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Analysis of the Application of Precision Farming Technology in Increasing Rice Productivity in Indonesia

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ABSTRACT

***Purpose**: This study aims to analyze the impact of precision farming technology on the productivity and sustainability of rice cultivation in Indonesia. The research focuses on evaluating improvements in water efficiency, nutrient management, yield performance, and socio-economic outcomes when compared with conventional farming practices.*

***Subjects and Methods:** The study was conducted on selected rice fields across different regions of Indonesia. A comparative experimental design was employed, where one group of fields used conventional irrigation and nutrient practices, while the other applied precision farming technologies, including automated irrigation, soil moisture sensors, and site-specific fertilizer management. Data collection included field measurements, farmer surveys, and documentation from agricultural offices. Descriptive statistics were used to provide an overview, while inferential analyses (t-tests, ANOVA, and regression) tested the significance of differences in efficiency and productivity.*

***Results:** The findings indicate that precision farming reduced water consumption by 37% per cycle and fertilizer input by 22%, while maintaining soil stability. Rice yields increased by 23%, and the proportion of high-quality grains improved by 15%. Socio-economic benefits included a 30% reduction in labor costs, a 50% decrease in irrigation-related work time, and higher farmer satisfaction scores. These results confirm that precision farming not only enhances agronomic efficiency but also strengthens farmer livelihoods.*

***Conclusions:** Precision farming demonstrates strong potential for modernizing Indonesian rice cultivation by improving resource efficiency, increasing crop productivity, and supporting sustainable agriculture. Its large-scale adoption, however, requires supportive policies, affordable access to technology, and continuous farmer training to maximize long-term benefits.*

INTRODUCTION

Agriculture is a strategic sector for Indonesia, playing a crucial role in national food security and employing a large workforce (Setiartiti, 2021; Ngadi et al., 2023). One of the main commodities with high strategic value is rice, given that it is the staple food of the majority of the Indonesian population. Mariyono (2018) and Rachman et al. (2022) said that, however, rice productivity in Indonesia still faces various challenges, such as limited land, climate change, soil fertility degradation, and inefficient use of production inputs. These issues demand technological innovations that can increase productivity while protecting undesirable agricultural ecosystems.

Precision agriculture, or precision farming, is a modern innovation that utilizes information technology, sensors, global positioning systems (GPS), satellite imagery, and big data analytics to manage agricultural resources more precisely and efficiently (Yadav & Sidana, 2023; Mishra, 2021). The main concept of precision agriculture is doing the right thing, in the right place, at the right time, and in the right way, namely applying production inputs according to the needs of specific crops and land conditions. Thus, this technology is believed to increase productivity, reduce production costs, and mitigate negative impacts on the environment (Balafoutis et al., 2017; Omer, 2009).

In the context of rice paddies, the application of precision agriculture technology includes the use of soil moisture sensors for irrigation management, drones for land mapping and crop growth monitoring, crop-based fertilizer application, and early warning systems for pest and disease attacks. These innovations have the potential to address classic problems in rice farming in Indonesia, such as wasteful air use, unbalanced fertilizer dosages, and delayed pest control (Susanti et al., 2024).

According to Farid et al., (2023), several previous studies have shown that the application of precision agriculture can increase the efficiency of agricultural input use by 20–40% and boost crop yields. For example, research in developed countries such as Japan, the United States, and Australia has shown that the use of sensors and drones in agricultural land management can increase productivity and crop quality (Roslim et al., 2021). However, in Indonesia, the application of precision agriculture remains relatively limited, both in terms of technology adoption by farmers and support from government infrastructure and policies (Rusmayadi et al., 2023; Agussabti etal. 2022).

This gap raises an important question: to what extent can the application of precision agriculture technology increase rice paddy productivity in Indonesia, which has different land, climate, and socio-economic characteristics than those of developed countries. Therefore, a comprehensive scientific study is needed to assess the effectiveness of precision agriculture in the local context, while identifying challenges and opportunities for its implementation on the ground (Lindblom et al., 2017).

Theoretically, this research is grounded in a sustainable agricultural systems approach that emphasizes the integration of productivity, resource efficiency, and environmental sustainability (Ikerd, 1993; Dale et al., 2013; Janker et al., 2019). Precision agriculture is viewed as a technological instrument that supports sustainable intensification, namely increasing production without having to expand land, but rather through optimizing the use of inputs and technology (Herdiansyah et al., 2023). Therefore, the analysis of the application of precision agriculture in lowland rice cultivation is not only academically relevant but also has practical significance for national agricultural development policy.

With this background, this research aims to analyze the application of precision agriculture technology in increasing lowland rice productivity in Indonesia. This analysis is expected to provide an empirical overview of the technology's effectiveness, identify inhibiting and supporting factors for its implementation, and recommend strategies for the government, farmers, and the private sector to expand the adoption of precision agriculture as an effort to improve national food security.

METHODOLOGY

Research Design

The appropriate research design for this study is a quantitative experimental approach with a comparative design (Esser & Vliegenthart, 2017; Fischer et al., 2023). The research compares rice cultivation under conventional farming practices and precision farming technologies, focusing on irrigation, nutrient management, yield performance, and socio-economic factors. By conducting field trials across selected paddy fields in Indonesia, the study ensures that the observed differences are attributable to the application of precision farming tools such as soil moisture sensors, drone-based nutrient monitoring, and automated irrigation systems.

Data Collection Methods

Data were collected through a combination of field measurements, farmer surveys, and documentation studies. Agronomic parameters such as water usage, soil moisture, nutrient application rates, yield per hectare, and grain quality were directly measured in the field (Neupane & Guo, 2019). Socio-economic indicators, including labor costs, time allocation, and farmer satisfaction, were obtained through structured interviews and standardized questionnaires. Documentation from local agricultural offices was also used to provide contextual validation of production costs and resource use.

Data Analysis Techniques

The collected data were analyzed using descriptive statistics and inferential analysis. Descriptive statistics, such as means, percentages, and standard deviations, were employed to provide an overview of performance differences between conventional and precision farming systems. Inferential techniques, including t-tests and ANOVA, were used to determine the significance of differences in water use efficiency, fertilizer input, and yield outcomes. Furthermore, regression analysis was conducted to identify the relationship between technology adoption and productivity improvements, while Likert scale analysis was applied to quantify farmer satisfaction levels.

Validation and Reliability

To ensure reliability, data were collected across multiple planting cycles and locations, minimizing the risk of seasonal bias. Instruments such as soil moisture sensors and automated irrigation systems were calibrated before use to maintain measurement accuracy. Triangulation was achieved by cross-verifying field data with farmer-reported outcomes and official records. This methodological rigor strengthens the validity of the study, ensuring that the results accurately reflect the impact of precision farming in Indonesian rice cultivation.

RESULTS AND DISCUSSION

To assess the effectiveness of precision farming in Indonesian rice cultivation, several key parameters were measured and compared with conventional practices. The results are presented in a series of tables covering water management, nutrient efficiency, yield performance, and socio-economic impacts. These findings provide comprehensive evidence of how precision farming technologies influence both agronomic outcomes and farmer livelihoods. The first set of results focuses on water use efficiency, as irrigation management is one of the most critical challenges in rice production.

Table 1. Comparison of Water Use Efficiency between Conventional Irrigation and Precision Farming

Parameter	Conventional Irrigation	Precision Farming	Change
Average water use per cycle (L)	60	38	Saved 37%
Total water use per season (L)	4,200	2,640	Saved 37%
Irrigation frequency (times/week)	7	4	Reduced 43%

The results show that precision farming significantly improved water use efficiency in rice fields. By applying soil moisture sensors and automated irrigation scheduling, the average water use per cycle decreased from 60 liters to 38 liters, resulting in a 37% reduction. This improvement is crucial in Indonesia, where water resources are increasingly threatened by climate variability. Furthermore, irrigation frequency decreased from 7 times per week to only 4 times per week, which indicates that water application was more targeted and aligned with actual plant requirements. These findings highlight the potential of precision irrigation technology to reduce water wastage while maintaining soil moisture within an optimal range for rice growth.

Table 2. Fertilizer Application and Nutrient Efficiency

Parameter	Conventional Practice	Precision Farming	Change
Nitrogen fertilizer use (kg/ha)	220	170	Saved 23%
Phosphorus fertilizer use (kg/ha)	90	75	Saved 17%
Fertilizer efficiency index (%)	68	84	+24%

Precision farming reduced fertilizer input while increasing nutrient efficiency. The use of nitrogen decreased by 23% and phosphorus by 17%, without compromising crop productivity. Instead, precision-based nutrient management improved fertilizer efficiency from 68% to 84%, which indicates that nutrients were better absorbed by plants rather than lost through leaching or volatilization. This improvement is attributed to the site-specific application of fertilizers using variable rate technology (VRT) and crop monitoring tools. By avoiding excessive fertilizer application, not only are production costs reduced, but environmental risks such as soil degradation and water pollution are also minimized.

Table 3. Yield Performance of Rice under Precision Farming

Parameter	Conventional Practice	Precision Farming	Change
Average yield per hectare (tons)	5.2	6.4	+23%
Grain weight per panicle (g)	2.1	2.6	+24%
Percentage of high-quality grains (%)	73	88	+15%

Yield performance data confirm the positive impact of precision farming on rice productivity. Average yield increased from 5.2 tons/ha under conventional methods to 6.4 tons/ha with precision farming, representing a 23% improvement. Similarly, the grain weight per panicle rose by 24%, and the proportion of high-quality grains increased by 15%. These improvements demonstrate that precise control over water, nutrient management, and pest monitoring directly translates into higher productivity and better grain quality. Such outcomes are highly relevant for Indonesia's rice self-sufficiency targets and could contribute significantly to national food security.

Table 4. Socio-Economic Impact of Precision Farming Adoption

Indicator	Conventional Practice	Precision Farming	Change
Labor cost per season (Rp)	1,400,000	1,000,000	Saved 29%
Working time per week (hours)	12	6	Saved 50%
Farmer satisfaction index (1–5)	3.4	4.7	Significant increase

Beyond agronomic benefits, precision farming also delivered socio-economic advantages for farmers. Labor costs decreased by 29% due to reduced manual watering and fertilizer application, while weekly working time decreased by half. This suggests that precision technology not only enhances efficiency but also lightens the workload for farmers. Moreover, farmer satisfaction scores increased significantly from 3.4 to 4.7 (scale of 1–5), indicating that farmers perceived precision farming as more reliable, less labor-intensive, and more profitable. Such findings are crucial for encouraging wider adoption of precision technologies among smallholder farmers in Indonesia.

Discussion

Water Use Efficiency

The findings of this study confirm that precision farming significantly enhances water use efficiency in rice cultivation. By integrating soil moisture sensors and automated irrigation, farmers were able to reduce water use by 37% per cycle and lower irrigation frequency from seven times per week to only four. This aligns with previous studies reporting that sensor-based irrigation can optimize water distribution and prevent unnecessary losses. Such efficiency is particularly relevant in Indonesia, where climate variability and increasing water scarcity demand more sustainable irrigation practices (Rejekiningrum et al., 2022; Darma et al., 2025).

Nutrient Management and Fertilizer Efficiency

In addition to water savings, the application of precision farming led to reduced fertilizer input while increasing nutrient efficiency. Nitrogen and phosphorus use decreased by 23% and 17%, respectively, while the fertilizer efficiency index rose to 84%. These results demonstrate that site-specific nutrient management avoids over-application, minimizes leaching, and supports balanced soil fertility. Compared with conventional blanket fertilization practices, precision technologies enable more targeted interventions, thus reducing production costs while maintaining environmental sustainability (Nath, 2024).

Yield Improvement and Grain Quality

The positive impact of precision farming on yield performance is evident from the increase in average yield per hectare (23%) and the higher percentage of quality grains (15%). These findings highlight that optimizing water and nutrient use does not compromise productivity; instead, it strengthens crop performance. The results support global research showing that precision farming can improve both yield quantity and quality by reducing crop stress and ensuring optimal growing conditions. For Indonesia, which prioritizes rice self-sufficiency, this technological shift could play a critical role in ensuring stable food production.

Socio-Economic Implications

Beyond agronomic outcomes, precision farming also generated significant socio-economic benefits. Labor costs were reduced by 29%, and working hours decreased by half, indicating that technology adoption can ease farmers' workload while improving efficiency. Moreover, farmer satisfaction increased considerably, reflecting the perceived advantages of higher profitability, reduced effort, and better crop reliability (Kassem et al., 2021). Such findings emphasize that precision farming is not only a technical solution but also a socio-economic driver that can enhance farmer livelihoods and promote wider adoption in rural communities.

Broader Implications and Policy Relevance

Overall, the study demonstrates that precision farming offers a holistic advantage by combining resource efficiency, productivity gains, and socio-economic benefits. The evidence suggests that wider implementation of precision agriculture could significantly contribute to national food security goals while reducing environmental pressures (Getahun et al., 2024). However, the transition requires strong institutional support, training, and access to affordable technology for smallholder farmers. Policymakers and stakeholders in Indonesia should therefore consider precision farming as a strategic investment to modernize the agricultural sector and strengthen resilience against climate change.

CONCLUSION

This study demonstrates that the application of precision farming technologies in Indonesian rice cultivation significantly improves agricultural efficiency, productivity, and sustainability. The integration of automated irrigation systems, soil moisture sensors, and site-specific nutrient management reduced water usage by up to 37% per cycle and fertilizer inputs by more than 20%, while maintaining optimal soil conditions. These findings highlight the role of precision farming in addressing resource scarcity and supporting environmentally responsible practices. The adoption of precision farming also resulted in higher yields and improved grain quality. Average rice productivity increased by 23%, and the proportion of high-quality grains rose by 15%, underscoring the potential of technology-driven farming to strengthen food security in Indonesia. These improvements demonstrate that sustainable resource management can coexist with enhanced crop performance, thereby challenging the assumption that environmental conservation limits agricultural productivity. In addition to agronomic benefits, precision farming provided notable socio-economic impacts. Operational labor costs declined by nearly 30%, and time allocated to irrigation and crop monitoring was reduced by half. Farmers reported higher satisfaction levels, reflecting improved profitability, reduced workload, and increased confidence in crop outcomes. These socio-economic advantages suggest that precision farming is not only a technological solution but also a catalyst for rural development. Overall, the study concludes that precision farming is a strategic innovation that can modernize Indonesian agriculture, enhance farmer livelihoods, and contribute to long-term food security. However, successful large-scale adoption will require supportive policies, affordable access to technology, and continuous farmer training to bridge the gap between technological potential and practical implementation.

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