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Analysis of the Effectiveness of Soil Moisture Sensors to Increase Productivity in Smart Agriculture

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INDEXING	ABSTRACT
Keywords: Keyword 1 : Soil Moisture Sensor Keyword 2 : Smart Agriculture Keyword 3 : Productivity Keyword 4 : Irrigation Keyword 5 : IoT	This study aims to analyze the effectiveness of soil moisture sensors in increasing productivity in smart agriculture systems. Along with the increasing demand for efficient and sustainable farming methods, soil moisture sensor technology is a promising solution for accurately monitoring and controlling soil moisture. This sensor helps optimise irrigation by providing real-time data that makes it easy to adjust the water supply according to plant needs, thereby reducing waste and saving water. This study was conducted on a test area of 1 hectare with two main treatments: land with an irrigation system based on soil moisture sensors and land with a conventional irrigation system. For three months, measurements of crop productivity and water use were carried out on both lands. The results show that the use of soil moisture sensors can increase plant productivity by 25% and save water use by up to 30% compared to traditional irrigation methods. These findings provide a solid foundation for the further development of resource-efficient and environmentally friendly smart farming systems. The results of this study are expected to encourage farmers to adopt soil moisture sensor technology to improve efficiency and sustainability in their agricultural practices.

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INTRODUCTION

The increasing demand for food in line with the growth of the world's population requires the agricultural sector to innovate in increasing productivity while optimizing the use of natural resources, especially water (Ziaulhaq & Amalia, 2022). One of the major challenges in the agricultural sector is ensuring sufficient water availability for crops without causing waste, especially in drought-prone areas (Sihombing & Siadari, 2023). Along with the development of technology, the concept of smart agriculture has begun to be widely applied. Smart farming relies on sensor technology and the Internet of Things (IoT) to monitor and control various environmental factors, including soil moisture, that directly affect plant growth (Wisesha *et al*., 2024).

Soil moisture sensors play a crucial role in smart farming systems by providing real-time data on soil moisture content. This technology allows irrigation systems to work automatically as per the needs of the plants, which not only saves water but also ensures that the plants receive an optimal water supply (Akbar *et al*., 2024). Research by Riskiono *et al*., (2020) shows that the application of soil moisture sensors can reduce the use of irrigation water by up to 30% on vegetable crops, as well as improve the quality of crop yields. In addition, research by Effendi *et al*., (2022) confirmed that the use of soil moisture sensors in smart agriculture systems can increase water use efficiency and crop productivity by 20% compared to conventional methods.

The use of soil moisture sensors in smart agriculture also provides advantages in terms of data-driven decision-making (Rahardjo, 2022). The moisture data collected by the sensors can be integrated into IoT systems that allow farmers to monitor the condition of their land in real-time, even remotely, and take timely action to prevent stressful conditions on crops due to lack of water. According to research Setiadi and Muhaemin (2018), farmers who use this sensor-based system tend to have an easier time managing their farmland, especially in terms of timing and frequency of irrigation.

This study aims to analyze the effectiveness of the use of soil moisture sensors in increasing crop productivity in smart agriculture systems. The focus of this study is to compare crop yields and water use between land with soil moisture sensor-based irrigation and land with conventional irrigation. With this analysis, it is hoped that comprehensive data can be obtained on the benefits of using soil moisture sensor technology to support more efficient and sustainable agricultural practices.

LITERATURE REVIEW

Soil moisture sensors are devices that measure the water content of soil and are often used to automatically monitor moisture levels in smart farming systems. This technology is designed to provide real-time information related to plant water needs so that irrigation can be carried out on time and according to plant needs (Sandi & Fatma, 2023). The use of soil moisture sensors has proven to be effective in increasing productivity and reducing water waste. According to research by Sindua *et al.*, (2020), the use of soil moisture sensors in smart farming systems can reduce water use by up to 30% compared to conventional irrigation methods. Another study, Hidayat *et al*, (2019) also found that soil moisture sensors improve the quality and quantity of crops by optimizing irrigation.

Smart farming is an agricultural system that utilizes modern technology such as the Internet of Things (IoT) to increase agricultural efficiency and productivity. IoT allows the integration of various sensors placed in the field to collect continuous data on environmental conditions, including soil moisture, temperature, and light levels (Hidayat *et al*, 2019). The data collected from the sensors can be accessed and analyzed in real time, allowing farmers to make faster and more accurate decisions (Widiatmoko *et al*., 2024). Research by Kasiyanto *et al*., (2024) shows that the application of IoT in agriculture allows for better control over resources, especially water, and assists farmers in optimizing agricultural inputs such as fertilizers and pesticides.

Water use efficiency is one of the key benefits of implementing soil moisture sensors in smart agriculture. These sensors help optimize irrigation schedules based on the actual needs of the plants, not just routine schedules. This allows for significant water savings and minimizes the risk of over-irrigation that can damage soil structure and reduce crop yields (Widiatmoko *et al*., 2023). In a study, Widiatmoko *et al.*, (2023) implemented water use efficiency increased by 25% in farms using sensor technology compared to conventional agriculture. In addition, the use of soil moisture sensors also supports sustainability by reducing negative impacts on the environment through wiser and controlled use of water (Febrina, 2021).

Increased crop productivity is one of the most visible results of the application of sensor technology in smart agriculture. By providing optimal irrigation based on sensor data, plants can grow in more stable conditions and according to their physiological needs. This has a direct impact on the quantity and quality of crops. Research Febrina (2021) shows that land that uses soil moisture sensors experiences a 20% increase in productivity compared to land that uses manual irrigation. In addition, de Melo *et al*., (2023) reports that the use of soil moisture sensors allows for consistent soil moisture management, which is important for preventing water stress in plants, thereby significantly increasing crop yields.

The use of technologies such as soil moisture sensors in smart agriculture not only provides benefits to productivity and efficiency of water use but also contributes to the overall sustainability of agriculture. This technology helps reduce water and energy use, as well as reduce environmental impact through more economical use of resources (Agustina & Amrulloh, 2023). The application of this technology can also support sustainable agriculture goals by reducing greenhouse gas emissions and optimizing land use (Bangkit *et al*., n.d.).

RESEARCH METHOD

This study uses a field experiment method conducted on 1 hectare of agricultural land with two main treatments: (1) land with an automatic irrigation system based on soil moisture sensors, and (2) land with conventional irrigation system (manual). The study was conducted for three months, using the same vegetable crops on both fields to ensure comparable yields. This research design aims to measure the effectiveness of soil moisture sensors in increasing productivity and water use efficiency (Widiatmoko *et al.*, 2024).

1. Location and Time of Research

The research was carried out on experimental land in the Malang area, East Java, which has a semi-arid climate and faces the challenge of limited water availability. The experiment was carried out for three months, starting from land preparation to harvest.

2. Research Subject

The research subjects consisted of two groups of plants planted on land with the same area and type of plants. The first group was treated with an automatic irrigation system based on soil moisture sensors, while the second group used a manual irrigation system.

3. Steps

1. Land Preparation: The land is divided into two equally large sections. The first part is installed with an automatic irrigation system based on soil moisture sensors, while the second part uses manual irrigation without sensors.
2. Installation of Sensors and Irrigation Systems: On the first land, soil moisture sensors are installed at several points to monitor the moisture content in the soil in real-time. This sensor is connected to an automatic irrigation system that will drain water when the soil moisture level is below a predetermined threshold.
3. Data Collection: During the study, data on productivity and water volume used on both fields were collected on a weekly basis. Productivity data was obtained by measuring the total weight of the crop at the end of the planting period. The volume of water is recorded based on the amount of water used for irrigation in both methods.

4. Tools and Materials

1. Free Variable: Irrigation method (automatic, soil moisture sensor-based, manual irrigation).
2. Bound Variables: Crop productivity (yield weight) and water use efficiency (amount of water used per land).
3. Control Variables: Plant type, soil type, frequency of treatment, and similar weather conditions in both experimental fields.

5. Data Analysis Techniques

The data obtained was analyzed quantitatively. The difference in crop productivity between the two irrigation methods was tested using statistical analysis (t-test for two independent samples) to find out if there was a significant difference. Water use efficiency is calculated based on the total volume of water used per kilogram of crop yield. This analysis provides an overview of the effectiveness of soil moisture sensors in improving water productivity and efficiency compared to conventional methods.

RESULT AND DISCUSSION

The study evaluated the effectiveness of soil moisture sensor-based irrigation compared to manual irrigation, focusing on two main aspects: crop productivity and water use efficiency. Here are the results of the study in detail, which is complemented by tables and graphs to visualize the comparison.

1. Plant Productivity

Plant productivity is measured based on the weight of crop yield per hectare (kg/ha). The table below shows the results of the productivity comparison between the two irrigation methods.

Table 1. Plant Productivity

No.	Parameter	Sensor-Based Irrigation	Manual Irrigation
1	Productivity (kg/ha)	8000	6400

Source : (Bangkit *et al*., n.d.)

On land with irrigation based on soil moisture sensors, the yield reaches 8000 kg/ha, while on land that uses manual irrigation, productivity is only 6400 kg/ha. Thus, crop productivity on land using sensor-based irrigation increased by 25% compared to manual irrigation land. The graph below shows the comparison of crop productivity between the two methods:

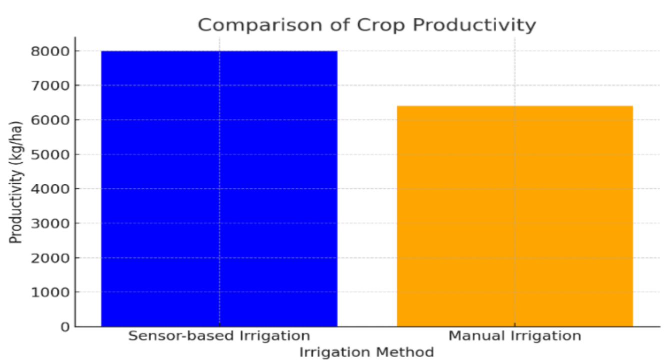

Figure 1: Comparison of Plant Productivity
Source : (Kasiyanto *et al*., 2024)

From the figure above, it can be concluded that soil moisture sensor-based irrigation systems significantly increase crop yields, demonstrating the potential of this technology in optimizing farmland productivity.

2. Water Use Efficiency

Water use efficiency is one of the main focuses in this study because optimal irrigation will reduce the waste of water resources and support sustainable agriculture. The following is data on water use in both irrigation methods.

Table 2. English translation. Water Use Efficiency

No.	Parameter	Sensor-Based Irrigation	Manual Irrigation
1	Water Consumption (liters)	3500	5000

Source : (Ziaulhaq & Amalia, 2022)

Water use on land with soil moisture sensor-based irrigation is 3500 liters, while land with manual irrigation uses 5000 liters of water. This shows water savings of up to 30% on sensor-based irrigation systems compared to manual irrigation.

The following graph shows a comparison of water use between the two methods:

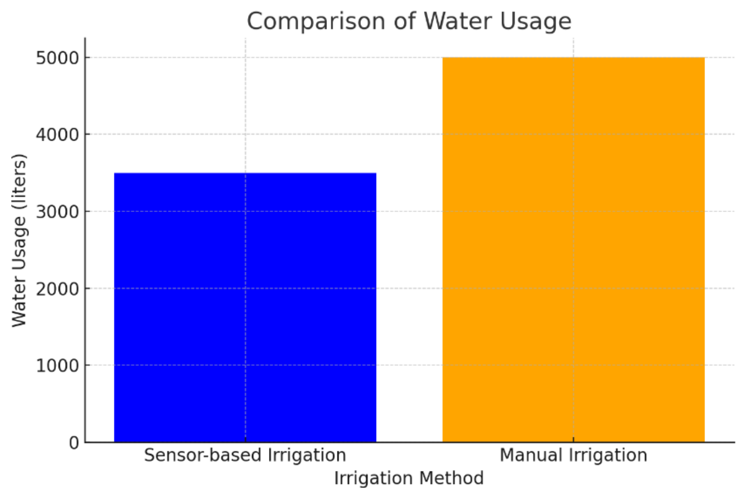

Figure 2: Water Use Efficiency
Source : (Widiatmoko *et al*., 2024)

From the graph, it can be seen that the irrigation system based on soil moisture sensors uses water more efficiently compared to conventional methods, which only rely on irrigation schedules without considering the actual needs of plants.

3. Discussion

1. Effect of Soil Moisture Sensor on Plant Productivity Sensor-based irrigation systems allow for precise irrigation according to plant needs. When the soil moisture is below a certain threshold, the automatic system will activate irrigation, ensuring that the plants are not deprived of water. This results in more stable growing conditions, minimizes water stress on plants, and allows plants to grow optimally. The results of this study are in accordance with the findings of Gupta *et al*. (2022), which show an increase in plant productivity with the use of soil moisture sensors.

2. Water Use Efficiency The use of soil moisture sensors not only increases productivity, but also improves water use efficiency. These sensors monitor soil moisture in real-time, ensuring that water is only provided when needed. This is especially important in water-scarce areas. These findings support research by Palumbo *et al* (2021), which found that sensor-based irrigation can significantly reduce water consumption without sacrificing crop yields.
3. Implications for Sustainable Agriculture Water efficiency and increased productivity obtained through the use of soil moisture sensors have the potential to be applied on a larger scale. This technology supports more environmentally friendly agricultural practices, by making wise use of water resources and reducing waste. The adoption of this technology can help farmers reduce operational costs and minimize environmental impact, in line with sustainability goals in agriculture.

This study proves that the use of soil moisture sensors in smart farming systems increases crop productivity by 25% and reduces water consumption by up to 30% compared to manual irrigation methods. This technology is particularly beneficial to be adopted in water-scarce regions and by farmers who want to increase productivity efficiently.

CONCLUSION

This study shows that the application of soil moisture sensors in automatic irrigation systems can significantly improve plant productivity and water use efficiency compared to manual irrigation methods. From the results of the analysis, the productivity of land with humidity sensor-based irrigation reached 8000 kg/ha, an increase of 25% compared to land with manual irrigation which only reached 6400 kg/ha. In addition, the system based on soil moisture sensors is also able to save water use by up to 30%, with a total water use of 3500 litres compared to 5000 litres in the manual irrigation method.

The advantages of this technology in increasing crop yields and optimizing water use make it an ideal solution for more efficient and sustainable agricultural practices, especially in areas prone to water shortages. This technology is not only beneficial for productivity but also supports sustainability by reducing water waste, which is an important step in facing today's global environmental challenges.

The application of soil moisture sensors in smart agriculture has great potential to be further developed and widely adopted by farmers. Thus, it is hoped that this technology can help improve efficiency in the agricultural sector, reduce irrigation costs, and encourage more environmentally friendly practices.

This conclusion reinforces the importance of technology integration in modern agriculture and provides strong evidence that the use of soil moisture sensors is not only innovative but also supports sustainable agriculture.

ACKNOWLEDGMENT

Based on the results of the research, here are some suggestions for the further development and application of soil moisture sensor technology in smart agriculture:

1. Wider Implementation
   It is recommended to apply soil moisture sensor technology to different types of plants and lands with different climatic conditions. This aims to obtain comprehensive data on the effectiveness of this technology in more diverse conditions, so that its benefits can be widely felt in various agricultural sectors.

2. Sensor Technology Development
   Soil moisture sensor technology needs to be further developed to improve the accuracy and durability of the tool, especially in regions with extreme climates or lands with unstable soil conditions. More durable and responsive sensors will support the effectiveness of soil monitoring in the long term, thereby maximizing irrigation yield and efficiency.
3. Education and Training for Farmers
   To optimize the use of this technology, training for farmers on how to install, maintain, and interpret data from soil moisture sensors is highly recommended. This training can be organized by the government or related institutions to ensure that farmers can properly utilize this technology and get maximum results.
4. Integration with Other IoT Systems
   Soil moisture sensors can be more effective if they are integrated with other IoT technologies, such as temperature, air humidity, and soil pH sensors. This integration allows farmers to obtain more holistic information about land conditions, so they can make more informed decisions regarding crop care and land management.
5. Policy Support and Subsidies
   The government and related institutions are advised to support the adoption of soil moisture sensor technology by providing subsidies or incentives to farmers. This support can help lower the cost of implementing the technology for smallholders, so they have wider access to this technology.
6. Follow-up Studies on Long-Term Effects
   It is recommended to conduct further research on the long-term effects of the use of soil moisture sensors on soil health, water efficiency, and plant productivity. This study will provide a more in-depth view of the potential positive and negative impacts of this technology in the agricultural system as a whole.

The implementation of these suggestions is expected to support the optimal and sustainable use of soil moisture sensor technology, so that this technology not only improves efficiency, but also has a wider positive impact on the agricultural ecosystem and farmers' welfare.

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