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Prospects for the introduction of resource-saving technologies in crop production with consideration of ESG factors

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Abstract. This research paper substantiates the relevance and prospects of introducing resource-saving technologies in crop production with consideration of ESG factors, which at the current stage of sustainable development of the crop sector exert socio-environmental and economic influence on the production and economic activities of agricultural enterprises. Several variants of resource-saving technologies are presented, in particular precision farming and no-till, or zero tillage. The article considers and justifies that socio-environmental modernization of agricultural production leads to an increase in the environmental and economic efficiency of crop production and also shapes the financial and economic performance indicators of an agricultural company, including through minimization of negative environmental impacts. A comprehensive system for assessing the innovation and investment performance of ESG-oriented projects is recommended and proposed.

1 Introduction

Sustainable agricultural development is the foundation of a country's economic and food security. It contributes to solving the problems that arise under modern conditions of agricultural functioning. These problems include, first of all, a shortage of qualified specialists, insufficient availability of highly productive machinery, and the underdevelopment of production and social infrastructure. This problematic situation can be addressed through the introduction of resource-saving technologies, including coordinate, or precision, farming technologies and the no-till system of zero soil tillage. At the same time, it should be noted that the implementation of these technologies has changed significantly in recent years. This concerns primarily the initial financing of such technologies, since they are highly expensive and often represent an unaffordable financial burden for managers of agricultural enterprises. According to expert assessments in the field of advanced resource-saving technologies, by 2030 the global market for advanced technologies is forecast to attract financial investments of approximately USD 45 billion. Agrodrones play a key role in precision farming systems and have a decisive influence on the efficiency of these technologies. Accordingly, agrodrones, also known as unmanned aerial vehicles (UAVs), are

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playing an increasingly important role in precision agriculture, helping agricultural professionals lead the implementation of sustainable farming methods while protecting and increasing economic efficiency [3, 8].

At the initial stage of implementing precision farming systems and other resource-saving technologies in agricultural enterprises, taking into account the scale and timing of the introduction of each system element of precision farming, it is necessary to conduct a comprehensive analytical assessment of an agricultural economic entity. This primarily concerns agronomic and production-economic assessment, while soil and climate analysis of the enterprise is also of considerable importance. When implementing a precision farming system, step-by-step actions are necessary. Each technological element should be analyzed separately, since simultaneous implementation of the entire system is unreasonable and irrational; it would be expensive and economically unjustified [6].

When studying resource-saving technologies in agricultural production, many scholars and specialists have identified the following trend: the introduction of a soil-protective farming system based on soil-saving and energy-resource-saving agriculture through the zero tillage of arable soil, including biological farming, or no-till. This system represents an environmental and economic model of modern crop production with consideration of the principles of ESG transformation. The use of no-till is relevant and effective in arid regions of the country where steppe zones with insufficient moisture in the arable soil layer predominate [1, 2].

In view of the above, the relevance of the research topic lies in the fact that the use of global positioning system technologies together with geographic information system tools forms a significant part of precision farming methods. These tools allow monitoring and mapping of yield data and crop parameters in fields. They provide more intensive and efficient cultivation methods that can help farmers adjust fertilizer prescriptions or identify crop diseases before they become widespread. With more data at their disposal, farmers can make decisions based on economic and environmental factors. For example, by optimizing fertilizer treatment and applying only the required amount of fertilizer at the proper time, significant financial and environmental savings can be achieved [9].

The use of drones in agriculture is steadily growing as part of an effective approach to sustainable agricultural management, enabling agronomists, agricultural engineers, and farmers to optimize their operations by using reliable data analytics to gain effective insight into their crops.

UAVs are especially useful for thorough monitoring of large areas of agricultural land, taking into account factors such as slope and elevation, for example, to determine the most suitable seeding prescriptions [3].

It is important to note that high-resolution drone data can be used to assess crop fertility, allowing agricultural specialists to apply fertilizers more accurately, reduce losses, and plan and troubleshoot irrigation systems. This technology can also be particularly effective after natural disasters such as floods, helping farmers assess damage in areas that may be difficult to access on foot [3].

Under modern conditions of agricultural transformation under the influence of the global ESG agenda, the sustainable development of agricultural enterprises is becoming not only an environmental but also an economic necessity. Crop production, as one of the basic branches of agriculture, directly depends on natural and climatic conditions, regional differences across the country, combinations of natural and soil-related factors, and enterprise resources, primarily land, water, and energy. This determines the special importance of the environmental component (E) in the ESG structure. Increasing requirements for non-financial reporting, the development of green investment instruments, and growing investor attention to the sustainability of business models are forming new criteria for the competitiveness of agricultural enterprises. In this context, the introduction of innovative resource-saving technologies is of particular importance and relevance for crop production [5].

At the same time, contradictions persist between the need for environmental modernization and the concerns of economic entities regarding the growth of capital expenditures. Enterprise managers often perceive investments in resource-saving technologies as an additional financial burden that is not always clearly connected with profit growth. However, modern scientific discussion and practice show that the environmental transformation of production can generate both a direct economic effect, expressed in the reduction of production costs, and an indirect effect through an improved ESG rating and better financing conditions [5].

Taking the above into account, the purpose of the study is to identify and substantiate the prospects for introducing resource-saving technologies in crop production with consideration of ESG factors. These factors have an effective impact both on the production of crop products and on the environmental and soil environment, and they also act as a stabilizing factor in the economy of agricultural enterprises in the country's agro-industrial complex.

2 Materials and methods

The article is based on theoretical and informational materials that rely on the concept of sustainable development and the integration of ESG criteria into the strategic management system of an enterprise. Particular attention was given to the analytical meta-study conducted by G. Friede, T. Busch, and A. Bassen, which identified the relationship between ESG criteria of companies operating in the agricultural sector and their financial and economic indicators. This study, which combined the results of more than two thousand studies, determined that there is a positive relationship between corporate social responsibility and the financial and economic performance of enterprises operating not only in the agricultural sector but also in other branches of the national economy [5].

The following research methods were used: economic analysis, statistical and economic analysis, and calculation-constructive analysis. All calculations, table and graph construction, and analytical procedures were performed using Microsoft Office Excel.

3 Research results

Resource-saving technologies in crop production, such as precision farming, digital monitoring of soil and crop conditions, variable-rate fertilizer application, and fuel consumption control systems, are directly related to the environmental component of ESG. Their use makes it possible to reduce the chemical load on soil, optimize water consumption, reduce greenhouse gas emissions, and increase the transparency of production processes. Resource- and energy-saving technologies contribute to the sustainable development of agriculture, including crop production, with consideration of the principles of ESG transformation of agribusiness [8].

The central elements of resource saving are economics, engineering, technology, and ecology, since a resource-saving approach involves implementation of a whole set of tasks covering these four areas of knowledge (Fig. 1).

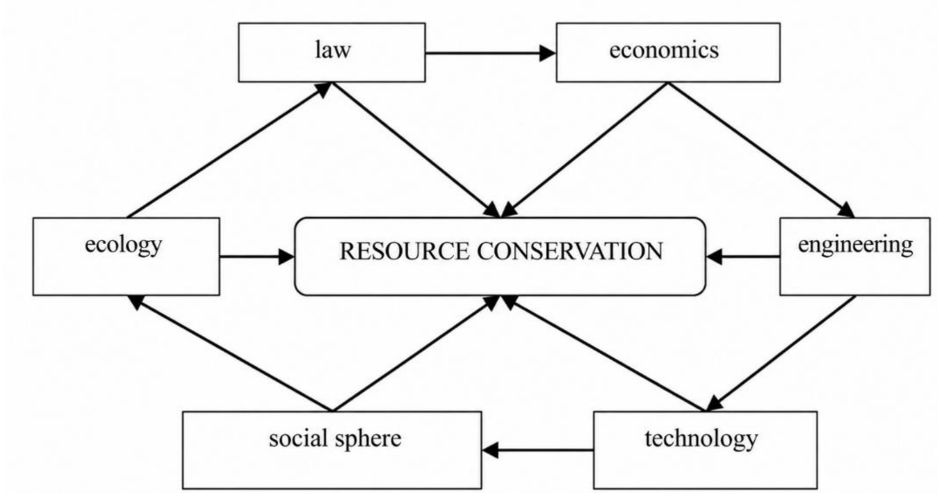

Fig. 1. Main components of resource-saving development in the agro-industrial complex.

Innovative resource-saving technologies are a major factor in the economic development of the agro-industrial complex (Fig. 2).

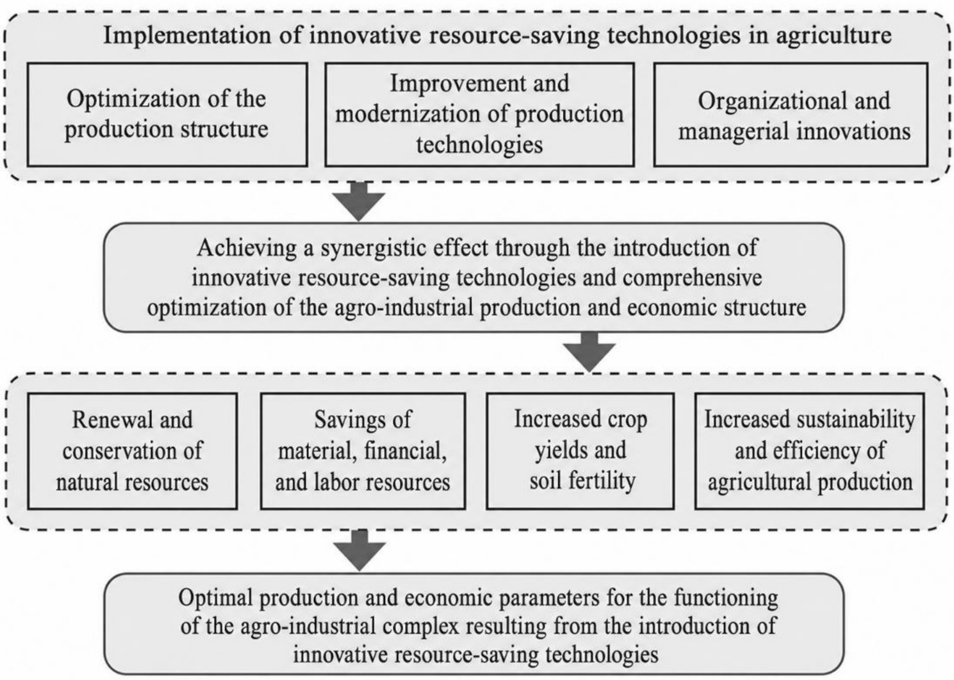

Fig. 2. Innovative resource-saving technologies as a factor in the economic development of agricultural enterprises.

Sustainable development is a systemic and comprehensive concept that affects all stages of activity of a producer-entrepreneur in the process of production and economic participation in the sphere of agricultural production and sales [7]. ESG principles are a systematized set of rules based on this concept of sustainable development. Compliance with these principles in the sphere of agricultural production and sales inevitably affects the sustainable development of any branch of the agro-industrial complex. Without this principle, effective functioning of any economic entity in the economic system is impossible. Figure 3, “Principles of Sustainable Development - ESG”, presents ESG principles for the sustainable development of any economic entity depending on its production activities [5, 6].

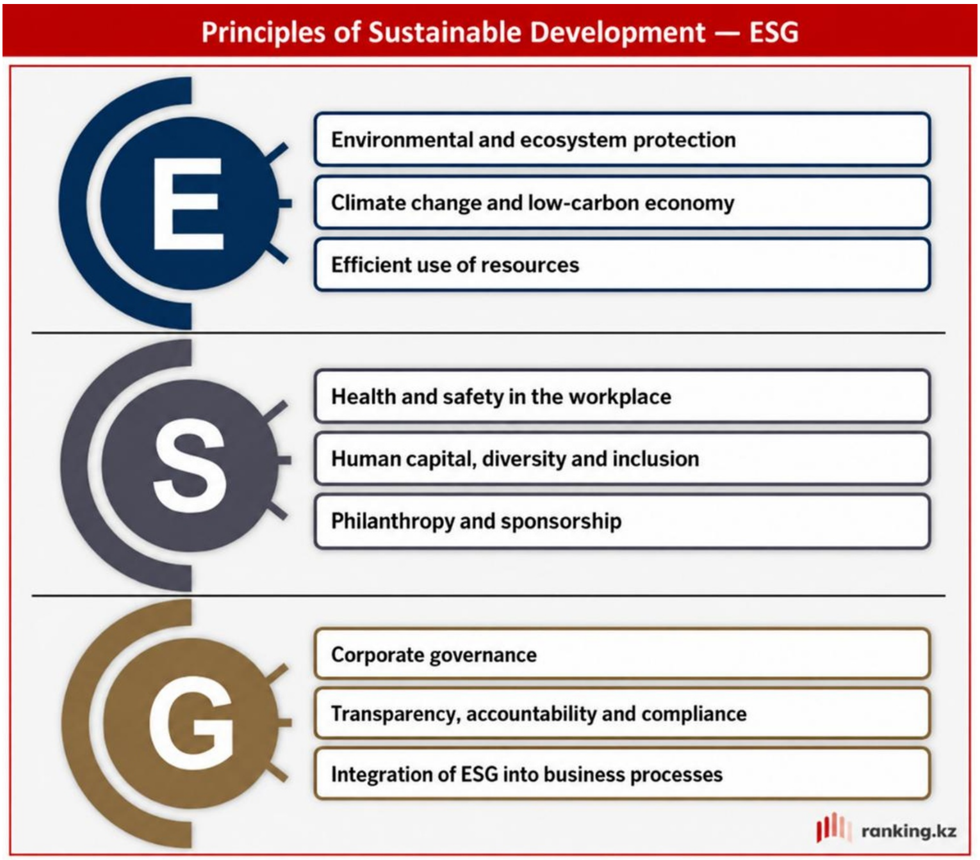

Fig. 3. Principles of sustainable development - ESG in the areas of activity of an economic entity [9].

It is necessary to take into account that not all principles can be applied simultaneously. For the agricultural sector, the principle of environmental friendliness plays a special role, whereby human activity must take into account its impact on the environment, ecological systems of fauna and flora populations, and the arable soil layer. Sustainable development, ESG factors, and economic efficiency are closely interconnected and interdependent in the production of material goods and provision of services. Thus, not only an environmental effect but also a managerial effect is achieved, since digitalization strengthens control and reporting, which has a positive influence on the governance component (G) [9].

At present, resource-saving technologies in the form of precision farming systems in crop production are among the most important foundations for increasing the productivity of agricultural land, increasing crop yields, and reducing the costs of crop production, which ultimately affects the economic efficiency of agricultural production. A detailed analysis of the precision farming system makes it possible to identify the following areas: geographic information systems (GIS), sensor systems for vegetation and soil fertility, robotic and automated systems for driving machinery and equipment, UAV technologies, parallel driving systems, systems for optimizing, monitoring, and regulating the seeding rate of seeds and planting material, variable-rate application of mineral fertilizers, and spraying of chemicals against diseases, weeds, and insect pests. These areas of precision farming make it possible to increase crop yields, gross output, reduce costs, and improve the efficiency of crop production through optimal and rational use of enterprise resources. The economic efficiency of using precision farming technology is confirmed by the following indicators: labor productivity increases by 3–4 times, while cost savings amount to 20–30% [10].

For a more accurate description and visual representation of the economic efficiency of introducing coordinate, or precision, farming systems, key indicators are presented in Table 1.

Table 1. Indicators of economic efficiency of introducing a precision farming system in selected regions of the Central Federal District.

Technology	Region	Indicator	Economic effect
GIS system	Lipetsk Oblast	Rational use of agricultural land	Reduction in mineral fertilizer application costs by 15–30%
UAV technologies	Voronezh Oblast	Mapping of soil and vegetation in fields	Yield increase of up to 10%
Parallel driving system	Oryol Oblast	Robotization and automation of machinery and equipment in fields	Fuel and lubricant reduction of up to 20%
Variable-rate fertilizer application	Tula Oblast	Dosed and coordinate-based application of mineral fertilizers on sown areas	Mineral fertilizer savings of 20–30%
Yield control system	Belgorod Oblast	Monitoring and operational response system for low-productivity zones of sown land and their elimination	Increase in crop yield and gross crop output by 10–15%
Robotic land reclamation works	Kursk Oblast	Automation of processes in soil reclamation	Cost efficiency and effectiveness of land reclamation works

The indicators presented in the table demonstrate that the precision farming system has substantial potential for increasing production profitability by reducing resource use costs while improving the ecological state of the environment and soil through the reduction of harmful waste, toxic substance emissions, and greenhouse gas concentrations in the air.

For a more accurate and detailed analysis of the results obtained, the economic effects of introducing resource-saving technologies should be divided into direct and indirect effects. Direct effects include lower costs for material resources, fuel, and agrochemicals, as well as yield growth resulting from more accurate compliance with agricultural technologies. Indirect effects are manifested through increased investment attractiveness of the enterprise, the possibility of attracting green loans and subsidies, improved market reputation, and strengthened positions in sustainable development ratings. Companies with a higher ESG rating, as a rule, demonstrate more stable financial indicators and gain access to capital on more favorable terms [1, 2].

For comprehensive assessment, it is proposed to use an integral efficiency indicator that takes into account the totality of direct and indirect results. The economic efficiency of technology implementation can be expressed as the ratio of the total effect to the investment volume. In this case, the direct effect is defined as the sum of cost savings and revenue growth, while the indirect effect is defined as the financial benefit from an improved ESG rating, for example through a reduction in the interest rate on borrowed capital. This approach makes it possible to go beyond traditional investment project analysis and take into account the institutional advantages of sustainable development [2].

Public data from Avangard-Agro Group, one of the largest agricultural holdings in Russia, were used as the empirical basis. The holding carries out crop production activities on an area of more than 450 thousand hectares. Its main production activity is crop production, primarily the production of grain and leguminous crops. It should also be noted that the holding includes more than 52 agricultural enterprises located in Voronezh, Belgorod, Kursk, Lipetsk, Oryol, and Tula oblasts. The company's annual production reports and industry reviews note the active introduction of elements of coordinate, or precision, farming: GPS navigation, parallel driving systems, variable-rate fertilizer application, and digital field monitoring. Based on open indicators of production costs and cost structure, an economic assessment of the implementation of these technologies was modeled for a production cluster of 5,000 hectares, comparable to an individual division of the holding. The agricultural company adheres to advanced resource- and energy-saving technologies aimed at minimizing production costs, increasing land productivity, improving crop yields and quality, and biologizing and ecologizing soil processes during the application of mineral and organic fertilizers. In addition, green manure practices are used as cover crops for soil improvement, contributing to an environmentally balanced approach for the environmental and soil environment in crop production.

Taking into account the identified characteristics of the holding and the regions in which Avangard-Agro Group operates, an ESG-oriented investment model was calculated and substantiated. The calculation model showed that investments in digitalization amounting to approximately 30 million rubles, including equipment, software, and training, provide a reduction in fertilizer costs by approximately 10–12%, which in monetary terms amounts to about 6 million rubles per year. Optimization of machinery logistics and reduction of overlaps during field operations additionally reduce fuel costs by 2 million rubles. Yield growth of 4–5% due to more precise management of agricultural technologies generates additional revenue of approximately 8 million rubles. The total direct economic effect reaches 16 million rubles annually [6].

For an accurate and correct analytical assessment of the production and economic activities of the agricultural holding, it is necessary to apply a methodology for comprehensive systemic assessment of the financial and economic indicators of the economic entity.

The sustainable development factor was additionally taken into account. For large agricultural holdings, including Avangard-Agro, this factor is reflected in ESG ratings and financing conditions. With a reduction in the cost of borrowed capital by 1.5 percentage points on an investment loan of 100 million rubles, annual savings in interest expenses amount to approximately 1.5 million rubles. Thus, the total effect reaches 17.5 million rubles, and the integral efficiency of the project is approximately 58% of initial investments:

$$\mathbf{ROI = Total\ annual\ economic\ effect\ /\ Investment\ volume \times 100}$$

$$\mathbf{ROI = (16.5 + 1.5)\ /\ 30 \times 100 = 58.3\%}$$

Table 2. Calculation of the annual economic effect of introducing elements of precision farming.

Indicator	Value	Economic effect, million rubles
Reduction in fertilizer consumption	10–12%	6.0
Reduction in fuel consumption	8%	2.0
Yield growth	4–5%	8.0
Total direct effect	-	16.0
Savings in interest expenses	−1.5 percentage points	1.5
Total economic effect	-	17.5
Investment volume	-	30.0
Efficiency, ROI	-	58.3%

The obtained results, based on public reporting of the agricultural holding and calculation-based adaptation to a farm area of more than 5,000 hectares, confirm the high economic feasibility of introducing precision farming technologies and their contribution to improving both operational and financial sustainability of agribusiness. In general, the table data allow the conclusion that there is a positive dynamic in economic efficiency indicators for the introduction of resource- and energy-saving technologies, in this case precision farming, with consideration of ESG factors.

At the beginning of the study, in addition to precision farming technology, another resource-saving technology was considered: zero tillage of the arable soil layer, or no-till. This technology places special emphasis on optimization of production and technological processes, which affects controllability, predictability, and environmental and economic efficiency of crop production.

In the traditional organization and management of agriculture, obtaining high crop yields depends by 80% on natural and climatic conditions. The introduction of the no-till system reduces this indicator to 20%, which means that the remaining 80% become dependent on and manageable through this technology.

In grain-producing farms in the eastern part of Rostov Oblast, which is a steppe zone with insufficient moisture, an analytical assessment of the introduction and functioning of zero tillage of the arable soil layer was conducted. The analytical assessment compared the environmental and economic efficiency indicators of traditional crop cultivation technology for grain crops and the resource-saving technology of zero tillage, or no-till. The introduction of soil-protective resource- and energy-saving technology helps reduce wind erosion of soils, which often occurs in the steppe zone of Rostov Oblast [7]. In particular, reducing wind erosion in the eastern part of Rostov Oblast is one of the most important areas in the farming system for increasing soil fertility, which contributes to higher crop yields, improvement of the ecological situation in this steppe zone, and creation of a more favorable environmental and soil environment for scientifically based farming systems and effective crop rotation under the current conditions formed by the introduction of resource-saving technologies. Taking this into account, the following groups of farms were analyzed: LLC Agricultural Enterprise Raduga, LLC Tyulpany, LLC Agro-Lider, and Agricultural Production Cooperative Kolos. The study obtained the following economic efficiency indicators (Table 3).

Table 3. Economic indicators of introducing zero tillage technology, no-till, in grain-producing farms in the eastern part of Rostov Oblast.

Indicator	**LLC Agricultural Enterprise Raduga, traditional technology**	**LLC Agricultural Enterprise Raduga, no-till**	**LLC Tyulpany, traditional technology**	**LLC Tyulpany, no-till**	**LLC Agro-Lider, traditional technology**	**LLC Agro-Lider, no-till**	**APC Kolos, traditional technology**	**APC Kolos, no-till**
Grain crop sown area, ha	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Yield, centners /ha	35	46	32	43	33	44	31	45

Continuation of Table 3.

Indicator	**LLC Agricultural Enterprise Raduga, traditional technology**	**LLC Agricultural Enterprise Raduga, no-till**	**LLC Tyulpany, traditional technology**	**LLC Tyulpany, no-till**	**LLC Agro-Lider, traditional technology**	**LLC Agro-Lider, no-till**	**APC Kolos, traditional technology**	**APC Kolos, no-till**
Gross grain harvest, tons	17,500	23,000	16,000	21,500	16,500	22,000	15,500	22,500
Grain production cost, rubles/ton	8,620	7,650	8,450	6,750	8,750	7,750	8,850	7,650
Grain selling price, rubles/ton	12,580	12,600	12,580	12,600	12,580	12,600	12,580	12,600
Cost of grain sales, rubles/ton	9,850	8,900	9,650	8,560	9,870	8,950	9,880	8,740
Grain sales volume, tons	14,000	18,400	12,800	17,200	13,200	17,600	12,400	18,000
Marketable output, revenue, million rubles	176.120	231.840	161.024	216.720	166.056	221.760	155.992	226.800
Cost of sales, million rubles	137.900	163.760	123.520	147.232	130.284	157.520	122.512	157.320
Profit, million rubles	38.220	68.080	37.504	69.488	35.772	64.240	33.480	69.480
Grain profitability, %	27.7	41.6	30.4	47.2	27.5	40.8	27.3	44.2

The conducted analysis, comparing traditional technology and resource-saving technology in grain-producing farms in the eastern part of Rostov Oblast, showed that the performance indicators of these technologies differ significantly. For example, the cost of production and sale of 1 ton of grain decreased by almost 11%, profit from grain production increased by 43%, and the relative indicator of grain profitability increased by 33%, while the grain sales volume amounted to 80% of the produced grain, or gross grain harvest.

It is also necessary to determine the environmental and economic aspects of introducing the resource-saving technology of zero tillage of the arable soil layer, or no-till. These aspects are presented in Fig. 4.

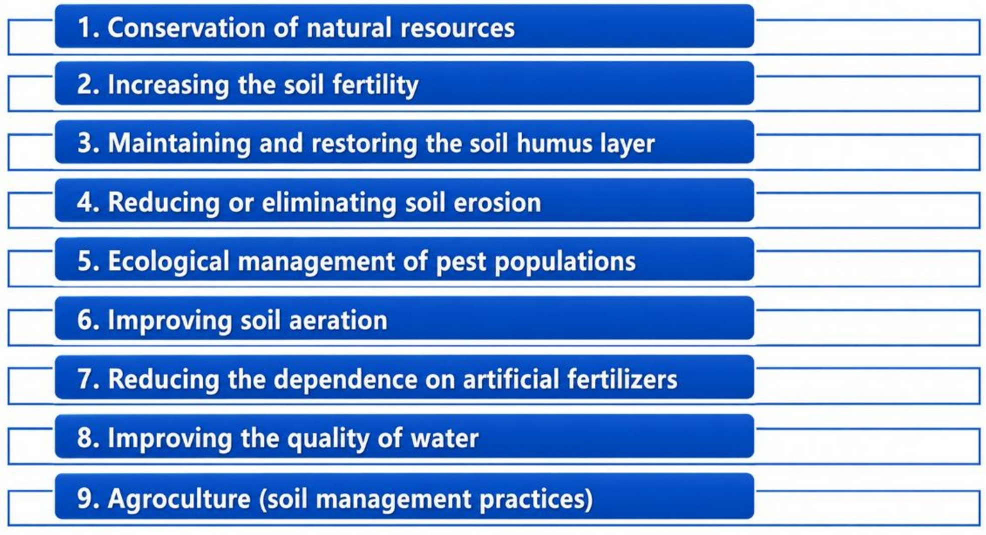

Fig. 4. Main advantages of introducing no-till as a resource-saving technology in crop production.

The introduction of zero tillage technology, or no-till, helps reduce investment expenditures and depreciation per hectare, as well as per unit of crop production. It also provides savings in current production costs for future years. The use of this technology makes it possible to significantly reduce technological logistics costs, thus combining environmental and economic advantages in the process of crop production [10].

4 Discussion

The obtained research results indicate that consideration of the ESG factor strengthens the overall investment attractiveness of resource-saving projects. If only direct savings are considered, efficiency would amount to 53%; however, inclusion of indirect benefits increases the final indicator. This confirms the hypothesis of the dual nature of the effect of sustainable modernization: environmental transformation can generate financial returns both through operational activity and through institutional mechanisms of the capital market. Taking into account the influence of ESG factors on the sustainable development of crop production in agricultural enterprises of the agrarian sector creates long-term stability for economic entities, reduces external and internal risks, and attracts private investors to finance ESG-oriented projects in the production of crop products. Under conditions of increasing demand for crop products on the global food market, the introduction of resource-saving technologies in crop production is an especially relevant and significant factor for increasing crop output [9].

The introduction of resource- and energy-saving technologies in farming during crop production is a kind of financial and economic model for the crop sector, combining two highly important systems: ecology and economics. As a result of the introduction of the soil-protective no-till farming system, savings are achieved not only in investment costs and depreciation charges per hectare of land and per centner of crop production, but also through the minimization of current production costs for many years ahead. It may be stated that this is the future foundation for the sustainable development not only of crop production but also of the entire agriculture of the country, taking into account the principles of ESG factors [9, 10].

5 Conclusion

Thus, the introduction of resource-saving technologies in crop production should be considered not as a forced measure dictated by environmental requirements, but as a strategic tool for increasing the competitiveness and financial sustainability of an agricultural enterprise. An improved ESG rating acts as an additional driver of economic growth by reducing the cost of capital and strengthening the enterprise's position in the market. The practical significance of the study lies in the possibility of applying the proposed integral approach when substantiating investment decisions in agribusiness. Under conditions of intensifying ESG transformation, it is the synergy of technological innovation and sustainable management principles that becomes the foundation for the long-term development of crop production.

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