

INNOVATION IN AGRICULTURAL ENVIRONMENTAL PROTECTION TECHNOLOGY, CONSERVATION OF PRODUCTION FACTORS, AND SUSTAINABLE AGRICULTURAL DEVELOPMENT

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Abstract

Technological innovation in the agricultural sector plays an important role in addressing environmental challenges, conservation of production factors, and sustainable agricultural development. This study discusses how modern technologies, such as smart irrigation, precision agriculture, and biopesticides, can protect the agricultural environment through efficient use of natural resources and reduced negative impacts on the ecosystem. In addition, conservation of production factors, including land, water, and energy, is a major focus in ensuring agricultural sustainability. These innovations enable more efficient use of resources, maintain productivity, while minimizing environmental damage. On the other hand, sustainable agricultural development integrates technological aspects with economic and social approaches to ensure farmer welfare and sustainable food production. Environmentally friendly technology plays a role in reducing dependence on chemicals and fossil fuels, and encouraging wise management of natural resources. Thus, technological innovation not only supports agricultural productivity, but also maintains ecosystem balance, ensures resource sustainability, and improves the quality of life of agricultural communities. This study confirms that through the application of appropriate technological innovation, the agricultural sector can become more efficient, productive, and sustainable, meeting global food needs without sacrificing environmental health and the welfare of future generations.

Keywords: Technological innovation, agricultural environmental protection, conservation of production factors, sustainable agricultural development

INTRODUCTION

In recent decades, agriculture has faced increasingly complex challenges. The need for increased global food production continues to increase along with rapid population growth (Yu, J., & Wu, 2018). However, on the other hand, intensive agricultural practices also often have negative impacts on the environment and natural resources. This raises concerns about the

sustainability of food production and ecosystem resilience. Therefore, technological innovation in the agricultural sector is increasingly needed to address environmental issues, conserve production factors, and support sustainable agricultural development. According to Kalogiannidis et al., (2022) the problem of land degradation is a major concern because land is a production factor that cannot be easily renewed. Poor land management can cause erosion, salinization, and decreased soil fertility, which ultimately threatens food production. In addition, inefficient use of water in irrigation also causes a decrease in the quality and quantity of water resources in many agricultural areas. Thus, technologies that support soil and water conservation are very important to maintain the sustainability of food production in the future. Conventional agriculture often uses large amounts of pesticides and chemical fertilizers, which not only have an impact on human health but also damage the environment. Accumulation of chemicals in soil and water can damage biodiversity, disrupt the food chain, and contaminate drinking water sources (Saikanth et al., 2023). Therefore, technologies that can reduce or even eliminate dependence on synthetic chemicals are needed for better environmental protection.

Along with the increasing awareness of the importance of environmental sustainability, technological innovation in the agricultural sector has grown rapidly. Precision agriculture technology, for example, has become one of the promising solutions to address environmental challenges in agriculture. According to research by Xie, H., & Huang, Y. (2021), precision agriculture allows farmers to optimize the use of agricultural inputs such as water, fertilizers, and pesticides, based on real-time data obtained from sensors and information technology. Thus, precision agriculture can reduce resource waste and negative impacts on the environment.

The use of sensors and information systems in precision agriculture allows for more accurate monitoring of soil conditions, moisture, and nutrient status (Ikendi, 2023). With this technology, farmers can make more informed decisions regarding the timing and amount of fertilizer or water application, thereby reducing the risk of land degradation and conserving water resources. In addition, drone-based technology and satellite imagery are also used to monitor crop conditions, map land, and detect pest or disease attacks early. This supports more efficient and environmentally friendly agricultural management.

In addition to precision agriculture, another technological innovation that supports environmental protection is biotechnology. According to Gryshova et

al., (2016), biotechnology allows the development of crops that are more resistant to environmental stress such as drought, salinization, and pest attacks. By using more adaptive crop varieties, dependence on chemical inputs can be reduced, thereby reducing the negative impact on the environment. Biopesticides and organic fertilizers produced from biotechnology also offer more environmentally friendly solutions compared to synthetic chemical products. The main production factors in agriculture include land, water, seeds, energy, and other inputs. For agriculture to be sustainable, there needs to be conservation efforts for these factors. Without proper management, production factors such as land and water will experience degradation and scarcity, which in turn will threaten long-term productivity. Soil conservation is an important component of sustainable agriculture. Soil conservation technologies such as minimum tillage systems, organic waste management, and planting cover crops have been shown to be able to maintain soil structure and increase its fertility.

According to Guo et al., (2020), this technology also helps in the absorption of carbon in the soil, which can reduce the concentration of greenhouse gases in the atmosphere. Therefore, innovation in environmentally friendly land management techniques plays a major role in mitigating climate change and maintaining soil productivity. In addition, water conservation is very important, especially in areas prone to drought. Modern irrigation technologies such as drip irrigation and automatic watering systems allow for more efficient water use, reducing water waste and increasing crop productivity. These technologies support sustainability by maintaining long-term water availability, which is critical given the threat of climate change to the global hydrological cycle.

Sustainable agricultural development encompasses economic, social, and environmental principles that must be considered in an integrated manner. According to the definition of Tey et al., (2014) sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. In the context of agriculture, this means that food production must be carried out in a way that preserves natural resources, reduces environmental impacts, and supports the welfare of farmers and communities.

Technological innovation plays a key role in sustainable agricultural development. Efficient and environmentally friendly technology can not only increase food production but also minimize environmental damage. According to Adisa et al., (2024), the adoption of appropriate technology can help reduce

social inequality by giving farmers better access to knowledge and tools to increase their productivity. On the other hand, government policies that support the adoption of environmentally friendly technology are also very important in ensuring the success of sustainable agricultural development. Sustainable agricultural development also includes increasing food security, which is increasingly relevant amidst climate change and global environmental challenges. With the application of innovative technology, a more resilient agricultural system can be created, which is able to adapt to changing climate conditions and maintain food productivity to meet global needs.

Technological innovation in the agricultural sector plays an important role in environmental protection, conservation of production factors, and sustainable agricultural development (Dogliotti et al., 2014). Increasing environmental challenges require effective technological solutions to ensure sustainable food production and ecosystem resilience. Precision agriculture, biotechnology, soil and water conservation, and the application of renewable energy are some examples of technologies that can contribute to sustainable agricultural development. Strong policy support and widespread adoption of technology will be key to realizing the vision of environmentally friendly and sustainable agriculture.

RESEARCH METHOD

This research method uses literature review to explore the role of technological innovation in agricultural environmental protection, conservation of production factors, and sustainable agricultural development. The literature review was conducted by identifying and collecting relevant academic sources, including scientific journals, books, and research reports. The selected literature focused on the latest technological innovations, the environmental impacts of agriculture, and sustainability strategies in agricultural practices. The literature selection process was carried out based on the criteria of relevance, quality, and contribution to the understanding of the topic.

Furthermore, the collected literature was analyzed and synthesized to identify key findings, trends, and important concepts related to the application of technology in agriculture. This analysis aims to develop a comprehensive understanding of how technological innovation can help overcome environmental challenges, improve the efficiency of resource use, and support sustainable agricultural development. The results of the literature review are then presented in narrative form that describes the contribution of technology

to the sustainability of the agricultural sector as well as its practical and theoretical implications.

RESULT AND DISCUSSION

The Concept of Technological Innovation in Agriculture

Technological innovation in agriculture has become a key factor in addressing various challenges faced by the agricultural sector, including increasing productivity, protecting the environment, and sustaining natural resources (Vargas Canales et al., 2018). In recent decades, technological developments in this field have accelerated significantly, presenting various solutions that not only increase agricultural efficiency but also minimize negative impacts on the environment. In this discussion, we will explain in more depth about several concepts of technological innovation that have an impact on agriculture, such as precision agriculture, biotechnology, and digital-based agriculture. Precision agriculture is one of the most significant technological innovations in the modern agricultural sector. This term refers to the use of information technology to optimize agricultural production by utilizing data collected from various sensors, satellites, drones, and other devices.

According to research by Glover et al., (2019), precision agriculture allows farmers to make better decisions based on accurate real-time data on soil conditions, weather, crop status, and water availability. The core concept of precision agriculture is the use of technology to adjust agricultural inputs such as water, fertilizers, and pesticides precisely according to the specific needs of each part of the land. GPS technology, for example, allows for high-detail land mapping so that each land zone can be managed according to its characteristics. This reduces resource waste and increases the efficiency of input use, which in turn reduces production costs and negative impacts on the environment. One of the important components in precision agriculture is soil and plant sensors that can provide information on soil moisture, nutrient content, and plant health in real time. Thus, farmers can decide when and how much water or fertilizer needs to be applied.

This technology supports the conservation of natural resources, especially water, which is one of the biggest challenges in the agricultural sector, especially in areas with low rainfall or prone to drought. The use of drones and satellite imagery is also an important part of precision agriculture. Drones can be used for fast and accurate crop monitoring, helping farmers detect problems such as pest or disease attacks early on. With this technology, pesticide applications can be carried out more specifically in areas that need

them, reducing the excessive use of pesticides which often have a negative impact on the environment.

Biotechnology is another innovation that has changed the way we produce food. According to Stræte et al., (2022), agricultural biotechnology involves the use of genetic engineering to develop crops that are more resistant to pests, diseases, and extreme environmental conditions such as drought and salinization. Genetically engineered crops have helped increase food production in many parts of the world that face climate and natural resource challenges. Increasing crop resistance to adverse environmental factors not only plays a role in increasing agricultural productivity but also helps in reducing the use of chemical inputs such as pesticides and fertilizers. For example, crops that are genetically engineered to be resistant to certain pests can reduce the need for chemical pesticides, which often pollute the environment and harm biodiversity. In addition, biopesticides and organic fertilizers developed through biotechnology have become a more environmentally friendly alternative to synthetic chemicals. Biopesticides based on natural microorganisms or certain plant extracts are not only effective in controlling pests but are also safer for humans and the environment. The use of biopesticides also reduces the risk of soil and water contamination, which is a serious problem in conventional agriculture. The development of crop varieties that are more efficient in using water and nutrients is also a focus of biotechnology. Crops that are more adaptive to extreme environmental conditions can help farmers in areas vulnerable to climate change, such as drought and flooding, to maintain productivity. Thus, biotechnology supports more sustainable agricultural development and resilience to future climate challenges (Andrade et al., 2020).

Along with advances in information technology, agriculture is increasingly connected with digital solutions that facilitate data-based decision-making and better system integration. The Internet of Things (IoT), artificial intelligence and blockchain technology are some of the innovations that are starting to be applied in the agricultural sector to increase efficiency and transparency in the supply chain. IoT in agriculture allows the integration of various sensor devices and machines connected to the internet to monitor the condition of land, crops and agricultural infrastructure (Bartkowiak et al., 2017). An example of its application is an automatic irrigation system that can be adjusted based on soil moisture data sent by sensors, so that water use becomes more efficient. AI is also used to analyze data collected from the field, such as predicting crop yields, identifying plant diseases and recommending

corrective actions. Blockchain in agriculture is used to increase transparency in the food supply chain. This technology allows for accurate tracking of the origin of agricultural products, so that consumers can be more transparent about the food production and distribution process. In the long term, this can support more sustainable agricultural practices and ensure that the products produced meet high environmental and social standards.

Theory of Agricultural Environmental Protection

The theory of agricultural environmental protection focuses on the principles and strategies to maintain a balance between agricultural productivity and ecosystem sustainability. In general, this theory aims to reduce the negative impacts of agricultural practices on the environment, such as soil degradation, water pollution, greenhouse gas emissions, and biodiversity loss (Linzhang, Y., & Yonghong, 2018). Environmental protection in agriculture includes concepts such as natural resource conservation, sustainable management, and environmentally friendly agriculture. One of the theoretical foundations of agricultural environmental protection is the theory of agricultural ecology, which emphasizes the importance of understanding the relationship between agricultural practices and natural ecosystems.

This theory views agriculture as an integral part of a broader ecosystem, where long-term sustainability depends on how humans manage natural resources such as land, water, and air. This approach includes practices such as integrated pest management, soil and water conservation, and crop rotation to maintain soil fertility. The theory of sustainable development is also relevant in agricultural environmental protection. In this context, sustainable agricultural development means maximizing production without compromising the ability of future generations to meet their needs. This principle encourages the use of environmentally friendly technologies, such as organic farming, biotechnology, and water-saving irrigation, which aim to minimize environmental impacts while still meeting global food needs (Juríčková et al., 2020). In addition, environmental economic theory plays a role in understanding the costs and benefits of agricultural practices on the environment. This theory emphasizes that environmental damage from agriculture, such as water pollution and carbon emissions, is a negative externality that needs to be internalized in agricultural policies and practices. This means that agricultural actors must take environmental impacts into account in decision-making and adopt technologies that support sustainability.

Conservation of Production Factors

According to Kameswara Rao et al., (2017) conservation of production factors in agriculture is an effort to maintain and efficiently utilize natural resources that support the sustainability of agricultural systems. The main production factors include land, water, energy, and input materials such as fertilizers and seeds. This conservation is very important to ensure that agricultural practices can continue to meet future food needs without damaging the natural resources needed for plant growth and ecosystem sustainability. Soil is one of the most vital production factors in agriculture. Soil degradation, such as erosion, decreased fertility, and loss of soil structure, often occurs due to unsustainable agricultural practices. To protect soil, conservation techniques such as no-tillage, cover crops, and crop rotation have been widely adopted. These methods aim to maintain soil structure, reduce erosion, and increase organic matter in the soil, which ultimately improves long-term fertility. Good land management also includes the use of technologies such as precision agriculture, where farmers can monitor the specific needs of the soil and provide inputs such as fertilizers only in areas that need them. This reduces resource waste while maintaining soil quality. Water use in agriculture must be managed properly, especially considering the challenges of climate change that can cause droughts or uncertain water availability. Efficient irrigation systems such as drip irrigation and modern sprinklers help reduce excessive water use. These technologies allow water to be delivered directly to the root zone of plants precisely, reducing unnecessary evaporation and runoff. In addition, practices such as watershed management and the use of water-efficient crop varieties are important parts of water conservation strategies in agriculture. The use of crops that are more tolerant of drought conditions helps farmers manage limited water resources more effectively (Aggestam et al., 2020).

Energy use in agriculture, especially fossil fuels for machinery and transportation, is one of the main challenges in efforts to maintain agricultural sustainability. Energy conservation efforts include the use of energy-efficient technologies such as fuel-efficient tractors, solar panels, and biogas production from agricultural waste. In addition to energy, other inputs such as fertilizers and pesticides must also be managed sustainably. The use of organic fertilizers and biopesticides is a step that supports environmental conservation while reducing dependence on synthetic chemicals that can pollute soil and water.

Sustainable Agricultural Development

According to Qaim, M. (2020) sustainable agricultural development is a concept that aims to create an agricultural system that is able to meet current food and economic needs without compromising the ability of future generations to meet their needs. This includes an approach that combines economic, social, and environmental aspects in a balanced way to maintain the sustainability of natural resources and ensure the welfare of farming communities in the long term.

From an economic perspective, sustainable agricultural development encourages increased productivity without damaging natural resources. The use of efficient and environmentally friendly technologies, such as precision agriculture and biotechnology, helps farmers increase crop yields while minimizing the use of inputs such as water, fertilizers, and pesticides. In addition, the development of better supply chains and diversification of agricultural products are also strategies to increase farmer incomes and reduce market risks. Thus, farmers can produce in a more efficient and economical way, while maintaining the sustainability of the agricultural ecosystem.

One of the main principles of sustainable agriculture is protecting and restoring agricultural ecosystems. This involves wise management of natural resources, such as soil, water, and biodiversity. Practices such as crop rotation, the use of organic fertilizers, efficient water management, and reducing dependence on synthetic chemicals support environmental protection. Reducing greenhouse gas emissions is also an important component in addressing the challenges of climate change, with the use of renewable energy and carbon-conserving agricultural techniques, such as minimum tillage systems (Singh et al., 2021).

Sustainable agricultural development also considers social welfare, especially among rural communities that depend on the agricultural sector. This includes increasing farmer capacity through training, technology transfer, and better access to markets and information. In addition, it is important to develop equitable and inclusive policies that support the rights of smallholder farmers and encourage their participation in decision-making. The social aspect is also related to food security. Sustainable agriculture aims to ensure the availability of sufficient, safe and nutritious food for communities now and in the future. By strengthening food security, sustainable agricultural development also helps reduce poverty and inequality in rural areas.

The Role of Technological Innovation in Addressing Agricultural Environmental Challenges

Technological innovation plays a central role in addressing the environmental challenges facing modern agriculture. These challenges include climate change, soil degradation, water scarcity, biodiversity loss, and excessive use of chemicals. As the demand for food increases due to population growth, agriculture is required to produce more in a way that does not damage the environment. In this context, technological innovation is an effective tool in creating sustainable solutions, which can increase agricultural productivity while preserving natural resources (Adenle et al., 2015).

One of the biggest environmental challenges in agriculture is water scarcity. Traditional farming systems often use excessive amounts of water, resulting in groundwater depletion and environmental degradation. Technological innovations in irrigation systems have offered more efficient solutions through smart irrigation technologies, such as drip irrigation and sensor-based irrigation. Drip irrigation is a system designed to deliver water directly to the root zone of plants, reducing evaporation and runoff. This allows water to be used more efficiently, especially in areas with limited water availability. Meanwhile, soil moisture sensors connected to the Internet of Things (IoT) technology can monitor soil moisture in real time and control irrigation automatically (Tittonell et al., 2016). Thus, water is only provided when and where it is needed, reducing excessive water use and reducing pressure on water resources.

In addition to saving water, this innovation also contributes to soil conservation, as efficient water management can reduce erosion and nutrient leaching that often occur due to uncontrolled irrigation. Smart irrigation technology not only helps in maintaining the quality of agricultural land, but also plays a role in reducing the environmental footprint of the agricultural sector as a whole.

The use of pesticides and chemical fertilizers in traditional agriculture often causes soil and water pollution, and has a negative impact on biodiversity. Precision agriculture is one of the technological innovations that plays a major role in addressing this problem. With the help of GPS technology, drones, and advanced sensors, precision agriculture allows farmers to provide inputs (such as fertilizers and pesticides) precisely according to the specific needs of each part of the land. This technology reduces the waste of fertilizers and pesticides that are often spread evenly without taking into account the different needs of plants or soil. For example, the use of drones for land mapping or crop imagery can detect problems such as nutrient deficiencies or pest attacks in certain areas, so that chemical applications can be carried out precisely. This not only

reduces the negative impact on the environment but also reduces production costs (Méndez-Zambrano et al., 2023).

Other innovations that support the reduction of chemical use are biopesticides and organic fertilizers. Biopesticides based on natural microorganisms or plant extracts function as a substitute for synthetic pesticides, which are more environmentally friendly and do not leave harmful residues on plants or the environment. With the application of modern biotechnology, the development of plant varieties that are resistant to pests and diseases is also increasingly advanced, drastically reducing the need for pesticides.

Climate change is a major threat to global agriculture, with phenomena such as rising temperatures, erratic rainfall patterns, and extreme weather events having a direct impact on agricultural productivity. Technological innovation plays a role in developing solutions to address the impacts of climate change. One example is the development of drought-resistant crop varieties through biotechnology (Abid et al., 2022). These crops have been engineered to survive in conditions of limited water, allowing farmers in dry areas to continue to produce adequate harvests. In addition, there is the development of crops that are more efficient in using water and nutrients, which are suitable for dealing with increasingly unpredictable climate change conditions.

Technologies such as climate mapping and satellite-based weather information systems are also important tools for farmers in dealing with climate change. With access to accurate weather data and predictions of extreme weather conditions, farmers can better manage planting times, irrigation, and crop protection. For example, farmers can adjust planting schedules based on predicted rainy seasons or prepare mitigation measures if flooding or drought is predicted.

Agricultural waste management is one of the focuses of environmental technology innovation. Waste from agricultural activities, such as crop residues and livestock waste, is often not managed properly and can cause pollution problems. The latest technology allows agricultural waste to be converted into useful resources through bioconversion processes, such as the use of biogas and composting. Biogas produced from livestock waste and crop residues can be used as a renewable energy source for agricultural operational needs (Qayyum et al., 2023). In addition, innovations in the manufacture of organic fertilizers from crop residues and other wastes help reduce dependence on chemical fertilizers and minimize soil and water pollution. This waste management not only supports more sustainable agriculture but also helps

reduce greenhouse gas emissions resulting from the decomposition of organic waste. This technology plays an important role in creating a more environmentally friendly and energy efficient production cycle.

CONCLUSION

Technological innovation plays a vital role in protecting the agricultural environment by creating effective solutions to challenges such as soil degradation, water scarcity, and pollution from excessive use of chemicals. Technologies such as smart irrigation, precision agriculture, and biopesticides help improve the efficiency of natural resource use, reduce negative impacts on the environment, and maintain productive agricultural ecosystems. In addition, conservation of production factors, including land, water, energy, and agricultural inputs, is a key element in ensuring the sustainability of agricultural production.

Technological innovation enables farmers to use resources more wisely, such as through the use of water-efficient irrigation, environmentally friendly land management, and the application of renewable energy. With this conservation, not only is the sustainability of agriculture assured, but the balance of the ecosystem can also be maintained in the long term. Sustainable agricultural development integrates environmentally friendly technologies with a holistic social and economic approach. Sustainable agriculture ensures that the agricultural sector can meet current food needs without compromising the potential of future generations. Thus, technological innovation not only increases productivity, but also promotes social welfare and preserves the environment, creating a resilient and sustainable agriculture.

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