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Relevance and prospects of precision agro-technology development in the context of sustainable agriculture

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Abstract. The article considers the relevance of the development of precision agro-technologies at the present stage of agricultural development. The problems of traditional farming leading to soil degradation, lower production efficiency and negative impact on the environment are analyzed. Alternative approaches such as biological and sustainable farming are considered and their limitations in ensuring food security are shown. The importance of precision agro-technologies based on differentiated management of agro-systems taking into account their heterogeneity is emphasized, which allows optimizing the use of resources and reducing the negative impact on the environment. The results of experimental work demonstrating the savings of fertilizers and pesticides in the application of precision agriculture, as well as the increase in the accuracy of technological operations are presented. The necessity of developing a new economic strategy for agriculture, stimulating the introduction of innovative technologies and ensuring the sustainability of the agricultural sector is substantiated. The aim of the work is to substantiate the need for an integrated approach to agricultural development, taking into account technological, economic, social and environmental aspects, as well as the role of the state in supporting innovation.

1 Introduction

In today's world, agriculture, being the cornerstone of human civilization, faces a growing set of challenges that call into question its sustainable development and ability to meet the needs of an ever-growing world population. Global food security, which once seemed inviolable, is now threatened by a number of interrelated factors, including soil degradation [1-3], declining efficiency of traditional agricultural practices, and worsening global environmental problems [4, 5]. Intensive, often irrational exploitation of land resources, with an emphasis on extensive farming, as well as unjustified massive use of chemical fertilizers and pesticides, have led to irreversible processes of soil depletion, loss of soil fertility, disturbance of biodiversity and ecological balance in general. These negative trends have a direct impact on crop yields, which in a number of regions show an alarming downward trend, which, in turn, seriously jeopardizes the food security of entire countries and continents. The ever-growing world population, on the one hand, requires more and more food, and on the other hand, puts additional pressure on the agricultural sector, which has to work under the conditions of deteriorating environmental situation and decreasing available land resources [6-8]. All these factors together put before the world agricultural community the task of searching for fundamentally new approaches and development strategies that can ensure sustainable and environmentally safe food production in the long term.

In search of a solution to such a complex and multifaceted problem, mankind turns to various alternative approaches and technologies that lie in the plane of transition to more sustainable, resource-saving and environmentally friendly methods of farming. One of such approaches is biological farming, which is based on the principles of minimizing the use of anthropogenic energy, reducing dependence on synthetic fertilizers and pesticides, and preserving the ecological balance of agroecosystems [9, 10]. This approach implies the use of organic fertilizers, crop rotations, biological methods of pest and plant disease control. However, despite its attractiveness in terms of environmental sustainability, practice shows that this method, unfortunately, cannot fully meet the food needs of the growing world population. The reasons lie in the higher cost of the final products, which, as a rule, are unaffordable for the majority of consumers, as well as in the lack of effectiveness of biological methods of plant protection against weeds and diseases, which can lead to significant crop losses. As an alternative to organic farming, the concept of sustainable farming, which is a more comprehensive and integrated approach, is gaining attention. Sustainable farming involves not only the use of biological methods, but also combining them with

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other advanced technologies such as minimum tillage, crop rotation optimization, precision farming, and freshwater conservation. This concept focuses on preserving and improving soil fertility, minimizing the negative impact of agriculture on the environment, and improving the economic performance of agricultural production. Nevertheless, the implementation of the concept of sustainable agriculture requires significant efforts and investments, as well as the development of comprehensive programs and regulatory framework that would facilitate its wide implementation in practice. Another very promising and promising direction in the development of modern agriculture is precision agro-technology, which is an integrated approach to the management of agro-systems based on targeted and differentiated impact on them, taking into account their individual characteristics and features. Precision farming is based on the principle of taking into account the heterogeneity of soil cover, phytosanitary condition of crops and other factors affecting the yield and quality of agricultural products. These technologies allow optimizing the application of fertilizers, plant protection products, as well as seed, thereby reducing their negative impact on the environment, reducing production costs, and increasing the economic efficiency of agricultural production. However, the effective implementation of precision technologies requires the development and implementation of special equipment and software [11-13], as well as in-depth study of specific agroecosystems and processes occurring in them.

In the context of the above and taking into account the analysis of advantages and disadvantages of various approaches, the direction of precision agro-technologies seems to be the most relevant and important for solving a set of problems facing modern agriculture. This approach opens new opportunities for increasing crop yields, reducing the ecological load on the environment [14, 15], as well as optimizing the use of natural and economic resources [16]. The introduction of precision technologies facilitates the transition to resource-efficient and sustainable agriculture, which is a key factor for ensuring food security, preserving the environment for future generations, as well as for increasing the competitiveness of the agricultural sector. This approach allows for differentiated management of agro-ecosystems, which leads to a more efficient and rational use of resources, higher yields, lower production costs, and reduced negative impact on the environment. However, it should be noted that the development and implementation of such technologies in the practical activities of the agricultural sector requires a detailed study and comprehensive analysis of specific agroecosystems, taking into account regional characteristics [17, 18], as well as the creation of appropriate infrastructure and support system for farmers and other agricultural producers.

The purpose of the work presented in this file is to comprehensively analyze the relevance of the development of precision agro-technologies at the current stage of agricultural development, as well as to discuss the importance of developing a new economic strategy for farming, which would stimulate the introduction of innovative agro-technologies and ensure the economic sustainability of the agricultural sector. This study will also address the problem of the need for an integrated approach to agricultural development, which takes into account not only technological, but also economic, social and environmental aspects [19], as well as the role of the state in supporting and stimulating the innovative development of the agricultural sector.

2 Method and materials

In the article, a number of experimental works aimed at studying and applying precision farming technologies were carried out. The overall work plan included field trials at a stationary site equipped with modern agricultural machinery and software.

John Keer 6920 tractor with a set of narrow wheels and MTZ-1221 tractor were used during the research. To apply mineral fertilizers we used spreader ZAM 900 with Troni system, which allowed to dose fertilizers, taking into account soil heterogeneity. Spraying was carried out by sprayer UF-901 with a capacity of 1050 liters and working width of 15 m, which provided uniform distribution of working solutions. Seed sowing was carried out with K 9-30 Superc and KMC seed drills, the latter of which was used for direct sowing. For potato planting a CF34 KL4 potato planter was used. Harvesting was carried out by SAMPO 2010 combine harvester with 1.5 m cutterbar and potato harvester. For tillage, vertical milling harrow KE-303, disk harrows Catros 3001 and Pegasus SG 3002 were used, as well as comb-former GF-75-4 and Eur Opal 7 plow.

The equipment operated in different modes corresponding to the agronomic operations performed. Fertilizer spreader and sprayer used automated systems for differentiated application of materials based on soil fertility maps. Seed drills operated at preset seeding rates and seed placement depths. All tillage equipment ensured the fulfillment of technological operations in accordance with the set parameters. In addition, the "Autopilot" system for John Keer tractor was used, providing 2-3 cm positioning accuracy, as well as IN liquid application control system. The Insight system was used for yield mapping and the FRITZMEIER PRKFT 90 soil sampler was used for soil sampling. The RT 200 N and Sensor ALS systems were used for differential fertilizer application. SMS Advanceed software was used for field data collection, storage and processing.

3 Results and discussion

This work was carried out to investigate in detail the possibilities and benefits of introducing precision farming technologies in the context of a training farm. The study was designed as a long-term field experiment conducted at a fixed site that was specially equipped for precision farming. The site was equipped with a variety of agricultural machinery including tractors, fertilizer spreaders, sprayers, seeders, harvesting equipment, and tillage equipment. All machines were equipped with automated control and monitoring systems, including GPS navigation, sensors to monitor material application, and yield mapping systems.

The process of conducting experimental work within the framework of precision farming technology research included several consecutive stages, starting with the preparatory phase and ending with the analysis of the results obtained. The initial phase involved a thorough analysis of the characteristics of the experimental site, including soil properties, topography and history of land use. This involved grid soil sampling, which was then analyzed in the laboratory for major nutrients, trace elements, organic matter, and acidity. The data obtained were used to create detailed soil fertility maps, which in turn served as a basis for planning differential fertilizer application.

Next, the selection of crops to be used in the experiment was carried out. Local agro-climatic conditions and economic feasibility were taken into account. The scheme of the experiment was developed, including different variants of soil treatment, fertilizer application and plant protection products. To ensure the accuracy of technological operations, modern agricultural equipment equipped with GPS-navigation and automatic control systems was used. In the process of sowing, fertilizer application and tillage, all necessary parameters, including seeding rates, fertilizer and pesticide application doses, working speed, working width and tillage depth, were recorded with the help of sensors and control systems.

During the vegetation stage, regular monitoring of crop condition was carried out, including assessment of plant stand density, phytosanitary condition and weed infestation. Both visual method and automatic weed detection systems were used to assess weediness. Based on the data obtained, decisions were made on the need for herbicide treatment, and treatment was carried out differentially, only in those areas where a high degree of weediness was observed. During the growing season, soil moisture and temperature were also monitored to assess the impact of different tillage methods on water and heat regimes.

After reaching the phase of full maturity, harvesting was carried out. Modern harvesting equipment equipped with yield mapping systems was used to assess the yield and quality of the harvested products. During the harvesting process, data on harvested crop weight, moisture content, protein content, oil content and other important indicators were recorded. After harvesting was completed, the data were analyzed, including statistical processing of results, graphical representation and trend analysis. The obtained conclusions served as a basis for assessing the efficiency of different variants of precision farming technology and their economic justification.

Visual method was used to control weediness of crops, as well as automatic weed detection systems installed on sprayers. Based on the data obtained, differentiated herbicide application was carried out, and only those areas of the field with high weed infestation were treated. The comparison of tillage methods included conventional plowing and direct seeding on stubble. In direct seeding, crop residues remained on the soil surface, creating a mulch layer that helped to reduce erosion and conserve moisture.

This paper demonstrates that the use of precision farming systems leads to a significant reduction in resource consumption while increasing or maintaining yields. The use of differentiated application of fertilizers and pesticides reduced their consumption by 25-30%. Similar works conducted by other authors show that the reduction in fertilizer consumption when using precision agriculture varies from 15% to 35%, depending on the type of soil, climate and type of crop grown. For example, in studies conducted in Canada on corn crops, it was shown that using differential nitrogen application, nitrogen use can be reduced by 22% while maintaining yields at the same level. At the same time, in studies conducted in Australia on cereal crops, it was shown that phosphate fertilizer consumption can be reduced by up to 30%, while yields increase by 5-7% due to more efficient distribution of nutrients in the soil.

The results of the study conducted by the authors showed a 25-30% reduction in pesticide consumption. These indicators are also confirmed by other researchers. In particular, studies in European countries have shown an average 25-30% reduction in herbicide consumption when using precision farming, which is associated with more accurate application of preparations and the use of technology for recognizing weeds. In studies conducted in the USA, it was shown that the use of precision farming technologies in cotton cultivation reduces the amount of necessary pesticide treatment by 33%, which leads not only to a reduction in pesticide costs, but also to a reduction in the negative impact on the environment.

The results of this work have shown that the use of precision farming leads to an increase in the accuracy of technological operations. In particular, the use of GPS navigation and parallel guidance systems allowed reducing the width of adjacent rows to 2.5-3.5 cm, compared to 5-7 cm when using traditional markers. According to the study, the use of parallel guidance and GPS systems can increase the accuracy of tillage and seeding by 30-40%, which reduces the number of skips and overlaps, and allows for more efficient use of resources.

Analysis of the results shows that precision farming technology is not only economically efficient, but also has significant environmental potential. Reduced consumption of fertilizers and pesticides leads to reduced soil and water pollution, and the use of zero-tillage technology helps to reduce erosion and improve fertility. Comparing these data with other studies, there is a growing body of scientific work supporting the importance of precision farming practices for sustainable agriculture. In a study conducted in Brazil, it was shown that the use of precision farming reduces greenhouse gas emissions from soil by 15-20% by conserving organic matter and reducing energy inputs for tillage.

At the same time, for effective implementation of precision farming technologies it is necessary to take into account local peculiarities and adapt them to specific agro-ecosystems. In particular, it is necessary to revise traditional views on weed infestation of crops and develop integrated plant protection systems that do not lead to mass death of weeds and use biological control methods. Studies have shown that using the principles of agroecology and integrated plant protection not only reduces dependence on pesticides, but also improves the biodiversity of agroecosystems, which, in turn, has a positive impact on their sustainability and productivity.

4 Conclusion

The conducted research emphasizes that the introduction of precision agro-technologies is a relevant direction for solving the problems of modern agriculture. Traditional methods have led to soil depletion and negative impact on the environment, which requires a transition to sustainable and resource-saving approaches.

The results show that precision farming can reduce the use of resources (fertilizers, pesticides) while maintaining or increasing yields. Differentiated application based on soil and crop data increases resource efficiency and reduces environmental impact. GPS and parallel driving systems improve operational accuracy, reducing overlaps and saving resources.

The no-till method reduces erosion, improves soil structure and fertility, but requires control of the phytosanitary condition of crops.

Precision farming is promising but requires specialized equipment, software, agroecosystem studies and economic incentives.

Technology adoption is not the only solution; a comprehensive approach that takes into account economic, social and environmental aspects is needed. There is a need for a new economic strategy that stimulates innovation and ensures the sustainability of agriculture with the support of the state.

Thus, the findings emphasize the importance of the transition to precision agriculture for sustainable agricultural development, food security and environmental conservation.

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