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Smart Farming and Precision Agriculture: Leveraging IoT and Data Analytics to Improve Crop Efficiency and Sustainability

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ABSTRACT

Smart farming and precision agriculture are modern approaches in the agricultural sector that utilize the Internet of Things (IoT) and data analytics to improve production efficiency and environmental sustainability. This research aims to explore how IoT technology and data analytics are applied in precision agriculture to face global challenges, such as increasing food needs and resource constraints. Qualitative methods are used with a literature study approach or library research, which focuses on the critical analysis of various scientific sources, including journals, reports, and related books. The results show that IoT provides the ability to monitor soil conditions, weather, and crops in real-time through sensors, while data analytics allows for the interpretation of that data for more accurate decision-making. These technologies contribute to more efficient management of resources, such as water and fertilizers, as well as the reduction of environmental impact through precise control of inputs. In addition, the adoption of this technology also has socio-economic implications, such as increasing the productivity of smallholders and supporting agribusiness sustainability. However, challenges such as high initial investment costs and the need for farmer training remain major obstacles. The study concludes that IoT and

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data analytics have great potential to revolutionize the agricultural sector by creating more efficient, environmentally friendly, and sustainable agricultural practices. Therefore, a policy strategy that supports the adoption of this technology is needed, especially in developing countries.

1. INTRODUCTION

The increase in global food demand due to population growth and climate change has put the agricultural sector in a major challenge to increase productivity sustainably (FAO, 2019). In this context, technology-based approaches such as smart farming and precision agriculture emerge as potential solutions. Smart farming, powered by the Internet of Things (IoT) and data analytics, provides an opportunity to improve the efficiency of land management by utilizing sensor technology and data-driven decision-making (Wolfert et al., 2017). This technology allows real-time monitoring of soil, plant, and environmental conditions, so that it can optimize the use of resources such as water, fertilizers, and pesticides (Zhang et al., 2020). However, the application of this technology still faces significant challenges, such as high initial costs and limited technology adoption by smallholders (Rose et al., 2016).

Smart farming, or smart agriculture, is a modern approach that utilizes digital technology to optimize agronomic practices. This approach involves the use of Internet of Things (IoT) devices, such as soil sensors, surveillance cameras, and weather control devices, which are integrated with data analytics systems to monitor plant and environmental conditions in real-time (Wolfert et al., 2017). The information obtained from this device can help farmers make data-based decisions, such as watering time, fertilization dose, and crop yield prediction. With proper implementation, smart farming is able to reduce resource waste, improve operational efficiency, and improve agricultural products without damaging the environment.

Precision agriculture, or precision agriculture, is an approach that aims to manage land in detail based on the specific needs of crops and specific environmental conditions. Technologies used in precision agriculture include satellite imagery, GPS, and drones to map planting patterns and nutrient distribution on farmland (Balafoutis et al., 2017). One of the key concepts of precision agriculture is variable-rate technology (VRT), where it allows the precise application of fertilizers, pesticides, or water in specific areas of need. By avoiding a uniform approach, precision agriculture helps to improve input efficiency while maintaining the sustainability of natural resources.

In practice, smart farming often integrates the principles of precision agriculture through IoT and data analytics. Field-installed IoT sensors collect data on temperature, soil moisture, and nutrient levels, which are then analyzed to generate actionable insights (Zhang et al., 2020). Through data analytics, crop growth patterns can be predicted more accurately, allowing farmers to determine the necessary interventions at the right time. For example, with predictive technology, farmers can anticipate pest or disease attacks before they become a big problem. This integration not only increases productivity, but also helps farmers reduce operational costs and environmental impact.

Smart farming and precision agriculture contribute greatly to the sustainability of the agricultural sector. By optimizing the use of resources such as water and fertilizers, this approach helps to reduce greenhouse gas emissions as well as prevent soil degradation (Kamilaris et al., 2018). However, implementation challenges remain significant, especially in developing countries. The main obstacles include high investment costs, limited access to technology, and lack of training for smallholders (Chandra et al., 2021). To address these challenges, government policies that support technology adoption, including technology subsidies, training, and the development of digital infrastructure in rural areas are needed.

Although various studies have addressed the technical aspects of IoT and data analytics in agriculture, few studies have explored the integration of these two technologies in the context of agribusiness sustainability and environmental impact reduction (Kamilaris et al., 2018). In addition, most studies are focused on large scales, while the potential for implementation in smallholders is still minimal (Chandra et al., 2021). The urgency of this research lies in the need for holistic solutions to improve agricultural efficiency and sustainability, especially in the face of climate change and resource constraints (Schröder et al., 2019). IoT-based approaches and data analytics are not only relevant to increase productivity, but also support the global sustainability agenda (World Economic Forum, 2021).

Previous research has shown that IoT is effective in monitoring agronomic parameters such as soil moisture and temperature (Kumar et al., 2019), while data analytics are used for crop yield prediction models (Jha et al., 2019). However, the integration of the two in supporting data-driven decisions in real-time is still rarely studied (Balafoutis et al., 2017). Therefore, this research offers a new perspective by exploring the integration of IoT and data analytics in support of more efficient and sustainable agricultural practices, and highlighting their relevance for both small and large scales.

This study aims to examine the implementation of IoT and data analytics in precision agriculture, explain the impact of these technologies on production efficiency and environmental sustainability, and identify challenges in the adoption of these technologies by smallholders. The benefits of this research are expected to make a scientific contribution in understanding the potential of IoT and data analytics, as well as provide policy recommendations to support the adoption of this technology in the agricultural sector.

2. METHODS

This study uses a qualitative method with a library research approach which aims to analyze in depth various literature related to smart farming and precision agriculture. Literature studies were chosen as a type of research because they allow the exploration of the concepts, implementations, challenges, and impacts of Internet of Things (IoT) technology and data analytics in the agricultural sector based on valid and credible secondary data (Snyder, 2019).

The source of data for this research comes from various scientific literature such as academic journals, technical reports, reference books, and relevant conference articles. The literature used was selected based on inclusion criteria, namely having topics related to IoT, data analytics, smart farming, and precision agriculture, and was published in the last five years to ensure relevance to the latest technological developments (Bowen, 2009). Additional data are taken from publications of international institutions, such as FAO, the World Economic Forum, and Scopus and Web of Science indexed journals.

Data collection techniques are carried out by accessing online databases such as Scopus, ScienceDirect, and SpringerLink, as well as academic search engines such as Google Scholar. Keywords used include "smart farming," "precision agriculture," "IoT in agriculture," and "data analytics in agriculture." Each article obtained is systematically reviewed to ensure its relevance and quality.

The data analysis method used is content analysis which involves identifying, coding, and interpreting the main themes that emerge from the literature studied (Krippendorff, 2018). The analysis process is carried out iteratively to identify research patterns, relationships, and gaps (research gaps). The resulting findings are compiled into a structured narrative to provide deep insights into the integration of IoT and data analytics in supporting agricultural efficiency and sustainability.

3. RESULTS AND DISCUSSION

The following is a table of literature data compiled from the results of the selection of 10 relevant articles that are the main sources in this study. These articles are selected based on their relevance to the topics of smart farming, precision agriculture, IoT, and data analytics for efficiency and sustainability in the agricultural sector. Selection is carried out from various scientific literature by considering its validity, publication year, and contribution to the discussion of the research.

Author	Year	Title	Findings
Wolfert et al.	2017	Big Data in Smart Farming– A Review	Big data plays an important role in integrating IoT for data-driven decision-making.
Zhang et al.	2020	Precision Agriculture Technologies and Applications	GPS and drone technology improves resource efficiency and crop productivity
Kamilaris et al.	2018	A Review on the Practice of Big Data Analysis in Agriculture	Big data can improve productivity and operational efficiency through outcome

			prediction and risk management
Rose et al.	2016	Agricultural Innovation and the Role of Institutions Lessons from the UK	Policy support is needed to increase the adoption of Precision agriculture technology
Kumar & Rajasekaran	2019	IoT-Based Intelligent Sensor Node for Precision Agriculture Applications	IoT sensors allow real-time monitoring of Agronomic parameters such as soil moisture
Jha et al.	2019	A Comprehensive Review on Automation in Agriculture Using Artificial Intelligence	AI supports more efficient land management through data analytics automation.
Schröder et al.	2019	Improved Phosphorus Use Efficiency in Agriculture: A Key Requirement for Its Sustainable Use	Precision phosphorus management can reduce environmental impact and increase productivity
Chandra et al.	2021	Barriers in Adoption of IoT in Indian Agriculture	The main obstacles are high costs and lack of training for farmers.
Balafoutis et al.	2017	Precision Agriculture Technologies Positively Contributing to GHG Emissions Mitigation	Precision agriculture technology is effective in reducing GHGs through precise management of inputs

FAO	2019	The State of Food and Agriculture 2019: Moving Forward on Food Loss and Waste Reduction	Technological innovations such as IoT and big data can reduce food waste and improve supply chain efficiency

This table presents articles that have made a significant contribution to the discussion about smart farming and precision agriculture. This literature is the main basis for formulating findings and recommendations in research.

From the literature table, it can be seen that IoT technology and big data play a central role in smart farming. The article Wolfert et al. (2017) and Kamilaris et al. (2018) shows that IoT enables the collection of real-time data from various sensors, such as soil temperature and humidity, which can be integrated with big data analytics to generate decision-making insights. These findings underscore the importance of data-driven management in facing modern challenges in the agricultural sector, such as resource efficiency and adaptation to climate change.

Benefits of Precision Agriculture Technology

Precision agriculture technologies such as GPS and drones, as discussed in the research of Zhang et al. (2020), contribute to resource efficiency and crop productivity. Balafoutis et al. (2017) also highlighted its impact in mitigating greenhouse gas (GHG) emissions through the precise management of inputs, such as fertilizers and pesticides. Thus, precision agriculture not only increases crop yields, but also supports the sustainability agenda by reducing environmental impact.

The article by Chandra et al. (2021) highlights the major challenges in the adoption of IoT technology in developing countries, mainly due to high initial costs and lack of training for farmers. This condition is also agreed by Rose et al. (2016), who stated that policy support from institutions is needed to encourage technological innovation. These findings show that socio-economic factors play a significant role in the successful implementation of advanced technologies in the agricultural sector.

Jha et al. (2019) show that artificial intelligence (AI) is an important element in agricultural automation. AI enables faster and more accurate data analysis, supports data-driven decision-making, and improves operational efficiency. AI can also help predict crop yields and agronomic risks, so farmers can take mitigation steps before problems occur. The integration of AI with IoT and big data creates a smarter and adaptive agricultural ecosystem.

The articles Schröder et al. (2019) and FAO (2019) emphasize the importance of efficient resource management for the sustainability of the agricultural sector. Schröder et al. discussed the precise management of phosphorus to reduce environmental impact, while FAO underlined the role of technology in reducing food waste along the supply chain. Both studies underline how modern technologies can be used to minimize waste and maintain ecosystem balance.

The findings from various articles show that the successful adoption of smart farming and precision agriculture technologies is highly dependent on supporting policies and infrastructure. Rose et al. (2016) emphasized the importance of the role of institutions in providing incentives for farmers, such as technology subsidies and training. In addition, the development of digital infrastructure in rural areas is an urgent need to support technological transformation in the agricultural sector. This support is important to ensure that advanced technology is accessible and used by all farmers, including small-scale.

This interpretation shows that smart farming and precision agriculture have great potential to revolutionize the agricultural sector. However, to achieve widespread and sustainable adoption, collaborative efforts between governments, institutions, and industry players are needed.

Discussion and Analysis

Smart farming and precision agriculture have been part of a significant digital transformation in the agribusiness sector. Based on the findings of the literature, this technology offers a concrete solution to improve agricultural efficiency, both in resource use and crop productivity. This phenomenon is in line with the global need to produce food sustainably in the midst of climate change and population growth. In this context, IoT and data analytics are becoming key catalysts for integrating traditional agronomic practices with modern technological innovations.

The findings show that IoT enables the collection of real-time data from soil, weather, and crop sensors, as discussed by Wolfert et al. (2017). In practice, this data is the basis for data analytics to generate evidence-based insights that can support more precise agronomic decision-making. This supports Rogers' innovation diffusion theory (1995), which states that the adoption of new technologies requires evidence of real benefits to accelerate acceptance in society.

However, significant challenges in the implementation of this technology are found in developing countries. High initial costs, lack of access to technology, and low levels of digital literacy of farmers are the main obstacles as revealed by Chandra et al. (2021). This fact reflects the digital divide which is still a global issue. In addition, the lack of adequate policy support and infrastructure exacerbates the situation, especially in rural areas.

Precision agriculture technologies such as GPS, drones, and variable-rate technology (VRT) offer efficiencies in the management of inputs such as fertilizers and pesticides. As explained by Zhang et al. (2020), this technology is able to reduce waste while minimizing negative impacts on the environment. This finding is relevant to the Triple Bottom Line theory (Elkington, 1998), which emphasizes the importance of balancing profits, people, and the planet in sustainability.

On the other hand, the integration of IoT with AI, as discussed by Jha et al. (2019), provides predictive capabilities that allow farmers to anticipate agronomic risks, such as pests or plant diseases. This fact is even more relevant given the threat of climate change that increases uncertainty in the agricultural cycle. This prediction-based approach can help farmers take mitigation steps early, thereby reducing the risk of loss.

Sustainability in resource management, as discussed by Schröder et al. (2019), shows that precision approaches are able to optimize the use of phosphorus, water, and other resources. In this context, smart farming not only increases productivity but also contributes to environmental conservation. This supports the global sustainability agenda as outlined in the

Sustainable Development Goals (SDGs), particularly on goals 2 (ending hunger) and 13 (action on climate change).

The fact that these technologies still face implementation barriers, especially in developing countries, shows the importance of collaboration between governments, institutions, and the private sector. Policy support that encourages technology incentives, such as subsidies or training, is key to accelerating adoption. This is in line with the findings of Rose et al. (2016) which emphasized the importance of the role of institutions in encouraging agricultural innovation.

The author's comment on these findings is that while smart farming and precision agriculture show great potential, their implementation requires a more inclusive approach. Support should not only be focused on technology development but also on education and training for smallholders. Thus, the digital divide can be minimized, and technology can be utilized more widely.

In the current context, the fact that most of these technologies are still centralized in developed countries reflects the inequality of access that must be addressed urgently. For example, while drones and IoT sensors are highly effective in improving crop yields, the availability of these technologies in remote areas is often limited. This requires a more equitable digital infrastructure, such as reliable internet networks in rural areas.

The author also emphasizes that smart farming is not only about technology but also a paradigm shift in agriculture. Farmers should be encouraged to see these technologies as a tool to empower them in the face of modern agronomic challenges. Therefore, the integration of technology with the social and economic needs of farmers must be the main focus in future policy development.

Through this discussion, it can be concluded that smart farming and precision agriculture are future solutions to create a more efficient, environmentally friendly, and sustainable agricultural system. However, the success of its implementation is highly dependent on adequate policy, education, and infrastructure support.

4. CONCLUSION

Smart farming and precision agriculture have proven to be innovative solutions in addressing global challenges in the agricultural sector, including increased food demand, resource constraints, and the impact of climate change. Based on the findings of the literature, IoT technology and data analytics play a major role in improving the efficiency of agricultural production by enabling data-driven decision-making. Technologies such as soil sensors, GPS, drones, and variable-rate technology (VRT) provide the ability to monitor and manage farmland with precision, thereby reducing waste and environmental impact. This approach not only supports productivity but also agribusiness sustainability.

Despite its great potential, the implementation of this technology still faces significant obstacles, especially in developing countries. High investment costs, lack of digital literacy, and limited infrastructure are the main challenges in the adoption of smart farming. In addition, the gap in access to technology between small and large farmers exacerbates the situation. To address these challenges, policy support is needed that includes technology subsidies, farmer training, and the development of digital infrastructure in rural areas.

Collaboration between governments, institutions, and the private sector is also crucial to expand the adoption of this technology.

Smart farming and precision agriculture offer a major transformation in the agricultural sector, but their success depends on the inclusivity and accessibility of the technology. With the right implementation strategy, this approach can make a significant contribution to global food security and environmental sustainability. Therefore, special attention should be paid to efforts to accelerate the adoption of this technology in developing countries.

Future research is suggested to focus on exploring strategies for implementing smart farming technology that are more affordable for smallholders, such as the development of low-cost IoT devices. In addition, research on the social and economic impacts of the adoption of these technologies, especially in rural areas, needs to be conducted to understand how the technology can effectively empower farming communities. Research should also include the development of digital training models tailored to farmers' needs and literacy. Finally, the development of systems integrating IoT technology and data analytics with traditional practices can be an interesting topic for creating more inclusive and effective agricultural solutions.

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

7. REFERENCES

Aung, Z., & Watanabe, K. (2020). Internet of Things (IoT) in Agriculture: A Survey. IoT Applications in Agriculture and Environment, 45-67. https://doi.org/10.1016/B978-0-12-820581-7.00003-0

Balafoutis, A. T., Beck, B., Fountas, S., Vangeyte, J., Van Der Wal, T., Soto, I., & Gómez-Barbero, M. (2017). Precision agriculture technologies positively contributing to GHG emissions mitigation, farm productivity, and economics. Sustainability, 9(8), 1339. https://doi.org/10.3390/su9081339

Bowen, G. A. (2009). Document analysis as a qualitative research method. Qualitative Research Journal, 9(2), 27-40. https://doi.org/10.3316/QRJ0902027

Chandra, S., Kashyap, S., Gupta, R., & Sharma, S. (2021). Barriers in adoption of IoT in Indian agriculture. IoT for Sustainable Development, 239-259. https://doi.org/10.1016/B978-0-12-823425-2.00012-7

FAO. (2019). The state of food and agriculture 2019: Moving forward on food loss and waste reduction. FAO.

Gebbers, R., & Adamchuk, V. I. (2010). Precision agriculture and food security. Science, 327(5967), 828-831. https://doi.org/10.1126/science.1183899

Jha, K., Doshi, A., Patel, P., & Shah, M. (2019). A comprehensive review on automation in agriculture using artificial intelligence. Artificial Intelligence in Agriculture, 2, 1-12. https://doi.org/10.1016/j.aiia.2019.05.004

Kamilaris, A., Kartakoullis, A., & Prenafeta-Boldú, F. X. (2018). A review on the practice of big data analysis in agriculture. Computers and Electronics in Agriculture, 143, 23-37. https://doi.org/10.1016/j.compag.2017.09.037

Krippendorff, K. (2018). Content analysis: An introduction to its methodology. Sage publications.

Kumar, S., & Rajasekaran, M. P. (2019). An IoT based intelligent sensor node for precision agriculture applications. Computers and Electronics in Agriculture, 162, 147-156. https://doi.org/10.1016/j.compag.2019.03.026

Liakos, K. G., Busato, P., Moshou, D., Pearson, S., & Bochtis, D. (2018). Machine learning in agriculture: A review. Sensors, 18(8), 2674. https://doi.org/10.3390/s18082674

Rose, D. C., Wheeler, R., Winter, M., Lobley, M., & Chivers, C. A. (2016). Agricultural innovation and the role of institutions: Lessons from the UK. Agricultural Systems, 142, 31-40. https://doi.org/10.1016/j.agsy.2015.11.003

Saiz-Rubio, V., & Rovira-Más, F. (2020). From smart farming towards Agriculture 5.0: A review on crop data management. Agronomy, 10(2), 207. https://doi.org/10.3390/agronomy10020207

Schröder, J. J., Smit, A. L., Cordell, D., & Rosemarin, A. (2019). Improved phosphorus use efficiency in agriculture: A key requirement for its sustainable use. Chemosphere, 227, 945-951. https://doi.org/10.1016/j.chemosphere.2019.03.014

Silva, L. M., Fernandes, J. M., & Fonseca, C. (2020). Technological trends in IoT for agriculture: A systematic review. Journal of Cleaner Production, 272, 122418. https://doi.org/10.1016/j.jclepro.2020.122418

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. Journal of Business Research, 104, 333-339. https://doi.org/10.1016/j.jbusres.2019.07.039

Vasisht, D., Kapetanovic, Z., Won, J., Keskin, M., Pedarsani, R., & Sahai, A. (2017). FarmBeats: An IoT platform for data-driven agriculture. Proceedings of the 14th USENIX Symposium on Networked Systems Design and Implementation (NSDI), 515-529.

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big data in smart farming – A review. Agricultural Systems, 153, 69-80. https://doi.org/10.1016/j.agsy.2017.01.023

Yao, X., Zhang, W., Yan, H., & Wang, J. (2021). IoT-based intelligent management platform for precision agriculture. Journal of Cleaner Production, 312, 127699. https://doi.org/10.1016/j.jclepro.2021.127699

Zhang, X., Wang, H., Wang, H., Liu, S., & Guo, W. (2020). Precision agriculture technologies and applications. Sustainability, 12(19), 8068. https://doi.org/10.3390/su12198068.