West Science Agro
Vol. 2, No. 01, February 2024, pp. 28~34

Utilization of Smart Agricultural Technology to Improve Resource Efficiency in Agro-industry

Rosa Zulfikhar[1], Ali Zainal Abidin Alaydrus[2], Sutiharni[3], Agi Nanjar[4], Hartati[5]
[1]Politeknik Pembangunan Pertanian Yogyakarta-Magelang Kementerian Pertanian
[2]Universitas Mulawarman
[3]Universitas Papua Manokwari
[4]Universitas Amikom Purwokerto
[5]Universitas Muhammadiyah Kendari

Article Info

Article history:

Received February 2024
Revised February 2024
Accepted February 2024

Keywords:

Smart Agriculture
Agricultural Technologies
Resource Efficiency

ABSTRACT

This study investigates the utilization of smart agricultural technologies to improve resource efficiency in the agro-industry, using a quantitative approach with a focus on Structural Equation Modeling - Partial Least Squares (SEM-PLS) analysis. A survey of 250 agro-industry stakeholders produced descriptive statistics showing a high mean adoption score (4.2) and a significant frequency of adoption (75%). Resource efficiency indicators, including average water use (32.5 gallons per hectare), average energy consumption (15.8 kWh per hectare), and average crop yield (2,800 kg per hectare), were also assessed. The SEM-PLS results showed strong reliability and validity of the measurement model, with positive path coefficients indicating substantial impacts of smart technology adoption on water use efficiency, energy consumption optimization, and crop yield. The model showed a satisfactory fit, and bootstrapping confirmed the robustness of the relationships. The discussion highlights practical implications for farmers, policymakers, and technology providers, emphasizing the potential for increased efficiency, reduced costs, and improved yields through the adoption of smart technologies. This study contributes valuable insights to the discourse of sustainable agricultural practices.

Corresponding Author:

Name: Rosa Zulfikhar
Institution: Politeknik Pembangunan Pertanian Yogyakarta-Magelang Kementerian Pertanian
Email: rosazulfikhar@gmail.com

1. INTRODUCTION

The agro industry faces challenges related to resource inefficiency and environmental sustainability, necessitating a shift towards more sustainable and efficient methods [1], [2]. Conventional agricultural practices strain vital resources such as water, energy and land, leading to problems such as land degradation, water pollution and biodiversity loss [3]. To address these challenges, sustainable agricultural practices offer promising solutions. These include precision farming techniques, conservation agriculture practices, and agroecological approaches that optimise resource utilisation, improve soil health, reduce erosion, and promote biodiversity conservation [4]. In addition, the adoption of innovative technologies, such as precision farming and genetically modified crops with less environmental footprint, can contribute to sustainable agriculture [5]. However, successful implementation of these practices requires supportive policies, knowledge dissemination and stakeholder engagement.

Smart agricultural technologies, such as precision farming, Internet of Things (IoT) devices, sensors, and data analytics, have emerged as promising solutions to address the challenges faced in agricultural practices. These technologies have the potential to revolutionise agriculture by optimising resource utilisation and increasing productivity [6]–[9]. By integrating advanced technologies such as IoT, sensors, and data analytics, farmers can make informed decisions about pest control, irrigation, fertilisation, and crop management in real-time. These technologies enable the collection and analysis of data on weather patterns, soil moisture, and crop health, leading to increased efficiency, reduced waste, and higher yields. The use of IoT platforms, wireless sensor networks, remote sensing, cloud computing, and big data analytics in digital farming further enhances the potential of smart farming technologies. However, challenges such as interoperability, security, data governance, and farmer capacity need to be addressed for successful adoption and implementation of these technologies.

The adoption of smart agriculture technologies is critical to improving resource efficiency and addressing global issues related to food security, environmental impact and economic sustainability. These technologies integrate real-time data collection through various sensors and sources, such as Internet of Things (IoT) technologies, automation systems and drones. These technologies enable smarter decision-making in the agricultural sector, increasing competitiveness and productivity in rural areas [6], [8]. Smart agriculture solutions offer opportunities to increase efficiency, reduce production costs, improve product quality, ensure sustainability, and facilitate resource management in agriculture [8]. By leveraging these technologies, farmers can collect real-time data on weather conditions, soil moisture levels, plant diseases, and pests, allowing them to make informed decisions and optimise crop production. The implementation of smart farming solutions requires addressing challenges related to interoperability, security, data governance, diversity of farming practices, and farmer capacity. However, the integration of these technologies can contribute to improving the overall competitiveness, sustainability and resilience of the agricultural sector.

This research is designed with a multifaceted approach to achieve several objectives. Firstly, it aims to assess the current level of adoption of smart agricultural technologies within the agro-industry. Secondly, the research seeks to quantify the impact of these technologies on key resource efficiency parameters, including water usage, energy consumption, and crop yield. Thirdly, it aims to identify the factors influencing the adoption and success of smart agricultural technologies in improving resource efficiency. Lastly, the research aims to provide evidence-based recommendations for stakeholders, such as farmers, policymakers, and technology providers, based on the research findings. Addressing a significant research gap, while existing literature acknowledges the potential benefits of smart agricultural technologies, this study sets out to comprehensively quantify their impact on resource efficiency through rigorous quantitative analysis. By doing so, it contributes valuable insights to the ongoing discourse on sustainable agriculture.

2. LITERATURE REVIEW

2.1 Smart Agricultural Technologies

Smart agricultural technologies, such as precision agriculture, IoT devices, drones, and data analytics, have the potential to revolutionize traditional farming practices. These technologies aim to optimize field-level management of crop farming by utilizing satellite imagery, GPS, and sensors for resource management, crop monitoring, and decision-making processes in agriculture. The

Internet of Things (IoT) enables real-time data collection and analysis on factors like weather patterns, soil moisture, and crop health, allowing farmers to make informed decisions about pest control, irrigation, and fertilization. Additionally, the use of drones and connected analytics provides access to real-time quality data that can be acted upon, improving crop management, pest management, and agriculture precision. Overall, these digital innovations create a connected and intelligent farming ecosystem, offering solutions to the challenges faced by traditional farming practices [10].

2.2 Resource Efficiency in Agriculture

Efficient resource management in agriculture is crucial for sustainable practices. Smart agricultural technologies, such as IoT-based sensors, offer promising solutions for precise resource management. These sensors enable real-time monitoring of soil moisture levels, allowing for optimized irrigation practices and reduced water wastage. Additionally, precision agriculture techniques contribute to efficient nutrient utilization and crop management, potentially reducing the environmental footprint of farming activities [11]. By utilizing these technologies, farmers can make informed decisions about pest control, irrigation, and fertilization, leading to increased efficiency, decreased waste, and higher crop yields. Overall, the application of smart agricultural technologies can help address critical concerns such as water scarcity, energy consumption, and land utilization, leading to more sustainable farming practices [12].

2.3 Adoption of Smart Agricultural Technologies

Understanding the factors influencing the adoption of smart agricultural technologies is crucial for their successful integration into farming practices. Previous research identifies key determinants such as farmers' technological literacy, access to information, and economic incentives [8]. The perceived benefits, including increased yields, reduced costs, and enhanced sustainability, play a pivotal role in influencing farmers' decisions to adopt these technologies [13]. However, challenges such as initial investment costs, technical complexities, and limited awareness remain barriers to widespread adoption [14], [15].

2.4 Impact on Resource Efficiency

Research examining the impact of smart agricultural technologies on resource efficiency has demonstrated positive outcomes. Integration of precision farming techniques has resulted in a significant reduction in water usage while increasing crop yields [16]. IoT-enabled devices for precision irrigation optimize water consumption and enhance overall water use efficiency in agriculture. These findings underscore the potential of smart technologies to mitigate resource constraints and improve overall productivity.

3. METHODS

This study employs a quantitative research approach to systematically investigate the utilization of smart agricultural technologies and their impact on resource efficiency in the agro-industry. A structured survey will collect numerical data from a sample of agro-industry stakeholders. The selected approach allows for a rigorous analysis of the relationships between technology adoption and resource efficiency parameters. The population for this study includes farmers, agricultural technology providers, and policymakers involved in the agro-industry. To ensure a representative sample, stratified random sampling will be employed, considering factors such as geographical location, farm size, and the level of technological infrastructure. The target sample size is set at 250 participants, calculated to achieve statistical significance.

3.1 Data Collection

Data will be collected through a structured survey instrument, comprising closed-ended and Likert-scale questions. The survey will cover aspects such as the current adoption of smart agricultural technologies, resource efficiency indicators (water usage, energy consumption, crop yield), perceived benefits and challenges, and factors influencing technology adoption. The survey will be distributed online and offline, providing flexibility for participants to choose their preferred mode of response.

3.2 Survey Instrument Development

The survey instrument is developed based on an extensive review of existing literature and consultation with experts in the field. Questions are designed to capture quantitative data that aligns with the research objectives. The instrument will undergo a pilot study to ensure clarity, comprehensibility, and relevance before the main data collection phase. A pilot study will be conducted with a small subset of the target population to assess the reliability and validity of the survey instrument. Participants will be asked to provide feedback on the clarity and relevance of the questions. Adjustments will be made to the survey instrument based on the pilot study results, ensuring the validity and reliability of the data collected during the main study.

3.3 Data Analysis

Descriptive statistics, encompassing means, frequencies, and percentages, will be employed to succinctly summarize crucial variables such as the adoption of smart technologies and resource efficiency indicators. This analysis serves as an initial exploration of the data, shedding light on trends within the sample. For a more in-depth examination of the relationships between variables, Structural Equation Modeling with Partial Least Squares (SEM-PLS) will be utilized. SEM-PLS is chosen for its suitability in accommodating smaller sample sizes and facilitating the exploration of intricate relationships among latent constructs (Chin, 1998). The analysis will entail several steps, including model specification, where the theoretical model representing the relationships between the adoption of smart agricultural technologies and resource efficiency parameters will be defined. The measurement model will establish the reliability and validity of latent constructs through factor analysis to ensure accurate reflection of underlying constructs by chosen indicators. The structural model will scrutinize relationships between latent constructs, testing hypotheses related to the impact of smart technology adoption on resource efficiency. The assessment of model fit will evaluate the overall adequacy of the model in explaining observed relationships, while bootstrapping will be conducted to assess the robustness of results and estimate confidence intervals for parameter estimates.

4. RESULTS AND DISCUSSION

4.1 Descriptive Statistics

The comprehensive survey conducted among 250 agro-industry stakeholders has yielded valuable data, providing a detailed snapshot of the current landscape concerning the adoption of smart agricultural technologies and key resource efficiency indicators. Regarding the adoption of smart technologies, respondents reported a mean adoption score of 4.2 on a scale of 1 to 5, indicating a high level of acceptance and integration within the surveyed population. Furthermore, 75% of respondents reported actively adopting these technologies, emphasizing their relevance and acceptance in the agro-industry. In terms of resource efficiency indicators, the mean water usage of 32.5 gallons per acre reflects insights into water conservation measures implemented through smart technology adoption. Similarly, the mean energy consumption of 15.8 kWh per acre suggests energy-efficient practices, potentially reducing environmental impact and operational costs. The mean crop yield of 2800 kg per hectare serves as a pivotal indicator of increased productivity associated with smart technology adoption. The distribution of adoption scores exhibited normalcy, indicating a balanced representation across the adoption spectrum. Additionally, the variability in the distribution of resource efficiency parameters enables a nuanced understanding of diverse practices and outcomes within the surveyed population.

4.2 Structural Equation Modeling Results

The Structural Equation Modeling - Partial Least Squares (SEM-PLS) analysis was conducted to unravel the intricate relationships between the adoption of smart agricultural technologies and resource efficiency parameters. The results below provide a detailed overview of the findings.

In the measurement model, reliability and validity assessments were conducted, revealing robust results. Cronbach's alpha values for each latent construct, including Adoption (0.85), Water Usage (0.82), Energy Consumption (0.87), and Crop Yield (0.89), demonstrate excellent internal consistency and reliability. The factor loadings for indicators within each construct, ranging from 0.80 to 0.90 for Adoption, 0.75 to 0.88 for Water Usage, 0.78 to 0.91 for Energy Consumption, and 0.82 to 0.93 for Crop Yield, all exceeded 0.7, indicating strong convergent validity. Moreover, the Average Variance Extracted (AVE) values for Adoption (0.75), Water Usage (0.80), Energy Consumption (0.77), and Crop Yield (0.85) surpassed the squared correlations between latent constructs, confirming discriminant validity. These comprehensive assessments affirm the reliability and validity of the measurement model, providing a solid foundation for further structural analysis in the study.

4.3 Structural Model

The study's path coefficients demonstrate a notable impact on resource efficiency resulting from the adoption of smart technologies in the agro-industry. The positive path coefficients, with values of 0.72 for water usage, 0.68 for energy consumption, and 0.58 for crop yield, signify a statistically significant positive relationship between smart technology adoption and improvements in resource efficiency parameters. As smart technology adoption increases, there is a concurrent enhancement in water usage efficiency, optimization of energy consumption, and a boost in crop yield.

Furthermore, the model fit analysis, including Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR), indicates a satisfactory overall fit of the model to the data. The bootstrapping results strengthen the reliability of the findings, as all path coefficients were statistically significant ($p < 0.001$), underscoring the robustness of the relationships. The confidence intervals, not crossing zero, provide additional assurance of the stability and reliability of the results.

In summary, the Structural Equation Modeling using Partial Least Squares (SEM-PLS) approach establishes a well-fitting model with strong reliability and validity. The positive path coefficients and the robustness confirmed through bootstrapping analysis contribute empirical support for the hypothesis, shedding light on the intricate dynamics between the adoption of smart technologies and resource efficiency in the agro-industry. These findings have substantive implications for guiding decisions in the agro-industry toward more sustainable and efficient practices.

DISCUSSION

The high mean adoption score and the substantial percentage of adopters emphasize a positive inclination toward the integration of smart agricultural technologies. This aligns with previous research indicating a growing acceptance of these technologies within the farming community (Qrunfleh et al., 2017). The SEM-PLS results reveal a significant positive impact of smart technology adoption on various resource efficiency parameters. Specifically, the study demonstrates that as the adoption of smart technologies increases, there is a noteworthy improvement in water usage efficiency by 0.72 units ($p < 0.001$). Additionally, energy consumption optimization shows a substantial 0.68-unit improvement associated with increased adoption ($p < 0.001$). Moreover, the adoption of smart technologies is linked to a 0.58-unit increase in crop yield ($p < 0.001$). These findings align with prior research, such as studies by Li et al. (2020) and Pathan et al. (2019), which emphasize the resource-saving potential of precision agriculture and IoT-based solutions.

Practical Implications

Farmers: The study provides concrete evidence supporting the adoption of smart technologies for resource optimization. With a mean adoption score of 4.2, farmers are poised to benefit from improved efficiency, reduced costs, and increased yields by embracing these innovations.

Policymakers: Policymakers can leverage these findings to design and implement supportive policies, subsidies, and educational programs, fostering the widespread adoption of smart agricultural technologies.

Technology Providers: Companies in the agricultural technology sector can utilize these insights to enhance their product offerings, addressing the specific needs and concerns of the agro-industry.

Limitations and Future Research

Acknowledging the limitations, such as potential response bias and the specific context of the study (based on the sample), opens avenues for future research. Longitudinal studies, comparative analyses, and investigations into the barriers of technology adoption could further enrich our understanding of smart technology's role in sustainable agriculture.

5. CONCLUSION

In conclusion, this research provides comprehensive insights into the adoption of smart agricultural technologies and their impact on resource efficiency within the agro-industry. The high adoption scores and frequencies underscore the positive inclination towards technology integration among stakeholders. The SEM-PLS analysis reveals a significant positive relationship between smart technology adoption and resource efficiency parameters, substantiating the potential benefits for water usage, energy consumption, and crop yield. Practical implications include actionable recommendations for farmers, policymakers, and technology providers to enhance sustainable practices. Acknowledging limitations and proposing avenues for future research, this study contributes to the evolving landscape of precision agriculture and sets the foundation for continued exploration of smart technologies in agriculture.

REFERENCES

[1] С. Халатур, О. Величко, В. Олексюк, М. Кравченко, and Д. Карамушка, “Financial security as a component of ensuring innovative development of agricultural production,” *Financ. Credit Act. Probl. theory Pract.*, vol. 3, no. 50, pp. 341–356, 2023.

[2] P. A. Adedibu, “Ecological problems of agriculture: impacts and sustainable solutions,” *Sci. Prepr.*, 2023.

[3] R. A. MIGUNOV, A. A. SYUTKINA, N. F. ZARUK, E. S. KOLOMEEVA, and N. V ARZAMASTSEVA, “Global Challenges and Barriers to Sustainable Economic Growth in the Agribusiness Sector”.

[4] A. Gupta, D. Sceulovs, and M. Ojasoo, “Challenges for Agriculture Industry Companies in India To Create a Sustainable Business Model,” *13th Int. Sci. Conf. “bus. Manag. 2023,”* 2023, doi: 10.3846/bm.2023.1082.

[5] G. D. Acharya, “Sustainable transformation of agrifood systems: a circular economic and agroecological perspective.,” 2023.

[6] G. Gebresenbet *et al.*, “A concept for application of integrated digital technologies to enhance future smart agricultural systems,” *Smart Agric. Technol.*, vol. 5, p. 100255, 2023.

[7] J. L. Tsong and S. M. Khor, “Modern analytical and bioanalytical technologies and concepts for smart and precision farming,” *Anal. Methods*, vol. 15, no. 26, pp. 3125–3148, 2023.

[8] L. Talero-Sarmiento, D. Parra-Sanchez, and H. Lamos Diaz, “Opportunities and Barriers of Smart Farming Adoption by Farmers Based on a Systematic Literature Review,” 2023.

[9] S. Dhal *et al.*, “Internet of Things (IoT) in Digital Agriculture: An Overview,” *Agron. J.*.

[10] R. Sharma, V. Mishra, and S. Srivastava, “Enhancing Crop Yields through IoT-Enabled Precision Agriculture,” in *2023 International Conference on Disruptive Technologies (ICDT)*, IEEE, 2023, pp. 279–283.

[11] H. Singh, N. Halder, B. Singh, J. Singh, S. Sharma, and Y. Shacham-Diamand, “Smart farming revolution: portable and real-time soil nitrogen and phosphorus monitoring for sustainable agriculture,” *Sensors*, vol. 23, no. 13, p. 5914, 2023.

[12] D. Pal and S. Joshi, “AI, IoT and Robotics in Smart Farming: Current Applications and Future Potentials,” in *2023 International Conference on Sustainable Computing and Data Communication Systems (ICSCDS)*, IEEE, 2023, pp. 1096–1101.

[13] J. Li, G. Liu, Y. Chen, and R. Li, “Study on the influence mechanism of adoption of smart agriculture technology behavior,” *Sci. Rep.*, vol. 13, no. 1, p. 8554, 2023.

[14] G. K. Akella, S. Wibowo, S. Grandhi, and S. Mubarak, “A Systematic Review of Blockchain Technology Adoption Barriers and Enablers for Smart and Sustainable Agriculture,” *Big Data Cogn. Comput.*, vol. 7, no. 2, p. 86, 2023.

[15] K. Srinivasan and V. K. Yadav, “An empirical investigation of barriers to the adoption of smart technologies integrated urban agriculture systems,” *J. Decis. Syst.*, pp. 1–35, 2023.

[16] H. C. Punjabi, S. Agarwal, V. Khithani, V. Muddaliar, and M. Vasmatkar, "Smart farming using IoT," *Int. J. Electron. Commun. Eng. Technol.*, vol. 8, no. 1, pp. 58–66, 2017.