

Designing an Early Detection System for Agricultural Land to Reduce the Risk of Crop Failure Based on Information Technology

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Abstract: Crop failures in Indonesia still occur frequently and become a source of problems due to the reduction of food supplies for the community. One of the causes of crop failure is the decline in soil quality due to nutrient content, which is rarely detected by farmers. However, the land quality analysis process that has been carried out so far still tends to take a long time and incur high costs. Therefore, it is necessary to create technology that is expected to be able to detect land quality directly, quickly, and easily. PKM- KC Soil Nutrient Monitoring is designed by creating hardware that can analyze moisture, pH, temperature, and essential macro nutrients, namely nitrogen, phosphorus, and potassium. Additionally, software that can process data and produce results in the form of land quality, land improvement recommendations, and suggested crop commodities. This Soil Nutrient Monitoring tool has been tested and calibrated with an accuracy level of 95%. This tool successfully processes data from hardware in the form of temperature, pH, humidity, and NPK sent via a Bluetooth Low Energy network to software that produces outputs in the form of land quality, land improvement recommendations, and suggested crop commodities.

Keywords: Agriculture; Information Technology; Land Quality; Soil Nutrient Monitoring.

1. Introduction

Indonesia agriculture is an important sector of the economy, contributing around 14% to the Gross Domestic Product (GDP) and employing more than 30 million people. The country agricultural land amount is approximately 31.4 million hectares and accounts for almost 11.5% of the total area of Indonesia as a whole in 2013. running ahead of Java Island and Sumatra with the largest farm land are followed by Kalimantan. The government has developed several policies and initiatives to support this sector that includes fertilizers and seeds subsidies, irrigation infrastructure improvements, as well agriculture research and development. However, despite these efforts this remains an important challenge and will continue to need stronger investment and longer term assistance so that it may be self-sustainable. Technological and information access disparities, especially among farmers in remote areas have proven to be a persistent barrier that has not been sufficiently addressed [1][3]. Land is the core of all agricultural activities directly affecting how agriculture operations will be successful. Soil fertility depends on the site and is greatly influenced by differences in soil types, locality etc. The soil is the main medium by which all plants, be it food crops or plantation commodities, grow. Healthy Soil — a soil without heavy metals, nutrient dense, and possesses the requisite physical and chemical attributes to support root development as well as nutrient availability for example invertebrates insects and beetles [2], Soil fertility is primarily based on nutrient content and macronutrients such as nitrogen (N), phosphorus (P) and potassium (K) have a critical impact on crop productivity in the land.

In addition, primary land quality impacts such as moisture, pH and temperature are at least similarly critical for ideal climatic conditions. Many farmers are confronted by failure in their agriculture work because of a lack of knowledge of the growth requirement behind specific types of plant species to be meticulously identified and never detected until the time is too late [1]. Measuring soil fertility testing is a very complicated process that can not be predicted until you test the nutrient levels Soil conventional laboratory analysis often times processes that can be time-consuming which results the delay of quickly responding to plant needs. However plant requirements must be identified promptly to ensure the soil has enough quantity and type of nutrients in terms of physical nature. Abiotic stress in the soil, which results from deficiency or imbalance in nutrients, may result in an uncontrolled development of plants involved, leading to stunted growth or low yields. Also, laboratory testing often utilises chemical reagents that may be detrimental in the long term with environmental consequences which would have been avoided.

To counter this, an Internet of Things (IoT)- based soil nutrient detection system which can do evaluation without physical and non-destructive way take speedy, efficient, clean way soil score and fertility evaluation. This technology facilitates dynamic assessment, so that the farmers will be able to take responsive actions on sub-optimal soil status and choose the right crops according to essential nutrient levels or other fertility parameters [2]. A comprehensive guideline on land characteristics in terms of nutrient quality by the Ministry of Agriculture, provides a useful reference for reading the Land Quality Evaluation book published in 2011. Similarly, it also makes recommendations for crops consistent with land evaluation results to help farmers increase soil capacity, at a time when many commodities are wrong in those in which we cultivate the land [4]. With this guide in mind, the brewing of land assessment technology for convenient and precise way comes to importance. In our PKM-KC project we have called his work as "Soil Nutrient Monitoring: Development and Design of an Information Technology Land Quality Detector in the Agricultural Sector Innovations". Mainly, there is focusing on installing sensors to measure macronutrients like nitrogen (N), phosphorus (P), potassium (K) and also some other parameter such moisture, pH, soil temperature. Land traits could be analysed in software and the data from the sensors are processed to determine what to do with, and propose soil improvement methods were recommended especially to plant crops. Then this technology at its core is aiming to help landowners till their agricultural fields faster and more effectively minimizes the risk of crop failure that is caused now and then mismatch in soil conditions with chosen crop varieties [4].

This is a response to real challenges farmers face in the field and not just technical beyond that Building this land quality detection tool is a unique technical exercise. Key problem point is access to accurate and timely soil conditions information. Most farmers, especially in the rural place still rely on traditional practices or their subjectivity when selecting the crops to plant they forget the empirical results in analysing fronted on soil fertility. Since harvests are often only half as hoped for this leads to huge losses economically. We have developed an IoT based technology to close this gap, where the portable, user-friendly but at an affordable price device will help to generation farmer's wise decision through valid and measurable data. Moreover, going with this strategy aids the government in achieving its policy goals of increasing national food security as agriculture is a cornerstone for many community in Indonesia [3]. The intention of this innovation goes beyond addressing soil productivity and promises to lower the environmental impacts commensurate via conventional soil testing approach. Use of chemicals in analytical laboratory is expensive, time consuming and hazardous especially the residues that can contaminate surrounding ecosystems. Transitioning to non-destructive technologies like soil IoT sensors has made soil evaluation more ecological, without hazards and soil erosion effecting soil structures. This is in tandem with sustainable agriculture principles, including significantly

resource efficiency and environmental preservation as key elements to land management. We have imagined that the Soil Nutrient Monitoring tool will drive higher productivity in farmers and still keep agricultural ecosystems for next generation for its preservation [2].

Farmers have also been slow to adapt to technologies with which they directly interact. Although this tool is intended to be accessible to non-experts, digital literacy among farmers especially in rural communities is still quite low. To implement this technology wide-spread training and ongoing support programs must be put in place to ensure it gets the benefit it deserves. In addition, the cost of producing the device should be such that it is economically viable for smallholder farmers who make up the bulk of agricultural practitioners in Indonesia. Overcoming these obstacles would have this technology a transformative force in agriculture that would enable Indonesia to retain its status as a continental nation capable of meeting food security given global issues like climate change and population growth. Also, technology in agriculture has to be seen through prisms of critique. The efficiency of IOT solution is good, but data privacy is major headache and will continue to be a painful concern even for rural where there is not connectivity. If farmers see any level of threat to their autonomy, or the support they need for this advanced technology is far from immediate. Meeting these challenges will not come only through technological innovation but also a strong structure of education policy support and community based engagement to establish trust and ensure equitable access. Only when they are done in balance, can these advancements serve farmers as a spring board to stand on their own two feet, and make an independent contribution to sustainable agriculture systems both regional and national.

2. Related Work

In recent years, the integration of information technology within agriculture has been instrumental in developing early detection systems to mitigate the risks of crop failure, particularly in the context of soil nutrient monitoring and land quality assessment. The advancement of precision agriculture (PA) has been driven by a range of technologies that enhance monitoring, management, and decision-making processes. Several studies underscore how these technological innovations improve agricultural outcomes and optimize resource utilization, providing a foundation for our project on soil nutrient monitoring. The concept of precision agriculture is deeply rooted in data-driven technologies that analyze soil conditions, crop health, and environmental factors. Montalvo-Romero *et al.* (2023) highlight that agro-technological systems in traditional agriculture are increasingly supported by innovative practices that improve communication between farmers and stakeholders, thereby enhancing crop management and reducing risks associated with crop failure [5]. Similarly, Zhao and Li (2018) offer a comprehensive overview of precision agriculture, emphasizing the role of advanced technologies in identifying critical agricultural parameters such as soil fertility and crop responses to environmental stresses, which aligns with our focus on real-time soil nutrient detection [6]. The role of advanced monitoring technologies in agriculture is paramount. Ioja *et al.* (2024) discuss the transformative potential of aerial drones in precision agriculture, noting that high-resolution imagery and data collection enable timely interventions for crop and soil management [7]. This complements our project's ground-level approach to soil monitoring by illustrating the broader applicability of technology in agricultural oversight. Furthermore, Xu and Wang (2021) emphasize the use of Geographic Information Systems (GIS) for crop classification and recognition, demonstrating how spatial data analysis can enhance land use planning and agricultural productivity, a principle that supports our objective of matching soil conditions with suitable crops [11].

Moreover, the integration of Internet of Things (IoT) technologies into agriculture has emerged as a game-changing approach for real-time monitoring. Jadhav *et al.* (2023) illustrate the significance of IoT-enabled smart farming systems in tracking environmental conditions that influence crop growth, directly relating to our development of IoT-based soil nutrient detectors [8]. This perspective is reinforced by Pal *et al.* (2023), who propose an information-centric IoT-based smart farming model that optimizes data management, thereby enhancing monitoring and risk assessment—key components of our project's analytical software for soil health evaluation [9]. The development of expert systems tailored for precision agriculture further enriches this landscape. Yao and Zhang (2016) showcase how knowledge-based applications can provide customized recommendations for crop management based on real-time data, a concept mirrored in our project's aim to suggest crops and soil improvement strategies based on detected nutrient levels [10]. Additionally, Lindblom *et al.* (2016) reveal that decision support systems (DSS) significantly enhance sustainable farming practices by enabling farmers to adapt to changing conditions and optimize resource use, supporting our goal of empowering farmers with actionable insights [12]. Hamed *et al.* (2018) indicate that adopting advanced technologies in farming practices leads to more precise application of inputs, significantly enhancing yield potential compared to traditional methods. Their findings resonate with the challenges faced by Indonesian farmers and reinforce the need for accessible technological solutions like ours in diverse agricultural settings [13]. Closer to home, the Indonesian government has prioritized agriculture as a

cornerstone of national food security, implementing policies to promote technological adoption and infrastructure development, as noted by the Ministry of Finance (2024) [3]. This policy backdrop aligns with our project's mission to support farmers through innovative tools.

A foundational resource for our work is the technical guideline on land evaluation by Ritung *et al.* (2011), published by the Agricultural Land Resource Research and Development Center in Indonesia. This work provides a detailed framework for assessing soil characteristics and recommending suitable crops, serving as a critical reference for our project's design of a land quality detector that automates and accelerates this evaluation process [4]. The convergence of technologies such as remote sensing, IoT, expert systems, and decision support tools underscores the importance of developing comprehensive early detection systems in agriculture. These systems facilitate enhanced monitoring of soil health and crop conditions, ultimately reducing the risk of crop failures and promoting efficient farming practices. Our project, "Soil Nutrient Monitoring: Design and Development of a Land Quality Detector Based on Information Technology," builds on this body of work by integrating sensor-based data collection with analytical software, tailored to the needs of Indonesian farmers, to ensure sustainable agricultural productivity.

3. Research Method

The stages that need to be carried out to achieve the desired goals can be seen in Figure 1.

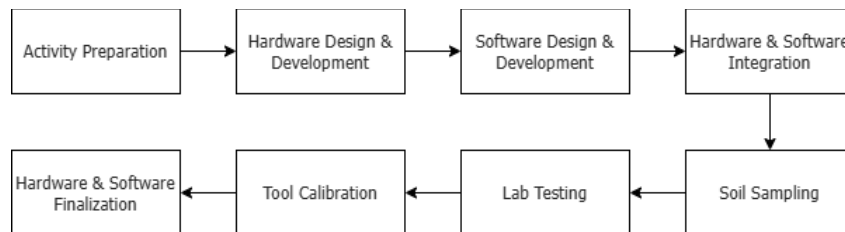


Figure 1. Stages of Activity Implementation

3.1 Activity Preparation

In the preparation phase, a literature review is conducted to gather preliminary knowledge or references related to the topic being studied. This is essential to obtain the theoretical foundation as well as previous research that can support the successful implementation of the activity. After completing the literature review, the next step is to conduct a preliminary study. The purpose of the preliminary study is to obtain detailed information about the system or method to be used. From this study, hypotheses, actual information, and the appropriate methodology will be developed to ensure smooth execution of the activity. This preparation phase will take place from April 29 to May 12, 2024, at Jember State Polytechnic.

3.2 Design and Development of Hardware

This device is designed to measure the soil nutrient content using various sensors. The sensors employed include the NPK sensor, pH sensor, temperature sensor, and soil moisture sensor. Figure 2 illustrates the components of the hardware.

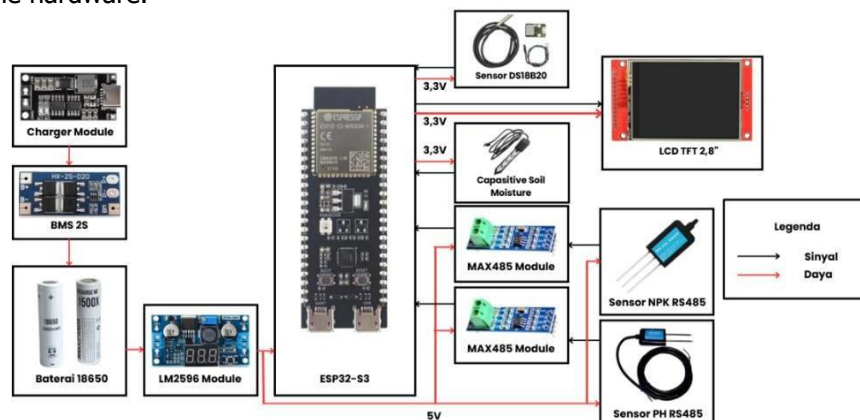


Figure 2. Hardware Components.

The data obtained from these sensors will be processed directly by the mobile application. The application will classify the land characteristics based on the detected nutrient content. In this way, users can obtain accurate and real-time information about the condition of their soil, which can assist in decision-making related to

agriculture and land management. This design and development phase will take place from May 13 to June 23, 2024, at the Electronics and Instrumentation Laboratory, Department of Engineering, Jember State Polytechnic.

3.3 Software Design and Development

In the software design phase, we conducted a needs analysis regarding the features and libraries that will be used to develop the Nutrisoil application. Figure 3 shows the architecture of the mobile application design.



Figure 3. Mobile Application Design Architecture

The development process began with the design phase using Figma, followed by coding using Visual Studio Code, and finally, application testing. In the development of this mobile application, we utilized several technologies, including the Flutter framework for building the front-end interface, Python Django for the back-end to execute the application's functions, and MySQL as the database to store data. This design and development phase will take place from May 13 to June 23, 2024, at the Computer Systems and Control Laboratory, Department of Information Technology, Jember State Polytechnic.

3.4 Hardware & Software Integration

After the soil nutrient detection tool and the Nutrisoil mobile application were developed, the next step was to integrate both systems. Bluetooth Low Energy (BLE) was used to transmit data from the Soil Nutrient Monitoring device to the mobile application. This integration process is crucial to ensure that the data collected from the detection tool corresponds to the data displayed on the mobile application, which is connected via Bluetooth. The system will then classify the land characteristics and provide crop recommendations. This integration phase will take place from June 24 to July 5, 2024, at the Computer Systems and Control Laboratory, Department of Information Technology, Jember State Polytechnic.

3.5 Soil Sampling

The soil sampling process was conducted as an initial step to test the nutrient detection tool. By using this tool, the nutrient content in the soil can be accurately determined. The data generated from these sensors will help in assessing soil quality and determining the nutritional needs required to improve land productivity. This phase of the activity will take place on July 6, 2024, at the Field Laboratory (Rice Field), Jember State Polytechnic.

3.6 Laboratory Testing

The soil sampling process is performed for laboratory testing initially. The purpose of this test is to determine the nutrient content in the soil. The results from the laboratory tests are then used to calibrate the detection tool, which is equipped with NPK, pH, temperature, and soil moisture sensors. This testing phase will take place from July 7 to 16, 2024, at the Bioscience Laboratory, Jember State Polytechnic.

3.7 Tool Calibration

After the previous stages, the system will undergo comprehensive testing to ensure the accuracy and reliability of the data produced. Calibration will be performed to adjust the sensor readings to align with the laboratory test results, ensuring that the data displayed on the mobile application corresponds to the actual conditions. This calibration phase will take place from July 17 to 28, 2024, at the Bioenergy Laboratory, Energy and Mechanical Workshop, Department of Engineering, Jember State Polytechnic.

3.8 Hardware & Software Finalization

The hardware and software finalization process involves retesting the soil samples after the calibration of the hardware and integration into the software, ensuring that the readings match repeated testing results. This finalization phase will take place from July 29 to August 8, 2024, at the Computer Systems and Control Laboratory, Department of Information Technology, Jember State Polytechnic.

4. Result and Discussion

4.1 Results

4.1.1 Installation mechanism and working principles of a system that is designed and developed



Figure.4. Installation and Working Principle of Soil Nutrient Monitoring Equipment.

Soil Nutrient Monitoring is a technology designed to assist farmers in determining land characteristics, providing land improvement recommendations, and suggesting appropriate crops, helping farmers prepare their agricultural land more quickly, effectively, accurately, and in an environmentally friendly manner. This tool is developed based on the needs of farmers, referring to the land evaluation book issued by the Ministry of Agriculture in 2011. This book indicates that each crop has ideal land parameters necessary for effective and healthy growth. Since plant growth is influenced by complex parameter factors, a tool is required to provide accurate information based on various monitored parameters, as well as actionable recommendations to improve the land medium. Figure 2 shows the relationship between the components and elements of the Soil Nutrient Monitoring tool. Below are the details of the sensors and electronic components used.

- 1) The soil pH sensor functions to detect the acidity (acidic) and alkalinity (basic) levels in the soil.
- 2) The temperature sensor (Waterproof DS18B20) is a temperature sensor that operates using the one-wire communication protocol. This sensor has a 12-bit ADC internal, which can detect changes as small as 0.0012 V when the reference voltage on the Arduino is 5V. Additionally, the sensor is water-resistant, making it safe to use in wet soil conditions. This sensor is used to detect soil temperature.
- 3) The capacitive soil moisture sensor measures soil moisture using the capacitive measurement method and is made of materials resistant to corrosion.
- 4) The NPK sensor is used to measure the nitrogen (N), phosphorus (P), and potassium (K) content in the soil. These three nutrients play a vital role in plant growth and health.
- 5) The charger module is used for charging the lithium 18650 battery, while the Battery Management System (BMS) monitors the voltage, current, temperature, and other critical parameters of the battery to ensure it operates within safe limits. Additionally, the BMS provides real-time feedback to the battery charger or power management system, ensuring the proper charging and discharging process. The BMS also has the ability to detect and isolate faulty cells or modules to prevent cascading failures.
- 6) The LM2596 module is a DC Buck Converter module using the LM2596S IC in its circuit to step down the DC voltage from its source. This module can accept input voltages ranging from 3V to 40V DC and convert it to a lower output voltage between 1.5V and 35V DC.
- 7) The 2.8" TFT LCD is a type of screen that uses thin-film transistor technology to control the pixels on an LCD (Liquid Crystal Display). TFT technology allows each pixel on the screen to be individually controlled, resulting in sharper and more responsive image quality compared to other LCD technologies. In our tool, the TFT LCD is used to display sensor data.
- 8) The MAX485 module is a TTL to RS485 converter used to connect a microcontroller device to an RS485 network. Below are some features and uses of the MAX485 module.

The hardware operates based on sensors measuring NPK, soil temperature, moisture, and pH. The data from these sensors is processed by the microcontroller to generate calibrated data. Once processed, the microcontroller sends the data to the mobile application via Bluetooth Low Energy (BLE) protocol for further data processing. The power source for this technology consists of four lithium 18650 batteries, where two batteries are connected in parallel and two batteries in series, subsequently reducing the voltage to 5V using the LM2596 module. These lithium batteries power the ESP32-S3 and all sensors. Based on the above hardware principles, this technology is designed to be portable so that farmers can easily bring it to various land conditions. Below is an illustration of the designed hardware, which includes the tool prototype and the PCB

prototype. The tool prototype consists of a control box, a sensor storage compartment, a PCB holder, and a cover. The following is an overview of the overall prototype and the interior of the prototype tool.



Figure 5. Overall tool prototype



Figure 6. The inside of the tool prototype



Figure 7. Prototype PCB design



Figure 8. Installation of sensors in soil samples.

The Soil Nutrient Monitoring tool itself uses a PCB so that the prototype tool produced is more portable, besides that, by using a PCB it will be safer and more organized. The PCB itself is a board that functions to unite electronic components in electronic devices (Figure 1). Soil Nutrient Monitoring facilitates farmers in determining land characteristics, suggesting land improvements, and recommending crops through software via a mobile application. The system workflow of the software is as follows: The hardware performs calculations based on soil sensors, ensuring that the sensor data generated is properly calibrated (Figure 2 & 3). The data from the hardware, including the NPK sensor, temperature, soil moisture, and pH, is transmitted via Bluetooth Low Energy (BLE) for communication between the hardware and the mobile application, which is designed to display the output of the land quality measurements.

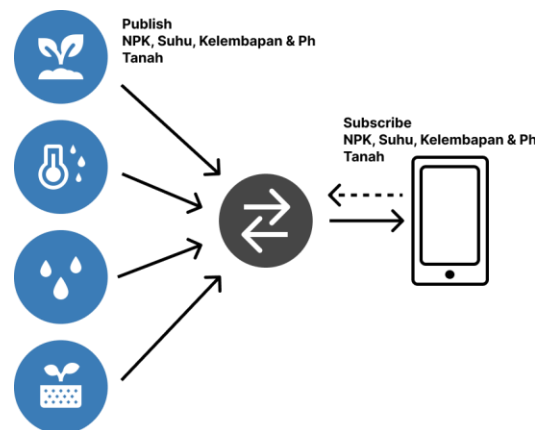


Figure 9. Illustration of Sending Data to Mobile

Subsequently, the data is processed on the backend hosting server. The processing involves decision-making methods for crop recommendations and land improvement, based on the land quality evaluation book.

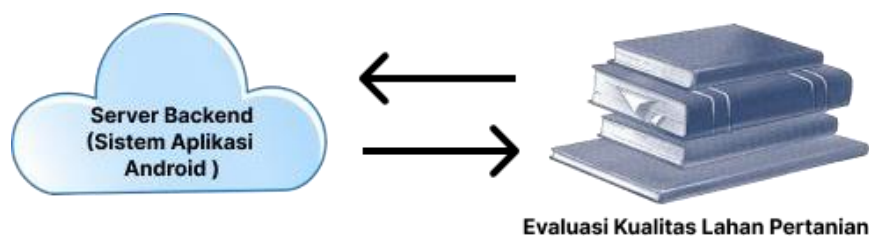


Figure 10. Data Processing Uses Forward Chaining Based on The Land Evaluation book.

The data is then stored in a MySQL database. The data storage in the database serves to store the measurements from the "Soil Nutrient Monitoring" tool and also manage user data. Next, the output of the measurements and the processed data from the "Soil Nutrient Monitoring" tool will be displayed on the mobile application.

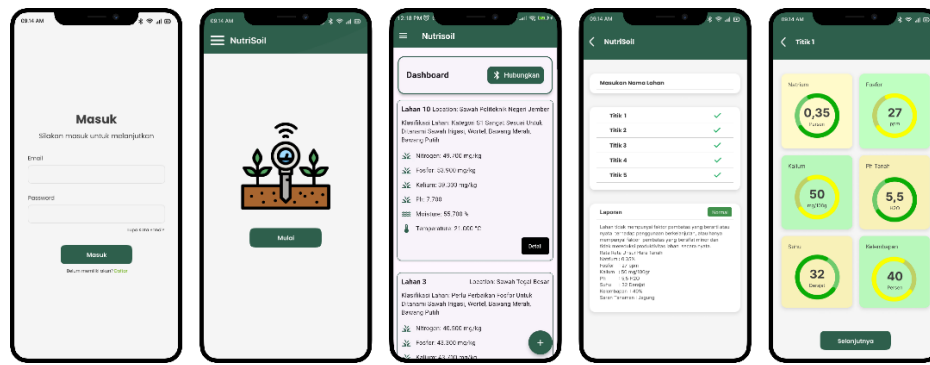


Figure 11. Soil Nutrients Monitoring mobile application view

The workflow of the Soil Nutrient Monitoring tool can be seen in Figure 11, which shows the flowchart of the Soil Nutrient Monitoring process.

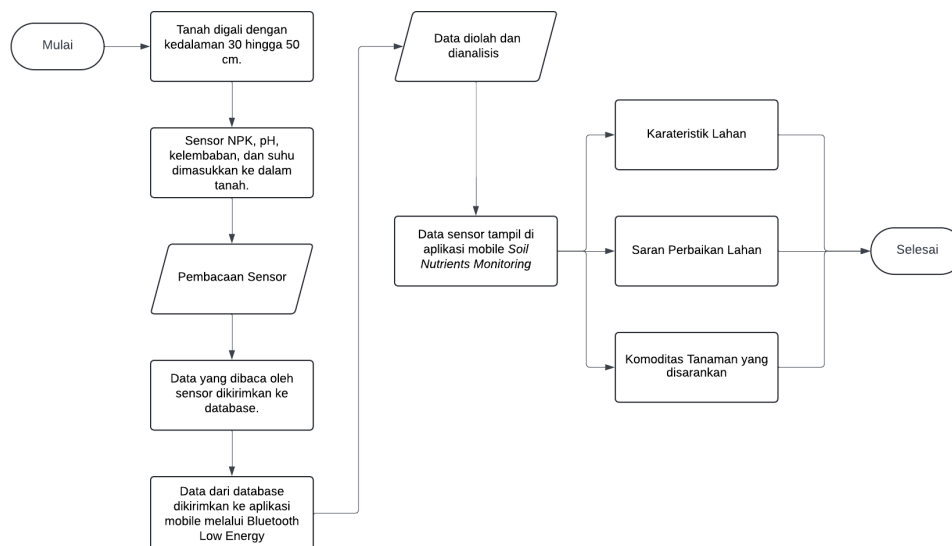


Figure 12. Flowchart of How Soil Nutrient Monitoring Works

The measurements of NPK, pH, temperature, and soil moisture in a particular area are conducted at 5 points within the land, specifically at the top-left and top-right corners, the bottom-left and bottom-right corners, and the center point of a plot of land measuring 300 – 400 m², as shown in Figure 13.

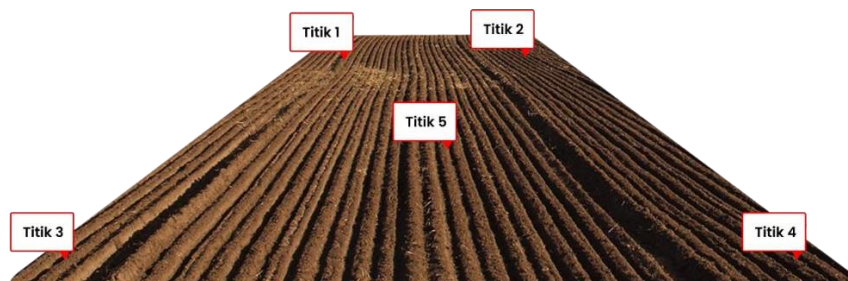


Figure 13. Points for measuring NPK content, pH, temperature and soil moisture in each field

Before performing measurements at the 5 points on a given land using the Soil Nutrient Monitoring tool, measurements were first conducted at 10 points within the same land, with closely positioned points. The results from these measurements showed no significant differences across the grid of land, leading to the conclusion that the measurements taken at 5 points within the land are representative of the soil nutrient content for the entire area. The measurement data from these 5 points will then be processed and analyzed to determine land characteristics, land improvement recommendations, and crop suggestions, as shown in Figure 14.

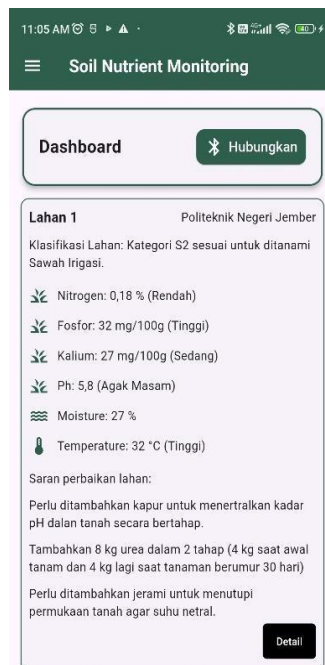


Figure 14. Land Measuring Results on Mobile Applications

The data obtained will then be processed and analyzed, and the mobile application will display the results, as shown in Figure 12. Before field testing, this tool underwent calibration at each sensor with similar testing equipment. The calibration results for each sensor are as follows.

4.1.2 Calibration Results for Moisture Sensor

Table 1. Soil Moisture Values vs. ADC Sensor Values

No	Soil Moisture (%)	ADC
1	0	2419,333
2	5	2380,75
3	10	2196
4	15	2163,25
5	20	1708,6
6	25	1724
7	30	1437,4
8	35	906,2
9	40	348,4
10	45	250
11	50	13,2

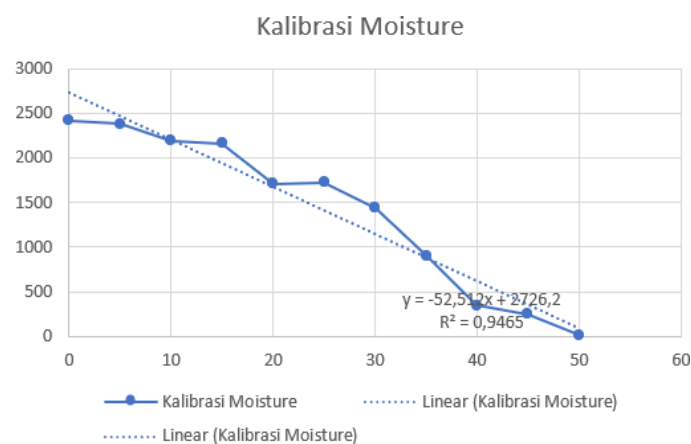


Figure 15. Humidity Calibration Value

The following are the calibration test results for the moisture sensor. For this calibration test, we used soil as the test object. Initially, we performed an oven drying process at 120°C to remove the moisture content from the soil. The next step was to stabilize the soil temperature using a desiccator. During the calibration test, we gradually added water content ranging from 5% to 50%, depending on the weight of the soil used in the test. Subsequently, we measured the readings from the sensor, which were then compared with the moisture content as a reference for the linear regression process, resulting in an accurate output of 94.65%.

4.1.3 Calibration Results for Temperature Sensor

Table 2. Soil Temperature Values vs. Alcohol Thermometer and Digital Thermometer Values

No	Sensor	Alcohol Thermometer	Digital Thermometer	Difference
1	34	34	34	0
2	35	35	35	0
3	36	36	36	0
4	37	37	37	0
5	39	39	38	0
6	40	40	40	0
7	26	26	25,8	0
8	25	25	25,2	0
9	24,5	24	24,5	0,5
10	23,5	23	24,1	0,5
11	23	23	23,7	0
Accuracy				99%

The following are the calibration test results for the temperature sensor. In this calibration test, we compared the sensor readings with measurements taken from both an alcohol thermometer and a digital thermometer. During the testing, we heated water and recorded the readings from the sensor, alcohol thermometer, and digital thermometer. The calibration results showed an accuracy level of 99%, as the measurements from the sensor, alcohol thermometer, and digital thermometer did not exhibit any significant errors.

4.1.4 Calibration Results for pH Sensor

Table 3. Soil pH Values vs Universal pH Values

No	Sensor	pH universal	Error
1	4,3	4,5	3,3
2	6,5	6	8,3
3	4,4	4	6,6
Average			6,1 %

The following are the calibration test results for the pH sensor. In this calibration test, we compared the sensor readings with the results obtained using litmus paper. During the test, we measured the pH of the soil using litmus paper and compared it with the readings from the sensor, which yielded a difference of 6.1% and an accuracy level of 93.9%.

4.1.5 Calibration Results for NPK Sensor

Table 4. Sensor NPK Soil Values vs. Laboratory Test NPK Values

No	Soil Type	Sensor N	Sensor P	Sensor K	Lab Test Nitrogen	Lab Test Fosfor	Lab Test Kalium
1	Humus Soil	1	80	81	0,99	79	80
2	Rice Field Soil, Jenggawah	0,12	21	22	0,1	20	21

The following are the calibration test results for the NPK sensor. In this calibration test, we compared the sensor readings with laboratory test results from the Biosciences Laboratory at Politeknik Negeri Jember. The calibration test validated the sensor readings with the laboratory tests, demonstrating an accuracy level of 99%. This indicates that the sensor is suitable for detecting the accuracy and predicting the nutrient content

in soil, specifically the Nitrogen, Phosphorus, and Potassium (NPK) levels. This tool introduces a novel innovation in the agricultural sector by developing a device for detecting soil nutrient content, including Nitrogen, Phosphorus, Potassium, pH, temperature, and soil moisture, based on hardware and a mobile application. The system is calibrated with an accuracy rate of 95%, providing a solution that aids in achieving stable food security and enhancing agriculture in Indonesia. The Soil Nutrient Monitoring tool is designed to be portable for ease of use, offering precise measurements of soil nutrients and a mobile application that provides recommendations for suitable crops, land improvement, land evaluation, and nutrient content in the soil.

4.2 Discussion

The development of a Soil Nutrient Monitoring tool that analyzes soil quality through the integration of multiple sensors is a significant advancement in agricultural technology. Research has demonstrated the significance of such tools in improving the efficiency and sustainability of agricultural practices, especially in areas facing soil health and food security issues. A growing body of literature supports the effectiveness of portable sensor technologies for soil monitoring. Mohanty *et al.* (2022) discuss the role of IoT-based devices that can measure multiple soil parameters—such as temperature, moisture, and nutrient content—to improve farmer decision-making and yields [14]. Devianti *et al.* (2019) also highlight the importance of near-infrared reflectance spectroscopy (NIRS) technology for rapid and simultaneous prediction of macronutrient levels in agricultural soils, which supports sensor-based approaches such as our tool [2]. This approach is in line with the design of the Soil Nutrient Monitoring tool that uses sensors to detect parameters such as NPK, pH, temperature, and soil moisture. The usability and accessibility of this monitoring system to multiple stakeholders—farmers, educational institutions, and the general public—are critical for its widespread adoption. Wati (2020) explores the complexities of land suitability assessment for rice cultivation and shows how technology can strengthen food security by providing tailored land evaluations and increasing productivity through in-depth data [15]. Ritung *et al.* (2011) in the technical guidelines for land evaluation for agricultural commodities published by the Indonesian Ministry of Agriculture also served as an important basis in the development of this tool, providing ideal parameters for plant growth that serve as the basis for our recommendations [4]. This underscores the need for a system that not only provides nutritional analysis but also actionable recommendations based on the data collected.

Calibration and accuracy of Soil Nutrient Monitoring tools greatly affect their effectiveness. Liu *et al.* (2022) presented a sophisticated system using neural networks to evaluate soil quality, demonstrating the importance of precision monitoring to provide reliable data to users [16]. Zhao and Li (2018) also highlighted the importance of precision in agriculture through advanced technologies to improve agricultural yields [6]. Our tool calibration results showed an accuracy rate of up to 95%, with the moisture sensor reaching 94.65%, the temperature sensor 99%, the pH sensor 93.9%, and the NPK sensor 99%. This shows that the development of effective monitoring tools requires a combination of advanced technology with strong data analytics capabilities. Engaging users through mobile application software is also very important. Ruiz-Martínez *et al.* (2020) explored a digital platform that delivers critical agricultural data, which can improve user experience and decision-making processes [17]. Jadhav *et al.* (2023) emphasized that IoT-based smart farming systems can improve crop growth efficiency through data integration that is easily accessible to farmers [8]. The Soil Nutrient Monitoring mobile application was designed to display measurement results, crop recommendations, and land improvement suggestions, in line with these findings. The benefits of improved soil monitoring technology extend beyond crop impacts to the broader farming community. Behairy *et al.* (2022) argue that integrating GIS approaches with soil assessment can lead to sustainable farming practices and better land use management, which are critical to addressing food security challenges [18]. Wahyuni (2025) also highlights the implementation of Geographic Information Systems (GIS) for mapping and managing natural resources in agricultural areas [19]. Lindblom *et al.* (2016) add that the development of decision support systems in precision agriculture can promote sustainable intensification, which is relevant to the objectives of our tool [12]. The implementation of a mobile application that provides insights into crop recommendations and soil conditions is in line with these findings, supporting community development initiatives.

Cahyani (2023) emphasized the role of IoT in Smart Farming 4.0 to improve agribusiness efficiency, which is relevant to the use of the Bluetooth Low Energy (BLE) protocol in our tool for data communication between hardware and mobile applications [20]. Pal *et al.* (2023) also discussed IoT-based smart farming with dynamic data optimization, which supports our approach in real-time soil data management [9]. Baladraf (2024) discussed the potential application of Digital Twin technology in the agricultural and food industry in Indonesia, indicating that digital innovations such as our tool can pave the way for more sophisticated agricultural solutions in the future [21]. In addition, Daniel *et al.* (2020) highlighted the use of forward chaining methods in expert systems for crop growth, which is in line with our approach in data processing for crop recommendations [1]. The Soil Nutrient Monitoring tool represents a significant step towards increasing

agricultural productivity and sustainability. By leveraging modern technology to provide accurate soil assessments and practical recommendations, it supports the broader goal of improving food security and reducing the risk of crop failure in Indonesia, ultimately fostering a resilient farming community. The integration of sensors, mobile applications, and literature-based data analysis of land evaluation makes this tool an innovative solution that is in line with the needs of Indonesian farmers, as supported by the government's primary concern for the agricultural sector to maintain food security.

5. Conclusion

The Soil Nutrient Monitoring tool has successfully been developed in the form of hardware capable of analyzing soil quality using four sensors: temperature, humidity, pH, and NPK. This tool is beneficial for educational institutions, farmers, and the general public. The Soil Nutrient Monitoring system is designed to be portable and has been calibrated to a high level of accuracy to facilitate ease of use. Additionally, with the mobile application software, which provides plant recommendations, land improvement suggestions, land evaluation, and soil nutrient content, it is hoped that this tool will help many people achieve food security in Indonesia, reduce crop failures, and develop agricultural communities.

References

- [1] Daniel, L. P., Mahmudin, A., & Auliasari, K. (2020). Sistem pakar pertumbuhan dan perkembangan pada tanaman cabai dengan metode forward chaining. *JATI (Jurnal Mahasiswa Teknik Informatika)*, 207-213.
- [2] Devianti, D., Sufardi, S., Zulfahrizal, Z., & Munawar, A. A. (2019). Near infrared reflectance spectroscopy: prediksi cepat dan simultan kadar unsur hara makro pada tanah pertanian. *Agritech*, 39(1), 12-19. <https://doi.org/10.22146/agritech.42430>.
- [3] Kementerian Keuangan Republik Indonesia. (2024). *Jaga ketahanan pangan, sektor pertanian menjadi perhatian utama pemerintah*. Diakses dari <https://www.kemenkeu.go.id/informasi-publik/publikasi/berita-utama/Sektor-Pertanian-Fokus-Utama-Pemerintah>
- [4] Ritung, S., Nugroho, K., Mulyani, A., & Suryani, E. (2011). *Petunjuk teknis evaluasi lahan untuk komoditas pertanian (Edisi Revisi)*. Bogor: Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Badan Penelitian dan Pengembangan Pertanian, Kementerian Pertanian.
- [5] Montalvo-Romero, N., Montiel-Rosales, A., & Purroy-Vásquez, R. (2023). Agro-technological systems in traditional agriculture assistance: A systematic review. *IEEE Access*, 11, 123047-123069. <https://doi.org/10.1109/ACCESS.2023.3329087>
- [6] Zhao, C., & Li, M. (2018). Highlights in precision agriculture. *Frontiers of Agricultural Science and Engineering*. <https://doi.org/10.15302/J-FASE-2018246>
- [7] Ioja, I., Nedeff, V., Agop, M., & Nedeff, F. (2024). Some possibilities of the aerial drones use in precision agriculture – A review. *Journal of Engineering Studies and Research*, 29(4), 43-49. <https://doi.org/10.29081/jesr.v29i4.006>
- [8] Jadhav, N., Rajnivas, B., Subapriya, V., Sivaramakrishnan, S., & Premalatha, S. (2023). Enhancing crop growth efficiency through IoT-enabled smart farming system. *EAI Endorsed Transactions on Internet of Things*, 10. <https://doi.org/10.4108/eetiot.4604>
- [9] Pal, S., VijayKumar, H., Akila, D., Jhanjhi, N., Darwish, O., & Amsaad, F. (2023). Information-centric IoT-based smart farming with dynamic data optimization. *Computers, Materials & Continua*, 74(2), 3865-3880. <https://doi.org/10.32604/cmc.2023.029038>
- [10] Yao, Y., & Zhang, Y. (2016). Application of maize precision fertilizer expert system in the maize production. <https://doi.org/10.2991/icmmct-16.2016.259>
- [11] Xu, H., & Wang, Z. (2021). Classification and recognition of crops based on GIS image. *International Journal of Frontiers in Sociology*, 3(17). <https://doi.org/10.25236/ijfs.2021.031702>

- [12] Lindblom, J., Lundström, C., Ljung, M., & Jönsson, A. (2016). Promoting sustainable intensification in precision agriculture: Review of decision support systems development and strategies. *Precision Agriculture*, 18(3), 309-331. <https://doi.org/10.1007/s11119-016-9491-4>
- [13] Hamed, M., Adam, A., Dawoods, M., & Fangama, I. (2018). Towards implementing the integrated technology of precision agriculture in Sudan. *Journal of Agronomy Research*, 1(2), 35-45. <https://doi.org/10.14302/issn.2639-3166.jar-18-2331>
- [14] Mohanty, P., Valagadri, V., & Ramya, S. (2022). Smart farming enabled by IoT and spectral imaging. *Journal of Physics: Conference Series*, 2161(1), 012044. <https://doi.org/10.1088/1742-6596/2161/1/012044>
- [15] Wati, S. (2020). System dynamics modelling for increasing of paddy production with land suitability level to support food security. *International Journal of Advanced Trends in Computer Science and Engineering*, 9(1), 233-240. <https://doi.org/10.30534/ijatcse/2020/35912020>
- [16] Liu, Y., Li, J., Liu, C., & Wei, J. (2022). Evaluation of cultivated land quality using attention mechanism-back propagation neural network. *PeerJ Computer Science*, 8, e948. <https://doi.org/10.7717/peerj-cs.948>
- [17] Ruiz-Martínez, I., Debolini, M., Sabbatini, T., Bonari, E., Lardon, S., & Marraccini, E. (2020). Agri-urban patterns in Mediterranean urban regions: The case study of Pisa. *Journal of Land Use Science*, 15(6), 721-739. <https://doi.org/10.1080/1747423X.2020.1836054>
- [18] Behairy, R., Baroudy, A., Ibrahim, M., Mohamed, E., Kucher, D., & Shokr, M. (2022). Assessment of soil capability and crop suitability using integrated multivariate and GIS approaches toward agricultural sustainability. *Land*, 11(7), 1027. <https://doi.org/10.3390/land11071027>
- [19] Wahyuni, R. (2025). Implementasi Sistem Informasi Geografis (SIG) untuk pemetaan dan pengelolaan sumber daya alam di kawasan pertanian. *Journal of Human and Education (JAHE)*, 5(1), 545-550. <https://doi.org/10.31004/jh.v5i1.2227>
- [20] Cahyani, M. P. (2023). IoT dalam Smart Farming 4.0 untuk upaya tingkatkan efisiensi agribisnis. *Teknois Jurnal Ilmiah Teknologi Informasi dan Sains*, 3(2), 154-190.
- [21] Baladraf, T. T. (2024). Potensi penerapan teknologi Digital Twin pada industri pertanian dan pangan di Indonesia: Sebuah tinjauan literatur. *Jurnal Teknotan*, 18(1), 21.