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Application of IoT-Based Technology in Soybean Cultivation Management: Water and Fertilizer Use Efficiency Strategy

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ABSTRACT

Agriculture plays a crucial role in fulfilling global food needs and promoting societal well-being. Soybean cultivation, as a strategic food crop, offers essential protein sources for humans and livestock while enhancing soil fertility through nitrogen fixation. However, the increasing global demand for soybeans poses challenges for farmers, particularly in terms of cultivation efficiency. These challenges are further exacerbated by climate change, land use, disease threats, and commodity price fluctuations.

The advancement of agricultural technology, such as IoT, remote sensing, artificial intelligence, and predictive modeling, holds significant promise in improving soybean cultivation's efficiency and productivity. Precision agriculture emerges as a pivotal approach to support agricultural efficiency, productivity, and profitability. Expert systems and image processing techniques like artificial neural networks and genetic algorithms play a vital role in implementing precision agriculture. Information technology's use in precision agriculture focuses on data collection, analysis, and application in farming.

Despite considerable research proposing technology integration in soybean cultivation, comprehensive studies on its potential integration remain limited. Thus, this international research aims to analyze the prospects of integrating agricultural technology into plant monitoring systems. Its primary goal is to contribute to the development of sustainable and efficient agricultural practices, considering environmental conditions and natural resource potentials. The findings will serve as a strategic foundation for agricultural stakeholders and policymakers to enhance soybean cultivation's sustainability, productivity, and quality, while effectively addressing global food challenges in the future.

Keywords: Framework, Controlling, Monitoring, Agriculture, Soybean.

INTRODUCTION

Agriculture is a vital sector in meeting food needs and supporting the economies of countries around the world. In particular, soybean cultivation has become an important component of food production and a source of livelihood for millions of farmers. However, increasingly complex challenges, such as climate change, population increase and growing global demand, are driving the need for innovation in the agricultural sector.

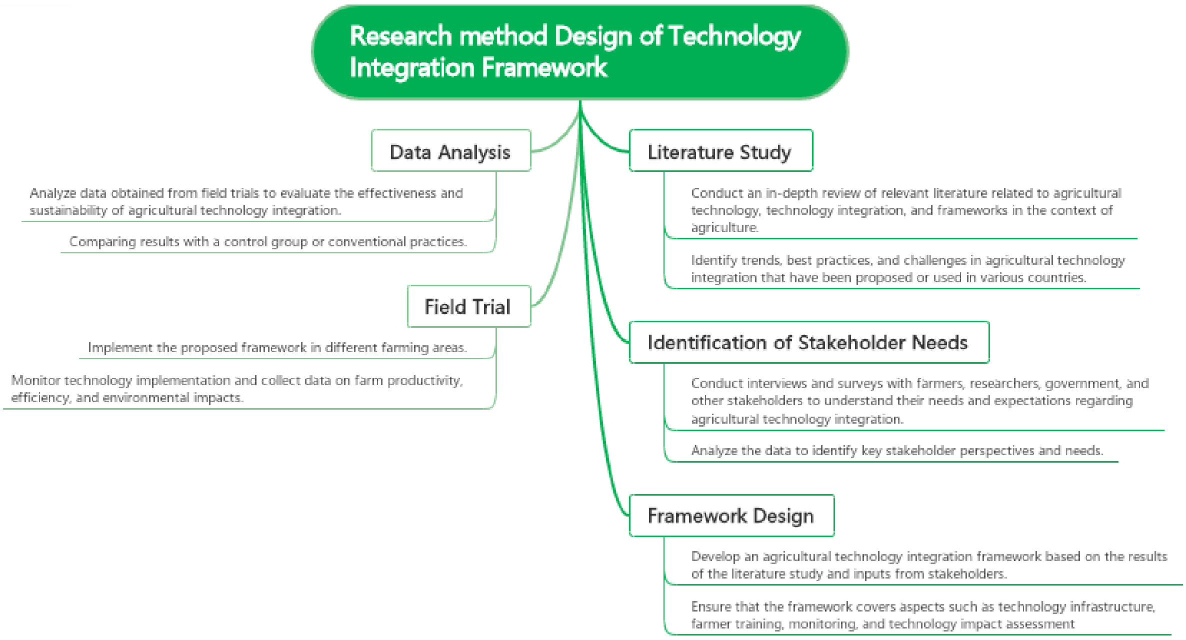
Increasingly extreme and unpredictable climate change has put extra pressure on the agricultural sector (Sukmawati, 2015). Unstable weather patterns, natural disasters and rising global temperatures have disrupted the planting and harvesting patterns that farmers used to rely on. This demands innovative solutions in crop cultivation that can cope with climate change and provide greater food security. The growing world population is an additional challenge that requires the agricultural sector to produce more food with increasingly limited resources. In this context, the cultivation of soybean crops, which are an important source of protein in human food and animal feed, is becoming increasingly crucial. The growing global demand for agricultural products, including soy, creates great economic opportunities for farmers (Priatna & Roswinna, 2019). However, it also emphasizes the need to improve agricultural efficiency and productivity to meet the needs of a rapidly growing market.

One promising approach is the integration of agricultural technologies that can improve agricultural efficiency and productivity. In this context, this research aims to design an agricultural technology integration framework that can be used to improve the efficiency of soybean cultivation. Soybean was chosen as the focus of the research due to its important role in food and as a source of raw materials in various industries. However, the implementation of agricultural technology in soybean cultivation is not as easy as it seems. Each region has unique environmental characteristics, local needs and challenges that require a customized approach. Therefore, there is a need for a solid framework that guides the development, testing and implementation of agricultural technologies in the context of soybean.

This research also responds to the need to improve the economic sustainability and welfare of farming families. In addition to increasing agricultural productivity and efficiency, the integration of agricultural technology is also expected to provide social and economic benefits for farming families, especially women farmer groups. In the era of digital transformation, the use of smart and integrated agricultural technology can accelerate the achievement of sustainable development goals in the agricultural sector. By identifying local needs, environmental conditions, and developing concrete work plans, this research is expected to provide valuable guidance for the development and implementation of relevant and effective agricultural technology integration frameworks. This research contributes to the understanding of how agricultural technologies can be effectively integrated in soybean cultivation to support the economic sustainability and welfare of farming families and has the potential to serve as a model for the development of sustainable agricultural technologies in the cultivation of other crops.

RESEARCH METHOD

This research elaborated and tested a framework for agricultural technology integration to improve the productivity and sustainability of the agricultural sector. The research steps applied include a series of essential stages:



Picture 1. Design of Technology Integration Framework

Literature Study

The research started with an in-depth literature review to understand the agricultural technology landscape, technology integration, and existing frameworks in the context of agriculture. The research aimed to identify trends, best practices and challenges that have been proposed or used in agricultural technology integration in different countries. This provides a strong theoretical basis for the development of the framework.

Identify Stakeholder Needs

The research continued with the identification of stakeholder needs and expectations involving farmers, researchers, government, and other stakeholders. Through interviews and surveys, data was collected to understand key perspectives and needs (Marina, et.al. 2020).

Framework Design

Based on information obtained from the literature and stakeholder studies, the research developed an agricultural technology integration framework. The framework is designed to cover key aspects, such as technology infrastructure, farmer training, monitoring, and technology impact assessment. This framework will be the basis for further implementation.

RESULTS AND DISCUSSION

A literature review on the development of plant monitoring technology in the last 2 years was conducted by searching various scientific journal databases such as PubMed, Google Scholar, and IEEE Xplore using the keyword "technology application." The search yielded a total of 13,600 articles. Subsequently, a more specific search was carried out using the keyword "Technology Application in Annual Crops," resulting in 799 articles.

Next, the exploration was focused on the theme "IoT-based Plant Monitoring System," which yielded 148 articles. Another theme investigated was "Drone-based Plant Monitoring System," with 23 articles found. Furthermore, for the theme "Remote Sensing-based Plant Monitoring System," 13 articles were discovered. Meanwhile, the theme "AI-based Plant Monitoring System" resulted in 13 articles. Lastly, for the theme "Cloud-based Plant Monitoring System," 6 articles were identified. The specific applications can be seen in the following table:

Tabel 1. Comparison of Technology Application in Various Plant Cultivation Monitoring Activities.

No	Activity	Monitoring Technology (Articles)					
		Plant Sensors and Internet of Things (IoT)	Drones for Monitoring	Remote Sensing	Artificial Intelligence	Cloud Platform.	Total Number of Monitoring Technology Articles" in English
1.	Land Preparation	30	16	11	18	11	94
2.	Cultivation.	33	15	10	18	9	85
3.	Fertilizing	17	9	6	10	4	46
4.	Weed Control	11	7	4	7	6	35
5.	Pest and Disease Management.	11	13	8	9	5	57
6.	Irrigation	20	5	3	4	1	33
7.	Harvesting	34	14	11	19	8	86

Source: Scientific journal databases such as PubMed, Google Scholar, IEEE Xplore, 2023.

The use of plant-based Sensor and IoT-based monitoring technology dominates almost all cultivation activities, signifying the importance of this technology in improving agricultural process efficiency (Agarwal & Patel, 2020). On the other hand, the utilization of Cloud Platforms remains the most limited in the application of monitoring technology, but it still plays a crucial role in supporting data-driven agriculture (Lee, et al. 2020) (Botta, et al. 2016).

The data in Table 1 confirms that the implementation of monitoring technology plays a significant role in various plant cultivation activities, assisting farmers in enhancing efficiency and productivity, and providing opportunities to better face future agricultural challenges through comprehensive technology integration (Mishra & Joshi, 2021). Findings from articles related to plant monitoring technology indicate that integrating technology with plant-specific characteristics, particularly in soybean cultivation, requires an understanding of environmental conditions and available natural resources (Agarwal, & Jain, 2019). This allows for effective and detailed use of monitoring technology in agricultural activities, as seen in the following Table 2.

Table 2. Analysis of Technology Implementation in Soybean Cultivation Process: Weaknesses and Potential Improvements.

No	*Activity*	*Application of Previous Technologies*	*Weaknesses of Previous Technologies*	*Potential Improvements*
1.	Land Preparation	Determining Land Potential with Geographic Information System. (Satriadi & Mawardi. 2019)	One of the weaknesses of implementing Land Potential Determination technology with Geographic Information Systems (GIS) is its dependence on accurate data and mapping. If the data used in the system is incomplete, inaccurate, or outdated, the resulting land potential analysis can become inaccurate or less reliable. (Tayyab, et al. 2020)	Collaboration of Artificial Intelligence with Remote Sensing: This data can be utilized for extensive analysis of vegetation, soil texture, and land quality. Through AI and ML technologies, price and demand projections can become more accurate and adaptable to dynamic market changes.
2.	Planting	Using data analysis and statistical techniques, such as linear regression, time series analysis, and other predictive models, to identify trends and patterns in past price and demand data.	Limitations in Processing Big Data: Some data analysis and statistical models may encounter limitations in processing large datasets quickly and efficiently (Wang, et al. (2019).	
3.	Fertilization	Remote Sensing and Unmanned Aerial Vehicles (UAVs) for Precision Fertilization in Soybean Production (Corbari, et al. 2017)	It has limited flight range and limited operational time (Wang, et al. 2018).	Collaboration of Artificial Intelligence with the Application of Cloud Platform Technology in Monitoring and Analysis of Soybean Fertilization Needs. (Ghatak, et al. 2020)
4.	Weed Management	Herbicide Sprayer, Monitoring System, and Android-based Weed Spraying Device (Zhang, et al. 2018))	The procurement of herbicide and pesticide sprayer equipment with Android-based monitoring systems may require a significant initial investment. Moreover, the availability and cost of the necessary hardware and software can also be a constraint for farmers with limited budgets (Cui, et al. 2018).	Collaboration of Image Recognition Technology and Artificial Intelligence (AI): Integrating image recognition technology and artificial intelligence into herbicide spraying equipment can enhance the accuracy and precision of spraying. (Jhanjhi, et al. 2021)
5.	Control Of Pest And Diseases	Aplikasi Sistem Pakar Untuk Diagnosis Hama Utama Kedelai, Alat Penyemprot Fungisida (Chlingaryan, et al. 2018).		
6.	Irrigation	Drip Irrigation Based on IoT, Automated Garden Irrigation Control with Webserver, Nodemcu-based Smart Watering System for Soybean Plants, Automatic	Incompatibility with Small Scale: Automated irrigation technology may be less suitable for small-scale farmlands or landowners with limited budgets. The initial expenses involved in	Intelligent Monitoring and Control Algorithms: Utilizing artificial intelligence (AI) and machine learning-based intelligent monitoring and control algorithms to

		Watering Device for Soybean using AT89S8252 Microcontroller (Choudhury, et al. 2017)	adopting this technology might not be proportional to the benefits obtained (Kamal & Madramootoo. 2019).)	optimize the timing and amount of irrigation based on historical data, weather conditions, and plant requirements. (Tayyab, et al. 2020)
7.	Harvesting	The translation in English is: "Soybean harvester is a mechanical device specifically designed for automatic harvesting of soybean plants (Anwar, et al. 2017)."	requires a relatively high initial investment cost (Uraz, S., Genc, M. 2020).	Collaboration with the use of other system technologies.

In land preparation activities, the collaboration of artificial intelligence with remote sensing can provide a broader and more accurate analysis of vegetation, soil texture, and land quality (Gao, et al. 2020). This can assist farmers in making better decisions in crop planning and optimal land use. For Price and Demand Projection (planting activities), AI and Machine Learning technologies can overcome limitations in processing big data and identify past price and demand trends more accurately. This will help farmers in planning marketing and production strategies more efficiently (Gupta & Singh. 2021).

In fertilization activities, the collaboration of artificial intelligence with the implementation of Cloud Platform technology in monitoring and analyzing fertilization needs can overcome limitations of UAVs that have limited flying distance and operational time. Smarter systems can provide more precise fertilization recommendations based on the latest monitoring and analysis data (Kumar, et al. 2019).

In weed control activities, the use of image recognition technology and artificial intelligence in herbicide spraying devices can improve the accuracy and precision of spraying, thereby reducing excessive herbicide use and controlling weed growth more effectively (Bai, et al. 2017).

In irrigation activities, intelligent monitoring and control algorithms based on artificial intelligence (AI) and machine learning can enhance the efficiency of automatic irrigation systems (Verma, R., Kumar, A., & Singh, R. 2020). Adjusting the timing and amount of irrigation based on historical data and weather conditions will help optimize water use and increase crop productivity (Santos, et al. 2021). Thus, integrating artificial intelligence into various soybean cultivation activities can provide solutions to overcome previous technological limitations, improve efficiency, and support more sustainable and innovative agriculture.

Environmental Conditions and Potential Natural Resources Support

Based on the preliminary survey in soybean production centers, reinforced by previous research, it is revealed that soybean cultivation often faces attacks from various types of pests, diseases, and weeds that have a negative impact on plant growth and production. Common pests attacking soybean plants include grasshoppers (Valanga nigricornis) and leaf caterpillars (Lamprosema indicata) (Garcia, et al. 2019). One of the problematic diseases is Fusarium root rot caused by Fusarium oxysporum f.sp. glycine. This disease leads to wilting, root rot, crown rot, and stem rot in plants (Harti & Marina. 2022). To counter pest and disease attacks, insecticide spraying and the application of the biological agent Trichoderma sp. are conducted before planting (Shimelis & Mohamed. 2019).

Not only that, soybean plants also have to compete with two weed species, namely purple nutsedge (Cyperus rotundus) and star grass (Hedyotis corymbosa). These weeds compete with soybean plants for nutrients, water, CO_2, and sunlight, thereby disturbing their growth. Weed control is usually carried out through mechanical methods, mainly by manual weeding with the use of hoes to remove weeds and prevent them from competing with the main crops. The presence of pest, disease, and weed attacks is an important factor that needs to be addressed in order to improve soybean cultivation efficiency and achieve sustainable food security (Hamilton, et al. 2019).

In the case of soybean cultivation in the production center based on the preliminary survey, the environmental conditions exhibit specific characteristics, with daily rainfall varying between 239.7 mm to 647.3 mm per month, averaging 9 to 26 rainy days per month. The pattern of rainfall during the experiment can influence plant growth and response to the given interaction treatments. The average minimum temperature ranges from 23.7°C to 24.1°C, while the monthly average maximum temperature ranges from 30.6°C to 32.5°C. The average humidity during the experiment ranges from 87% to 90%.

Optimal air humidity for soybean growth is within the range of 75 to 80% RH during the growth and pod filling period. However, during the pod maturation and harvest period, lower air humidity around

60 to 75% RH is considered ideal. Previous research findings also indicate that optimal air humidity and sufficient soil moisture have a significant positive effect on soybean growth and production (Garcia, et al. 2019; Santos, et al. 2022). These suitable environmental conditions are crucial in evaluating soybean cultivation to enhance production and the quality of crop yields sustainably.

Picture 2. Weather and Nutrient Deficiencies in Soybean Plants

In Figure 2, it is shown that the environmental conditions in several soybean cultivation centers have a negative impact on plant growth. Drought and extreme temperatures are the main factors causing plant stress, leading to the appearance of yellow spots on the leaves (Hussein, et al. 2021). Additionally, the yellow spot symptoms on the leaves indicate nutrient deficiencies, particularly nitrogen, iron, and magnesium (Baligar, et al. 2017). These nutrient deficiencies can inhibit plant photosynthesis and disrupt energy production processes, resulting in yellowing leaves and difficulties in optimal plant growth (Hanafy, et al. 2018).

These findings underscore the importance of understanding and addressing environmental challenges in soybean production centers, including water and nutrient management, to enhance sustainable productivity and quality of soybean crops. Moreover, efforts to identify soybean varieties that are more resistant to extreme environmental conditions should also be considered to optimize soybean production in these production centers (Chen, & Wang, 2020).

Picture 3. Growh of Soybean Plants Without Direct Sunlight

The growth of soybean plants without direct sunlight can lead to several consequences that affect plant health and productivity (Miao, et al. 2021). Soybean plants require sunlight as an energy source to carry out the process of photosynthesis, which enables them to convert carbon dioxide and water into sugar and oxygen. Plants growing in shade or limited sunlight conditions tend to experience inhibited growth due to energy limitations (Xu, et al. 2021). As a result, sugar and oxygen production decreases, and plants may not provide enough nutrients for optimal growth. Additionally, soybean plants not receiving direct sunlight tend to have longer stems and thinner, paler leaves (Figure 3) (Choudhury, et al. 2019). This condition makes the plants more vulnerable to environmental stress and pest attacks (Yao, et al. 2020).

On the other hand, the growth of soybean plants with direct sunlight has a significantly positive impact on plant health and productivity. Sunlight serves as a crucial energy source for the process of photosynthesis, where soybean plants convert carbon dioxide and water into sugar and oxygen. With sufficient exposure to sunlight, soybean plants can produce the nutrients and energy needed for optimal growth (Figure 4) (Buchanan, et al. 2015).

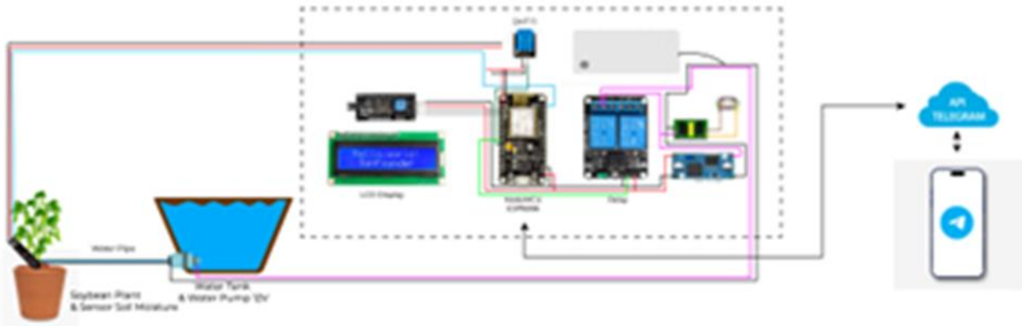
Picture 4. Growth of Soybean Plants With Direct Sunlight

Soybean plants that receive direct sunlight tend to have stronger growth and broader, greener leaves (Rahma & Marina, 2023). Increased photosynthesis helps the plants enhance sugar production, contributing to the development of sturdy stems and a healthy root system. With strong stems, the plants can withstand the weight of pods and reduce the risk of breakage due to wind or adverse weather conditions (Ort, et al. P. 2015).

Furthermore, sunlight exposure also influences flowering and pod formation. Soybean plants exposed to direct sunlight tend to undergo better flowering processes and produce more pods, ultimately increasing soybean seed production (Sato, et al. 2021).

Real-Time Soil Moisture Monitoring and Control for Soybean Cultivation

The tool created in this research has the capability to control irrigation in soybean plants through the Telegram application via a wifi network. The process of controlling the irrigation takes place when the sensor connected to the NodeMcu microcontroller detects soil moisture. When the sensor detects low humidity or dry soil conditions, the microcontroller will send real-time notifications via wifi to the Telegram application (Kavak & Borekci. 2018). By receiving these notifications, users can immediately be aware of the soil conditions and irrigation needs for the soybean plants. Subsequently, users can directly control the irrigation of soybean plants through the Telegram application by utilizing the integrated features with the tool.



Picture 5. The Sensor Connected to The NodeMcu Microcontroller Detects Soil Moisture

This allows farmers or users to respond quickly and accurately to the plant's conditions, thereby increasing efficiency in agricultural monitoring and control. The visible components of the designed tool are shown in the photo. At the front of the photo, there are several input, process, and output components (Ruan, S., Wu, J., Guo, W., Yang, H., & Wang, J., 2021). The input components include a 12V 2A power adapter, soil moisture sensor, and air temperature sensor (Yao, et al. 2020). The processing component is the microcontroller (device) responsible for processing data from these sensors. On the output side, there is a pump that controls the irrigation system based on the data obtained from the soil moisture and air temperature sensors (Gupta & Saingh, 2021).

Figure 6 shows the method of measuring soil moisture using a soil meter, where the soil moisture results will be displayed on the soil meter screen with indications of "DRY+," "DRY," "NOR," "WET," and "WET+" (Guan, et al. 2019).

Figure 6. Soil Meter Measurement Tool

Figure 7. Soil Moisture Measurement Tool

In Figure 7, there is a way to measure soil moisture using a Soil Moisture sensor inserted into the soil containing soybean plants. This Soil Moisture sensor is inserted about 3/4 of its length into the soil. To compare the results of the Soil Moisture sensor parameter, a soil meter with 5 levels of soil moisture is used, namely DRY+, DRY, NOR, WET, and WET+. Each level has a specific range of humidity, such as DRY+ with a humidity range of (10% - 25%), DRY with a range of (26% - 49%), NOR with a range of (50% - 60%), WET with a range of (61% - 80%), and WET+ with a range of (81% - 100%) (Jayakody, J. A. D. K., Wickramasinghe, I., & Dias, G., 2017). Furthermore, the soil moisture results from the Soil Moisture sensor are compared with the soil meter to evaluate the precision of the results provided by the Soil Moisture sensor compared to the soil meter (Ata-Ul-Karim, et al. 2017).

Additionally, Table 1 also shows the results of testing the Soil Moisture sensor compared to the soil meter to determine the relative humidity (RH), which is the ratio of the amount of water vapor present in the air to the maximum capacity of water vapor that can be held by the air at a certain temperature.

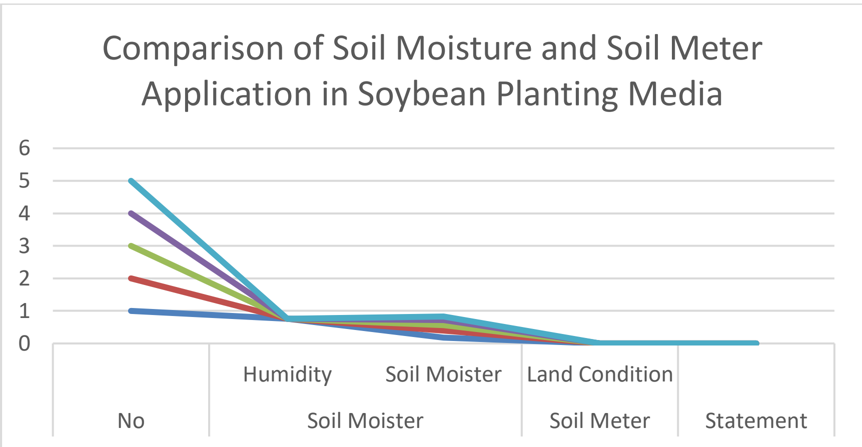


Figure 8. Comparison of Soil Moisture and Soil Meter Application in Soybean Planting Media.

Figure 8 shows a comparison between soil moisture levels measured using a soil meter and the classification of soil conditions. This data is related to optimizing soybean cultivation through plant monitoring technology. The plant monitoring technology, namely the soil meter, provides information about soil moisture levels. In soybean cultivation, soil moisture levels are an essential factor that influences plant growth and productivity (Setiawan, Y., Purbobasuki, B., Setiawan, B. I., & Eko, R., 2021).

The "DRY+" condition (range 10% - 25%) indicates that the soil is experiencing severe drought. In the context of soybean cultivation, this condition can cause stress to the plants and have a negative impact on growth and harvest yield. To optimize soybean cultivation, farmers can take action to increase soil moisture through efficient irrigation systems or regular watering (Hadi, A., and Purwono, 2021).

The "DRY" condition (range 26% - 49%) indicates that the soil moisture level is still low. In this situation, more intensive water management is necessary to keep the soil moist and support optimal soybean plant growth (Supriyadi, S., & Setiawan, A., 2019).

The "NOR" condition (range 50% - 60%) indicates a relatively ideal condition for soybean plant growth. In this condition, the plants will receive sufficient water to grow well and produce good harvest results. With plant monitoring technology, farmers can ensure that the soil moisture remains within this ideal range (Dara, E. N., & Heryanto, H., 2018).

The "WET" condition (range 61% - 80%) indicates that the soil has a high moisture level. If the soil moisture is above the upper limit of this range, the soil can become too wet and lead to excessive water accumulation. To optimize soybean cultivation, it is essential for farmers to carefully manage irrigation and ensure that the soil does not become waterlogged (Radanielson, A. M., & Brandle, J. R., 2019).

The "WET+" condition (range 81% - 100%) indicates that the soil is experiencing significant waterlogging. Soil moisture above the upper limit of this range can create unfavorable conditions for soybean plant growth, such as root rot and damage to the root system. In this situation, careful irrigation and drainage system management are necessary to optimize soybean cultivation (Gao. et al. 2019).

Regarding the working mechanism of the application on Telegram, it operates through commands, and the functions and workings are described in Table 2 as follows (no information about Table 3 provided in the previous text).

Table 3. Test Results of 12V Pump Voltage on Soybean Planting Media

No	**Command**	**Function**	**Result**	**Description**
1	Condition	To obtain information from plants.	EQUIPMENT Humidity 75%, Soil 85%, Temperature 30°C TELEGRAM Humidity 75%, Soil 85%, Temperature 30°C	In accordance with.
2	Notification: Dry Soil Status, Automatic Irrigation Active.	To determine if the soil moisture detects dry soil and the pump is active.	To determine if the soil moisture detects dry soil and the pump is active.	In accordance with.

In the trial results, the device successfully provided detailed information about the plant's condition. In the first status, the device reported a soil moisture level of 75%, soil moisture of 85%, and air temperature of 30°C. All the data obtained from this device can be monitored through the Telegram application, giving users the opportunity to know real-time information about the plant's condition.

Furthermore, the device is also equipped with notifications for dry soil status and active automatic watering. If the soil moisture sensor detects that the soil is dry, the device will send active notifications through the Telegram application, and the pump will start working automatically to water the plants. These notifications ensure that users can promptly respond to soil conditions and activate the necessary watering for soybean plants.

In the testing results, the voltage on the pump was accurately measured when the pump was both active and inactive during the testing process. This indicates that the device can control the pump effectively according to the desired commands and functions.

Table 4. Sensor Response Speed Test Application on Soybean Planting Media

Percobaan	**DHT 11**	**Soil Moister**	
		Basah ke Kering	**Kering ke Basah**
1	2.64 detik	6.92 detik	2.67 detik
2	4.56 detik	4.59 detik	2.00 detik
3	4.64 detik	8.72 detik	9.11 detik
4	4.34 detik	4.22 detik	7.55 detik
5	2.43 detik	6.06 detik	7.11 detik
6	2.46 detik	6.85 detik	7.82 detik
7	4,33 detik	5.47 detik	4.59 detik

8	3.64 detik	3.51 detik	4.66 detik
9	5.28 detik	3.27 detik	2.38 detik
10	2.54 detik	6.25 detik	1.38 detik
Rata - Rata	**3.69 detik**	**5.58 detik**	**4.22 detik**

The data in Table 3 regarding the response speed of the DHT 11 sensor and soil moisture in various experiments can be related to efforts to optimize soybean cultivation through plant monitoring technology. In soybean agricultural applications, monitoring the plant's environmental conditions is crucial to achieving optimal harvest results. The use of the DHT 11 sensor to detect air temperature and humidity, as well as the soil moisture sensor to measure soil humidity, is an essential step in efficient plant environmental monitoring.

From the recorded data, the average response speed of the DHT 11 sensor is 3.69 seconds, while the response speed of the soil moisture sensor is 5.58 seconds for conditions from wet to dry and 4.22 seconds for conditions from dry to wet. This data shows the sensors' ability to quickly respond to changes in environmental conditions.

By using plant monitoring technology such as the DHT 11 sensor and soil moisture sensor, farmers can obtain real-time information about air temperature, humidity, and soil moisture in soybean cultivation areas. This information is valuable for making informed decisions regarding irrigation, fertilization, and other treatments according to the actual conditions.

Development of Technology Integration Model in Soybean Cultivation

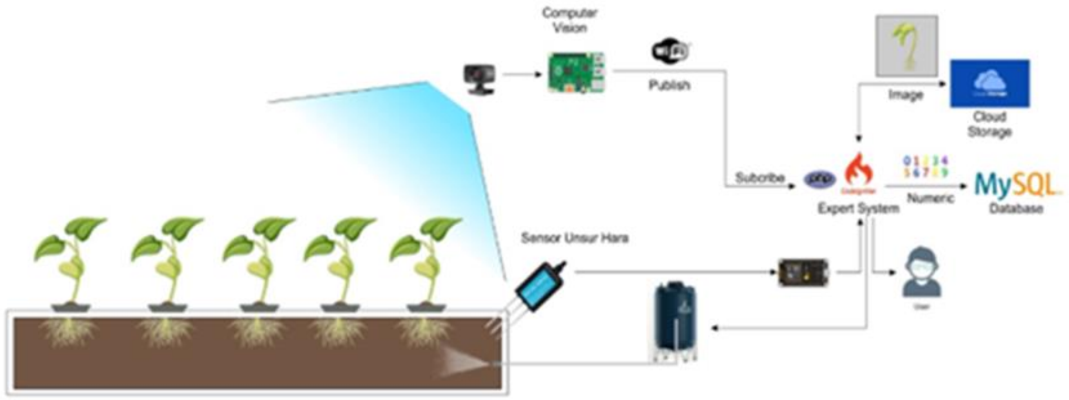


Figure 5. Development of Integrated Technologi Model in Soybean Cultivation

Integrating Technology in Soybean Cultivation to Enhance Cost Efficiency and Productivity, in order to improve cost efficiency and productivity, the integration of technology in soybean cultivation requires monitoring technology (Truong, et al. 2019). Preliminary survey data from soybean production centers and previous research findings reveal that soybean plants often face pest, disease, and weed attacks, which can adversely affect their growth and yield.

Monitoring technology can be utilized to track the real-time growth conditions of the plants (Hameed, et al. 2021). This monitoring can be accomplished using sensors and Internet of Things (IoT) devices installed in the field. The sensors measure environmental parameters such as rainfall, air temperature, humidity, and sunlight radiation. The data collected from these sensors can be accessed and analyzed online (Carrión, at al. 2019).

Farmers can monitor the development of their crops and detect early signs of pest, disease, or weed infestations. The monitoring data enables them to make faster and more accurate decisions regarding necessary control measures. Furthermore, the integration of monitoring technology can assist in more efficient irrigation and fertilization management. Farmers can adjust their watering and nutrient application patterns based on real-time environmental and plant data, reducing water and fertilizer wastage while enhancing resource utilization efficiency (Rahman,& Biswas, 2021).

Beyond the benefits in pest, disease, and weed control, monitoring technology will also improve the quality of the harvest and optimize plant productivity. Accurate information on environmental conditions and plant growth allows farmers to make better plans and timely preventive actions (Akhter, et al. 2019).

Overall, the integration of monitoring technology in soybean cultivation offers numerous advantages. By optimizing resource usage, minimizing losses due to pests and diseases, and increasing crop productivity, this model can effectively reduce production costs and enhance profits for farmers (Li, C., Zhang, S., Wang, Y., & Li, Z. 2020). An overview of the technology integration in soybean cultivation can be seen in Figure 5.

Monitoring technology provides the capability to monitor plant growth conditions in real-time using sensors and Internet of Things (IoT) devices installed in the field (Zhang, L., Wang, H., & Li, J. 2020). These sensors function to measure various relevant environmental parameters such as rainfall, air temperature, air humidity, and solar radiation. The data collected from these sensors are accessed and analyzed online, enabling farmers to obtain accurate information about the environmental conditions in their soybean cultivation areas. The analysis of this data can assist farmers in making more precise and efficient decisions related to irrigation, fertilization, and pesticide treatment (Misra, et al. 2021).

As a result, monitoring technology provides ease in identifying potential issues such as pest infestations, diseases, and nutrient deficiencies in soybean crops, allowing preventive measures to be taken faster and more timely. Moreover, monitoring technology also has the potential to enhance the efficient use of resources, such as water and fertilizers, while helping to reduce negative impacts on the environment. By utilizing monitoring technology, soybean cultivation becomes more productive, sustainable, and adaptable to environmental changes (Du, et al. 2021).

DISCUSSION

Designing a soil moisture, air temperature, and air humidity measuring device using NodeMcu ESP8266 based on the Internet of Things plays a crucial role in optimizing soybean cultivation through plant monitoring technology. This device can be controlled and monitored through a Telegram application, enabling farmers to obtain accurate and real-time information about soil conditions, air temperature, and air humidity that can influence soybean growth.

he soil moisture sensor was tested five times on different days. The testing involved comparing the sensor's soil moisture readings with a soil meter to ensure that the measured humidity values by the sensor align with the range of values from the soil meter, which has been determined as the optimal humidity standard for soybean plants.

The DHT11 sensor was also tested by comparing its readings with a smartphone thermometer and a soil meter. The experiment showed a difference of 1.6°C between the DHT11 sensor and the smartphone thermometer readings. However, the DHT11 sensor's readings matched the soil meter, measuring 31°C. The test was conducted ten times on different days, and the results indicated that the average temperature delay of the DHT11 sensor was 3.69 seconds, demonstrating its ability to provide quick information about air temperature and humidity around the plants. This information is crucial in determining the appropriate timing and frequency of fertilizer spraying for optimal plant growth and productivity.

Meanwhile, the Soil Moisture sensor is used to detect soil moisture around the plants. The sensor's response time, with an average range of 5.58 seconds, indicates that it can provide prompt information about soil moisture levels. This information is vital in regulating plant irrigation to ensure the plants receive sufficient water supply for healthy growth.

The testing of the 12V pump showed that when the pump is active, the measured input voltage is 11V, while when the pump is inactive, the input voltage is 0V. The test was conducted using a digital multimeter to ensure that the pump functions properly and can be controlled according to the soybean plant's irrigation needs (Ibrahim, et al. 2017).

By integrating data from both sensors into the spraying system, farmers can efficiently and timely manage fertilization and irrigation. The use of these sensor technologies in the spraying system will help optimize agriculture by providing intelligent and sustainable solutions for fertilization and pest and disease control in plants (Shanthini, & Rama, 2020).

With a measuring device capable of accurately measuring soil moisture, air temperature, and air humidity, which can be controlled for fertilization and pest and disease control in plants and monitored through the Telegram application, farmers can efficiently monitor and control soybean cultivation. This enables farmers to make informed and strategic decisions in soybean cultivation, thereby improving productivity and harvest quality (Vinothini, & Subhashini, 2021).

The next technology development plan is the development of monitoring systems that have the ability to real-time monitor crop development using sensors and IoT devices installed in the field. These sensors play a role in measuring various relevant environmental parameters, such as rainfall, air temperature, air humidity, and solar radiation. The data collected by the sensors will be accessed and analysed online, enabling farmers to get accurate information about the environmental conditions in the soybean cultivation area, along with meeting macro- and micro-nutrient needs and controlling pests and diseases in an open location, enabling use by all levels of farmers including small-scale farmers. Analysing this data can help farmers make more informed and efficient decisions regarding aspects such as irrigation, fertiliser and pesticide use.

Monitoring technologies facilitate the identification of potential problems such as pest infestations, diseases and nutrient deficiencies in soybean crops, which in turn allows for faster and more timely preventive measures. In addition, monitoring technologies also have the potential to improve the efficient use of resources such as water and fertiliser, and can help reduce negative impacts on the environment. With the application of monitoring technologies, soybean cultivation becomes more productive, sustainable and able to adapt to environmental.

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