

A Systematic Review of Sustainable Agriculture Practices: Evaluating Environmental and Economic Impacts

Tinjauan Sistematis terhadap Praktik Pertanian Berkelanjutan: Mengevaluasi Dampak Lingkungan dan Ekonomi

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ABSTRACT

No-till farming offers a variety of environmental benefits but faces challenges in terms of efficiency and economic sustainability. This research aims to explore the role of technological innovation in improving efficiency and economic sustainability in no-till farming practices through a systematic review of the literature. The research results show that the adoption of technologies such as no-till planting machines, soil sensors, and digital monitoring systems can increase productivity, reduce operational costs, and improve the quality of crop yields, thereby supporting long-term economic sustainability. These findings imply the need for policy support and training to overcome initial barriers to technology investment and promote more efficient and sustainable agricultural practices.

Keywords: No-till farming, technological innovation, efficiency, economic sustainability, sustainable agriculture, soil sensors, planting machines, digital monitoring.

ABSTRAK

Pertanian tanpa olah tanah (*no-till farming*) menawarkan berbagai keuntungan lingkungan namun menghadapi tantangan dalam hal efisiensi dan keberlanjutan ekonomi. Penelitian ini bertujuan mengeksplorasi peran inovasi teknologi dalam meningkatkan efisiensi dan keberlanjutan ekonomi pada praktik *no-till farming* melalui tinjauan sistematis literatur. Hasil penelitian menunjukkan bahwa adopsi teknologi seperti mesin tanam *no-till*, sensor tanah, dan sistem pemantauan digital dapat meningkatkan produktivitas, mengurangi biaya operasional, dan meningkatkan kualitas hasil panen, sehingga mendukung keberlanjutan ekonomi jangka panjang. Temuan ini mengimplikasikan perlunya dukungan kebijakan dan pelatihan untuk mengatasi hambatan awal investasi teknologi dan mempromosikan praktik pertanian yang lebih efisien dan berkelanjutan.

Kata Kunci: *No-till farming*, inovasi teknologi, efisiensi, keberlanjutan ekonomi, pertanian berkelanjutan, sensor tanah, mesin tanam, pemantauan digital.

1. Introduction

Sustainable agriculture practices are essential in addressing the challenges faced by modern agriculture, such as limited cultivable land, the need for higher yields, and growing environmental concerns (Santos et al., 2019). These practices aim to achieve sustainable production by satisfying human food and fiber needs, enhancing environmental quality, making efficient use of resources, sustaining farm economic viability, and improving overall quality (Firmanda et al., 2022). Sustainable agriculture involves an integrated system of plant and animal production practices tailored to specific sites, emphasizing long-term benefits (Firmanda et al., 2022).

The adoption of sustainable agricultural practices is crucial for maintaining food production levels while mitigating environmental impacts (Lamm et al., 2023). Practices like crop rotation, cover cropping, and reduced tillage can improve soil health and reduce the environmental footprint of agriculture (Nath, 2023). Harnessing microbial functions and

biodiversity is also crucial for enhancing plant growth and soil health, contributing to sustainable food production (Saleem et al., 2019).

In the pursuit of sustainable agriculture, the development of new technologies, such as deep learning for biotic stress classification and precision agriculture, has enabled farmers to reduce environmental impacts, increase productivity, and improve resource efficiency (Esgario et al., 2020; Lee et al., 2021). Additionally, the role of agricultural cooperatives in promoting environmentally friendly practices and innovation can enhance farm sustainability (Candemir et al., 2021).

Furthermore, sustainable agriculture practices encompass various approaches, including organic farming, ecological farming, and integrated farming, which aim to harmonize ecological conservation with agricultural production (Patel & Lepcha, 2023). Agri-environmental policies need to consider a range of practices that positively impact the environment and provide incentives for farmers to adopt them (Baaken, 2022). Sustainable intensification practices seek to enhance agricultural productivity and resilience while conserving natural resources (Xie et al., 2019). In conclusion, sustainable agriculture is a global imperative that requires the adoption of environmentally friendly practices, the integration of new technologies, and the promotion of sustainable intensification to ensure food security, environmental sustainability, and economic viability in agriculture (Pe'er et al., 2020; Zhu et al., 2022). By embracing sustainable agriculture practices, farmers can contribute to a more resilient and sustainable agricultural system that meets the needs of the present without compromising the ability of future generations to meet their own needs (Firmanda et al., 2022).

No-till farming is a practice of agriculture which avoids traditional soil turning, such as plowing, to maintain natural soil structure, reduce erosion and increase moisture retention. This approach is gaining increasing attention due to its potential to support agricultural sustainability through reduced soil disturbance and resource conservation. Technological innovation plays a vital role in agricultural modernization, including the implementation of no-till farming. This technology includes the use of special equipment, sensor-based information systems, and biotechnology applications that can increase operational efficiency and agricultural output.

Although no-till farming offers a variety of environmental benefits, the practice faces significant challenges in terms of efficiency and economic sustainability. These challenges include the need for expensive specialized equipment, reliance on chemical inputs for weed control, and limited technological adaptation by farmers. Therefore, innovative solutions are needed to increase efficiency and optimize the economic benefits of no-till farming. The development and adoption of new technologies is crucial in overcoming these obstacles and promoting more sustainable practices.

Currently, there is a lack of comprehensive studies that assess the specific impact of technological innovations on no-till farming practices. Most studies tend to focus on environmental aspects or agricultural outcomes in general, without paying special attention to the interactions between specific technologies and economic efficiency and sustainability. This gap shows the need for in-depth research to understand how technology can be effectively integrated in no-till farming to achieve optimal results.

This research aims to explore the role of technological innovation in increasing efficiency and economic sustainability in no-till farming practices. By conducting a systematic review of existing literature, this research will identify the most effective technologies and evaluate their impact on operational efficiency and economic profitability. This research will answer the question: "What is the role of technological innovation in increasing the efficiency and economic sustainability of no-till farming practices?"

This research offers a new contribution by focusing on the specific impact of technological innovation in no-till farming, which has not been widely discussed in previous

literature. By exploring the relationship between specific technologies and the economic aspects of no-till farming, this research provides unique insights that can aid in decision-making and implementation of more efficient and sustainable farming practices.

This research is expected to provide new insights that are useful for farmers and policy makers in adopting technology for no-till farming. The findings of this research can be used to develop strategies and policies that support the application of innovative technologies, thereby increasing operational efficiency and economic sustainability in no-till farming practices.

2. Research methods

Article collection for this research was carried out through three reputable international databases: Scopus, Web of Science, and Google Scholar. The selection of these data sources was based on their reputation for providing high-quality and relevant scientific literature. To ensure comprehensive coverage, article searches were conducted using a combination of specific keywords, such as "no-till farming", "innovative technology", "efficiency", "economic sustainability", and "agricultural technology". This keyword combination is designed to identify articles that are most relevant to the research topic.

The number of articles obtained from the initial search was recorded to provide an idea of the breadth of the literature available. In the screening process, strict inclusion and exclusion criteria are used. The articles included are peer-reviewed articles that have gone through a peer review process, have high relevance to the research topic, and were published within the last 5 years to ensure the information obtained is the most up-to-date and relevant to the latest developments. In contrast, non-peer-reviewed articles, articles of low relevance, and articles published before a certain deadline were excluded to avoid the use of outdated or scientifically unvalidated information.

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method was used to identify and screen relevant articles. The PRISMA diagram is used to illustrate the article selection process, from initial identification to final selection. This stage includes identifying the total number of articles found, filtering duplicate articles and irrelevant articles based on the title and abstract, reviewing the full text of the remaining articles to ensure they match the inclusion and exclusion criteria, and compiling a final list of articles to be analyzed further. This process aims to ensure that only the most relevant and high-quality articles are used in the literature review, so that research results are reliable and make a significant contribution to the understanding of the role of technological innovation in no-till farming practices.

3. Results and Discussion

3.1. Efficiency in No-Till Farming

3.1.1. Impact of Technological Innovation on Productivity

Technological innovation has significantly enhanced productivity in no-till farming practices. The utilization of no-till planting machines allows for efficient seed planting without soil plowing, preserving soil structure and reducing erosion (Monteiro et al., 2021). These machines facilitate quicker and more uniform seed planting, leading to reduced labor costs due to decreased manual labor requirements. Moreover, the integration of soil sensors and digital monitoring systems provides real-time data on soil conditions, enabling informed decisions on irrigation and fertilization, ultimately boosting crop yields by 15-20% (Monteiro et al., 2021).

The adoption of such technologies not only increases productivity but also ensures economic sustainability by lowering operational costs (Monteiro et al., 2021). Studies emphasize the pivotal role of technological innovation in addressing efficiency challenges in no-till farming, highlighting the potential of technology to enhance agricultural yields while safeguarding soil health (Monteiro et al., 2021). This underscores the importance of embracing

innovations like precision agriculture tools and digital monitoring systems to optimize resource utilization and improve overall farm efficiency.

In conclusion, the incorporation of advanced technologies in no-till farming practices has proven instrumental in elevating productivity levels and promoting sustainable agricultural practices. By leveraging innovations such as no-till planting machines, soil sensors, and digital monitoring systems, farmers can achieve higher yields, reduce operational costs, and contribute to the long-term health of soil ecosystems.

3.1.2. More Efficient Use of Resources

Efficiency in no-till farming is significantly improved through the utilization of advanced technologies that enable the optimal use of resources such as water and agricultural inputs. By employing tools like soil sensors and precision irrigation systems, farmers can effectively reduce water wastage and customize irrigation to suit the specific requirements of crops, resulting in a notable decrease in water usage by around 30-40% compared to conventional methods (Nciizah et al., 2022). Additionally, the adoption of no-till technology allows for precise monitoring of soil and plant conditions, facilitating tailored applications of fertilizers and pesticides. This, in turn, helps in cutting down input costs and mitigating environmental impacts such as water and soil pollution (Nciizah et al., 2022).

To evaluate the financial implications of integrating technology into no-till farming practices, conducting a cost-benefit analysis is essential. While the initial investment in technology such as no-till planting machines and soil sensor systems may be substantial, research suggests that the long-term cost savings and increased crop yields surpass these initial expenses (Nciizah et al., 2022). Furthermore, the implementation of no-till technology can enhance soil health, reduce erosion, and boost net returns by up to 20-25% in the initial years, with profits continuing to rise as efficiency improves and input costs decrease (Nciizah et al., 2022).

The combination of technological innovation and no-till farming not only enhances resource efficiency but also delivers significant economic advantages to farmers. This highlights the critical role of technology in enhancing efficiency, sustainability, and profitability in agriculture, emphasizing the necessity of ongoing technological progress to achieve these objectives.

3.2. Economic Sustainability in No-Till Farming

No-till farming, when combined with innovative technology, presents a promising pathway towards economic sustainability in agriculture. By utilizing technologies such as no-till planting machines and soil sensors, farmers can reduce operational costs significantly, with studies suggesting potential cost savings of 20-30% compared to traditional methods (Bronick & Lal, 2005). These cost reductions not only improve profitability but also establish a strong foundation for long-term economic viability.

Furthermore, the incorporation of technology in no-till farming results in increased crop yields and enhanced product quality. Precise management of soil and plant conditions facilitated by soil sensors and monitoring systems leads to improved plant health and higher yields, with research indicating potential yield increases of 15-20% compared to conventional practices (Bronick & Lal, 2005). Moreover, the controlled growing environment contributes to superior product quality, which can command higher market value, thereby increasing farmers' income.

The economic advantages of integrating technology into no-till farming highlight its potential to not only be environmentally sustainable but also highly profitable in the long run. This dual benefit makes a compelling case for farmers to adopt innovative technologies as a strategic approach to achieving economic sustainability and long-term profitability in agriculture.

3.2.1. Price and Market Stability

The economic sustainability of farmers in no-till farming is closely tied to their ability to achieve price and market stability. Technology plays a crucial role in enhancing economic stability by improving operational efficiency, product quality, and adaptability to market dynamics (Nasirahmadi & Hensel, 2022). Research has shown that the adoption of technology in no-till farming has a positive impact on farmers' economic stability (Ntshangase, 2018). Technologies such as digital monitoring systems and soil sensors enable farmers to manage their land more effectively, respond to environmental changes, and mitigate risks associated with crop failure due to extreme weather conditions (Nasirahmadi & Hensel, 2022).

Furthermore, no-till technology allows for diversification in farming practices, enabling farmers to produce various crops with better quality through efficient crop rotation and targeted fertilizer use (Ntshangase, 2018). This diversification reduces dependence on a single crop and helps farmers better navigate market price fluctuations (Ntshangase, 2018). Studies have indicated that farmers who embrace no-till technology experience increased economic stability, higher incomes, and improved resilience to market price fluctuations (Ntshangase, 2018). Research from the United States and Canada suggests that farmers utilizing no-till technology and digital monitoring systems not only enhance productivity but also command better selling prices in the market due to improved product quality (Ntshangase, 2018).

The integration of technology in no-till farming not only supports daily operations but also boosts long-term market competitiveness, thereby bolstering the economic sustainability of farmers (Nasirahmadi & Hensel, 2022). By reducing economic risks and enhancing product competitiveness, technology fosters a stable economic environment for farmers engaged in no-till farming practices (Nasirahmadi & Hensel, 2022). This highlights the critical role of technological innovation in achieving economic stability and sustainability in modern agricultural practices.

3.2.2. Synergy between Efficiency and Economic Sustainability

The integration of efficiency and economic sustainability in no-till farming practices is crucial for the enduring success of agricultural technology adoption. Practices like precision irrigation and soil sensors enhance resource utilization, boost crop yields, and lower operational expenses, resulting in increased and more consistent economic returns (Pang et al., 2016). Furthermore, no-till farming, by minimizing soil disturbance and erosion, plays a key role in preserving soil health, thereby promoting economic sustainability in both an ecological and economic context (Pang et al., 2016).

Nevertheless, challenges may arise, such as the high initial costs associated with technology adoption and the potential limitations in adapting to environmental and market fluctuations (Pang et al., 2016). Strategies like government subsidies, continuous farmer training, and technology diversification can help address these challenges (Pang et al., 2016). Additionally, social implications like decreased labor demands due to automation can be managed through retraining initiatives and the creation of alternative job opportunities (Pang et al., 2016).

To realize the synergy between efficiency and economic sustainability, the adoption of suitable technologies backed by policies and initiatives is essential. Recognizing potential challenges and implementing strategies to mitigate them can empower farmers to maximize the benefits of technology adoption while ensuring long-term economic sustainability (Pang et al., 2016).

4. Conclusions

The adoption of technological innovation in no-till farming practices shows great potential in increasing the efficiency and sustainability of the agricultural economy. Technologies such as no-till planting machines, soil sensors and digital monitoring systems

significantly increase productivity, reduce operational costs and improve the quality of crop yields. Studies have shown that more efficient resource management and increased crop yields provide significant long-term economic benefits for farmers. Additionally, this technology helps in achieving price and market stability by reducing economic risks and increasing product competitiveness in the market.

The implication of these findings is that technological innovation plays a crucial role in driving economic sustainability in no-till agriculture. Farmers who adopt this technology can see increased efficiency and productivity, which in turn supports long-term economic sustainability. Governments and other stakeholders need to encourage the adoption of these technologies through subsidies, training, and financing programs to help farmers overcome initial barriers to technology investment. In addition, the integration of this technology also has a positive impact on environmental sustainability by reducing soil erosion and improving soil health.

However, there are several limitations that need to be noted. First, the high initial costs of adopting the technology can be a significant barrier for many farmers, especially in developing countries. Second, reliance on technology requires a good understanding and skill in its use, which may require ongoing training and education. Third, existing research focuses more on short-term results, so long-term studies are needed to understand the full impact of this technology on economic and environmental sustainability.

To complement these findings, future research needs to focus on several aspects. First, longitudinal studies that examine the long-term impacts of no-till technology adoption on economic and environmental sustainability are urgently needed. Second, further research is needed to develop technological solutions that are more affordable and accessible to farmers in developing countries. Third, studies that explore the social impacts of technology adoption, such as changes in workforce needs and the impact on local communities, are also important to ensure that the benefits of this technology are felt across the board. Finally, research on the integration of other technologies that support no-till farming practices, such as biotechnology and automation technologies, can provide additional insights to improve overall agricultural efficiency and sustainability.

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