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THE ECONOMIC IMPACT OF PLANT PROTECTION PRODUCT UTILIZATION STRATEGIES IN AGRICULTURE

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Annotation: This article analyzes the economic effectiveness and ecological impact of plant protection products. The role of pesticides and biological agents in agricultural production, their effect on productivity, and their impact on ecological safety are examined. The article also discusses the importance of plant protection products in maintaining sustainable development and ecological balance in agriculture. Research highlights the potential to increase agricultural productivity through the effective use of pesticides and biological agents.

Keywords: plant protection, pesticides, biological agents, economic effectiveness, ecological impact, sustainable development, agriculture, ecological safety, innovative technologies.

Introduction. The agricultural sector plays a vital role in the national economy. It ensures food security, increases rural employment, and strengthens production and export potential. However, the development of agriculture depends on numerous internal and external factors, among which the effectiveness of plant protection measures against pests and diseases holds special importance. According to the Food and Agriculture Organization of the United Nations (FAO), each year 20–40% of global agricultural production is lost due to plant pests and diseases. Uzbekistan is also facing similar challenges. Consequently, the state is implementing various measures to improve the efficiency and ecological safety of plant protection methods in agriculture.

One of the key documents in this regard is the Presidential Decree of the Republic of Uzbekistan dated October 13, 2020, "On measures to further improve the activities of the state plant quarantine service." The decree emphasizes the importance of enhancing the effectiveness of plant protection agents and ensuring their ecological safety through the use of pesticides and biological agents. This policy aims not only to increase agricultural productivity but also to protect the environment and human health through a comprehensive and integrated approach.

Plant protection agents, particularly pesticides and biological products, are essential components of agricultural production. While pesticides are widely used to control pests and diseases, their excessive or improper use can result in serious environmental consequences. On the other hand, biological agents are considered more ecologically safe compared to chemical products; however, to improve their efficiency, they must be applied based on well-developed strategies. Moreover, the economic effectiveness of pesticides and biological agents is crucial, as they play a significant role in increasing production profitability and ensuring economic sustainability.

Currently, developing and managing effective strategies for the use of plant protection products requires balancing economic, environmental, and social aspects. Failure to achieve this balance may negatively affect the quality of agricultural products, environmental conditions, and human health. Therefore, it is essential to assess the economic and ecological efficiency of pes ticides

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and biological agents, identify existing challenges, and implement innovative approaches for more effective management.

The main objective of this research is to study the economic and ecological effectiveness of plant protection agents, analyze the impact of pesticides and biological agents in agriculture, and propose strategies for their optimal use. This study examines the efficiency of using these products, evaluates ecological safety, and explores ways to increase profitability. Furthermore, it emphasizes the importance of proper management of plant protection agents to improve yields, ensure economic gains, and promote environmental sustainability.

Literature Review. Research conducted by Uzbek scholars has placed particular emphasis on the economic efficiency and environmental safety of plant protection products used in agriculture. For instance, **M.M. Khodjaev**, [1] in his scientific investigations, has thoroughly analyzed the economic losses and ecological issues resulting from the improper use of pesticides. He proposes an integrated approach to optimize their application and suggests the development of safe, cost-effective, and efficient protection strategies tailored for agricultural producers.

N.S. To‘xtayev, [2] in his studies, examined the economic efficiency of using biological agents and their impact on crop productivity. He scientifically substantiated that the use of biological methods can reduce pesticide consumption by 30–35%. His findings clearly demonstrate the economic benefits of alternative technologies.

Similarly, **D.K. Nazarova**, [3] in her research, emphasizes the effectiveness of combining chemical and biological agents in enhancing crop yields and product quality. She highlights the economic advantages of integrated pest management strategies and underscores the need to introduce innovative biotechnologies into the agricultural sector.

S.Z. Rasulova [4] developed a methodology for evaluating the economic effectiveness of plant protection tools based on regional conditions and crop types. Her work provides a scientific foundation for developing adaptive strategies in local contexts using innovative approaches.

International experience in this area is also of great significance. **David Pimentel** (USA), [5] through his extensive research, has highlighted the environmental and human health impacts of pesticide use. According to his estimates, the environmental damages caused by pesticides in the United States amount to billions of dollars annually. Nonetheless, he asserts that if properly managed, the benefits of pesticides can outweigh their negative effects.

Miguel Altieri (Chile–USA), [6] a leading advocate of agroecological approaches, promotes the development of sustainable systems that are not entirely dependent on pesticides. He views biological diversity and ecosystem services as essential components of plant protection strategies.

In conclusion, both national and international studies demonstrate that the economic efficiency and environmental safety of plant protection tools — when managed through innovative and strategic approaches — play a critical role in ensuring the sustainability of agriculture. These findings underscore the need for complex and integrated management of such tools at a strategic level.

Research Methodology. This study employed a systematic approach to analyze the economic efficiency and environmental impact of using plant protection agents—particularly pesticides and biological means—in agriculture. A combination of scientific and practical methods was applied throughout the research process.

First, the **descriptive analysis method** was used to examine trends in the use of plant protection agents in Uzbekistan and abroad, identifying their application areas and evaluating their influence on crop productivity.

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Second, **correlation and regression analysis methods** were applied to determine the statistical relationships between the use of pesticides and biological agents and indicators such as crop yield, gross agricultural output, and other economic metrics. The analysis was based on official statistical data from 2018 to 2023.

Third, a **comparative analysis method** was used to compare Uzbekistan's experience with the strategies applied in countries such as the USA, India, and China. This enabled the evaluation of innovative technologies, bio-protection measures, and levels of ecological safety.

Fourth, the **expert evaluation method** was used to incorporate insights from leading researchers and agronomists to identify the practical relevance of plant protection strategies, the challenges faced in implementation, and potential solutions.

The necessary data for this study were obtained from the Ministry of Agriculture of the Republic of Uzbekistan, the State Committee on Statistics, the Food and Agriculture Organization of the United Nations (FAO), and other open-access statistical databases. These data were analyzed and systematized to ensure the reliability and scientific validity of the research results.

Analysis and Results. Plant protection products, particularly pesticides and biological agents, play a crucial role in increasing crop yields and combating pests and diseases in agriculture. In recent years, the application of these tools has not only improved the technological foundation of agricultural production but has also significantly enhanced economic efficiency.

In Uzbekistan, from 2018 to 2023, the annual volume of pesticides used on agricultural lands increased by an average of 5–7%. According to FAO (2023), approximately 20–40% of global agricultural production is lost due to pests and diseases. This underscores the urgent need to improve plant protection strategies.

Statistical analysis reveals that the average amount of pesticides used per hectare in Uzbekistan in 2023 was around 3.8 kg—significantly lower compared to developed countries such as China (13 kg/ha) and the United States (9 kg/ha). While this lower usage may be seen as positive in terms of environmental safety, it also suggests potential underutilization of protection methods in certain contexts.

Plant protection expenditures account for approximately 12–18% of total agricultural production costs. However, farms that implemented modern biological agents and integrated protection technologies observed a 15–20% increase in yields. In particular, farms in Surkhandarya and Kashkadarya regions that applied biological agents achieved crop yields that were 18% higher than those using traditional methods for wheat and vegetable cultivation.

Regression analysis conducted during this study indicated a statistically significant positive relationship between pesticide use and yield ($R^2 = 0.72$, $p < 0.01$). This finding confirms that rational use of plant protection products is a critical factor in stabilizing agricultural production and improving economic outcomes.

There is also a growing demand for biological agents aimed at ensuring ecological sustainability. According to data from the Ministry of Agriculture of Uzbekistan, the area treated with biological protection products in 2022 increased by 1.5 times compared to 2020. This not only contributes to yield improvement but also helps preserve soil fertility and minimize environmental impact.

An international review of best practices (e.g., in the USA, India, and the Netherlands) shows that the adoption of innovative technologies—such as drone-based spraying, digital monitoring systems, and automated dosage controls—can reduce pesticide consumption by 20–25% while increasing economic returns by up to 30%

Conclusion and Recommendations

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The conducted analysis reveals that plant protection tools—particularly pesticides and biological agents—play a vital role in achieving high crop yields in agriculture. Based on statistical data, it can be concluded that the rational and scientifically grounded use of these products can increase productivity by an average of 15–20%, reduce production costs, and enhance economic efficiency.

However, improper or excessive use of such tools can negatively impact environmental balance. Therefore, it is increasingly important to expand the use of biological agents and introduce monitoring and control systems based on digital technologies. Modern solutions—such as drone spraying, automated monitoring systems, and agrotechnological innovations—can reduce pesticide consumption while simultaneously increasing profitability.

Based on the findings of this study, the following **recommendations** are proposed:

1. **Improve the regulatory and legal framework for the use of pesticides and biological products** – including the development of safe usage standards and strict enforcement mechanisms.
2. **Organize scientific-practical training sessions for farmers and agricultural enterprises** to assist them in selecting and implementing optimal protection strategies.
3. **Introduce digital management systems for plant protection tools** – enabling automated monitoring, analysis, and safety control.
4. **Promote the production and widespread use of biological products in domestic markets**, especially those that meet ecological safety standards.
5. **Expand scientific research and attract investment in innovative developments in plant protection**, particularly in agro-technologies and environmentally safe alternatives.

Implementing these recommendations will help ensure a balance between sustainability, economic efficiency, and environmental safety in agriculture.

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