indicators that were formed at a fairly high level. Thus, when the yield was of 2.36 t/ha against a background without fertilizers and 2.75 t/ha on a fertilized background, the net income has amounted to 18.13 and 18.75 thousand UAH per 1 ha and 2.99 and 1.99 UAH per 1 UAH of production expenditures, respectively.

Analysis of energy efficiency indicators for the use of various tillage systems in crop rotation has shown that in most variants, the products with the lowest level of energy content and the highest coefficient of energy efficiency were obtained using No-till technology (table 2). At the same time, the best indicators have been formed when growing corn which is the most productive crop (1338 MJ/t and 11.95 on an unfertilized background and 1502 MJ/t and 10.65 on a fertilized one, respectively) (table 2). The products with the highest level of energy content of 1 ton and the lowest coefficient of energy efficiency have been obtained in the variants where plowing was used.

Table 2

Energy efficiency of tillage systems in crop rotation depending on the fertilizer background

Fertilizer background	Tillage system	Yield, tons per 1 ha	Total energy consumption per 1 ha, MJ	Energy content of 1 ton of products, MJ	Energy efficiency coefficient	Gross energy increase per 1 ha, GJ
Winter wheat						
Without fertilization	Moldboard	4,68	10291	2199	7,48	66,70
	Soil protection moldboardless	4,41	9545	2164	7,60	63,01
	No-till	4,41	8962	2032	8,10	63,59
$N_{45}P_{45}K_{45}$	Moldboard	5,27	13072	2481	6,63	73,63
	Soil protection moldboardless	5,05	12361	2448	6,72	70,72
	No-till	4,91	11681	2379	6,92	69,10
Sunflower						
Without fertilization	Moldboard	2,53	7128	2817	6,33	37,98
	Soil protection moldboardless	2,36	6430	2724	6,54	35,65
	No-till	2,24	5866	2619	6,81	34,07
$N_{45}P_{45}K_{45}$	Moldboard	3,07	10116	3295	5,41	44,62
	Soil protection moldboardless	2,75	9231	3357	5,31	39,80
	No-till	2,60	8631	3320	5,37	37,73
Spring barley						
Without fertilization	Moldboard	2,43	8210	3379	4,87	31,77
	Soil protection moldboardless	2,25	8018	3564	4,62	29,00
	No-till	2,12	7438	3508	4,69	27,44
$N_{45}P_{45}K_{45}$	Moldboard	2,94	10966	3730	4,41	37,40
	Soil protection moldboardless	2,71	10731	3960	4,15	33,85
	No-till	2,52	10099	4008	4,11	31,36
Corn for grain						
Without fertilization	Moldboard	5,48	7585	1384	11,56	80,07
	Soil protection moldboardless	5,07	6916	1364	11,73	74,18
	No-till	4,37	5848	1338	11,95	64,05
$N_{45}P_{45}K_{45}$	Moldboard	6,55	10513	1605	9,97	94,26
	Soil protection moldboardless	6,22	9889	1590	10,06	89,61
	No-till	6,09	9148	1502	10,65	88,27

The variants where spring barley and sunflower were grown on a fertilized background have become exceptions. Here, the moldboard tillage has shown the advantages with the energy content of 1 ton of products of 3379–3730 and 3295 MJ and the energy efficiency coefficient of 4.41–4.87 and 5.41, respectively.

In the variants where agricultural crops were grown using plowing, the highest level of yield was achieved, so the highest increase in gross energy per 1 ha was obtained here (from 31.77–37.40 GJ for growing spring barley to 80.07–94.26 GJ for growing corn).

The use of a soil protection moldboardless tillage system has contributed to the formation of energy efficiency indicators, which, as a rule, occupied an intermediate position in relation to the other two systems. Thus, the indicators of energy content of 1 ton have ranged from 1364–1590 MJ/t in the cultivation of corn for grain to 3564–3960 MJ/t in the cultivation of spring barley. The energy efficiency coefficient has been 10.06–11.73 and 4.15–4.62, and gross energy increase per 1 ha has been 74.18–89.61 and 29.00–33.85 GJ, respectively.

Conclusions. In general, according to the results of the research, it can be concluded that in the conditions of the northern Steppe of Ukraine, the moldboardless tillage system should be recognized as the recommended tillage system for all the studied crops in the crop rotation. Its use allows saving expenses per 1 ha of sowing and per 1 ton of products and also obtaining close or even higher economic indicators compared to the moldboard tillage system at the profitability level from 32.7–198.6 % against the

background of $N_{45}P_{45}K_{45}$ to 68.1–298.5 % against the background without fertilizers. This system performs a soil protection function and does not cause such pollution of products and soil with pesticides as the No-till system, which, by the way, is the most expensive due to the need to increase the environmentally dangerous chemical load per hectare of crops.

The use of fertilizers in the technology of growing agricultural crops is stipulated not only by the goal of increasing the yield per hectare of sowing but also the need to compensate for the nutrients that plants carry out of the soil. However, amidst disparity in prices for products of AIC, the use of high doses of fertilizers, as a rule, does not pay off with a sufficient increase in the value of products and leads to a decrease in corresponding economic indicators. This trend has been observed in recent years in most of the experiments conducted by the SE Institute of Grain Crops of NAAS, and it indicates the need to take measures for state regulation of relations in the country's agro-industrial complex, including support for domestic agricultural producers.

It was revealed that in most variants, the least energy content of products and the highest coefficient of energy efficiency have been obtained when using No-till technology. At the same time, the largest increase in gross energy per 1 ha has been provided by the use of a moldboard tillage system, which best contributes to the realization of crop yield potential. The use of the soil protection moldboardless tillage system has been contributed to the formation of energy efficiency indicators, which, as a rule, occupied an intermediate position relative to the other two systems. Thus, the coefficient of energy efficiency ranged from 4.15–4.62, when growing spring barley to 10.06–11.73 when growing corn for grain.

The search for the optimal ratio of indicators of economic and energy efficiency defined for different systems of tillage in the natural climatic conditions of the northern Steppe prompted us to make a choice in favour of a soil protection moldboardless system. It allows us to get sufficiently high indicators of productivity and net income per hectare of land, as well as payback of material, money and energy expenses, while achieving the goal of ensuring soil protection from erosion and reducing pollution of soil and products with pesticides. Depending on the weather and climatic conditions and the state of soil moisture availability in the field crop rotation of the northern Steppe of Ukraine, it is expedient to carry out plowing on part of the area (on the noneroded lands with a slope steepness from 0 to 10), and apply differentiated tillage techniques.

The development of effective adaptive technologies in plant growing requires the further research in the direction of optimizing tillage systems, taking into account the perspectives of the transfer of varietal, technical and technological innovations.

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