Engineering and Technology Journal e-ISSN: 2456-3358

Volume 10 Issue 06 June-2025, Page No.- 5505-5513

DOI: 10.47191/etj/v10i06.25, I.F. – 8.482

Construction of an Autonomous Nutrient Sensor System Based on the Internet of Things (IoT) on Cassava Land

Ramli Rumeon[1], Heru Sukoco[2], Hendra Rahmawan[3]

[1,2,3]Computer Science Department, IPB University, Bogor, Indonesia

ABSTRACT Cassava farming in the Jonggol region faces various challenges, especially in terms of water and fertilizer use efficiency. Management that is still carried out manually often causes waste of resources, as well as difficulties in monitoring soil conditions in real-time. This research aims to develop and implement an Autonomous Nutrient Sensor System based on the Internet of Things (IoT) on cassava land in Jonggol, with a focus on efficient water and fertilizer management. The system allows for automatic and manual watering and fertilization arrangements, giving farmers flexibility in caring for cassava plants. Through web applications and mobile applications, farmers can access information related to soil and crop conditions, as well as remotely control watering and fertilizing crops. With the integration of sensor technology and IoT, this research has succeeded in providing a smart solution to improve the efficiency of resource use in precision agriculture, especially in cassava plants in a 10-hectare land area in Jonggol, allowing farmers to manage land more efficiently and effectively.

KEYWORDS: Internet of Things (IoT), Sensors, Cassava Plant, Land Management, Precision Agriculture

INTRODUCTION

Land is the result of the complexity of the interaction between biotic and abiotic factors. Among the abiotic factors that dominate land formation, soil plays a key role [1] Soil is formed from the interaction between weather, type of rock of origin, land shapes, living things, and the process of time. The composition of each soil grain is 45% minerals, 5% organic matter, 25% water, and 25% air [2]. In line with the formation process, the availability of nutrients in the soil has different amounts and types. This depends on the type of soil, the process of its formation and the amount of organic matter present in the soil. Measures to increase crop yields will only be successful if the soil properties are still in accordance with the existing land suitability [3], [4], [5]. The suitability of land in the West Java region is adequate for planting locations, including the planting of cassava plants [6]. This is strengthened by the results of the analysis of cassava production data carried out by [7] One Agricultural Data, (Cassava Outlook 2020). Therefore, the IPB Experimental Garden which is located in Jonggol Cileungsi-Bogor District, West Java, which has a large plantation area, there is also great opportunity and potential for the development of cassava commodities in the area.

The Jonggol cassava plantation has a total area of 120 hectares which is used for the Oil Palm Education Plantation, the location of the farm, and the location of cassava development. The land used as a cassava planting object is 10 ha, with the soil type being ultisol, in addition to being mentioned by [8] the minimum air temperature ranges from 25°C in 2015 and 26-27°C in 2016 to 2020, while the maximum air temperature remains stable between 30°C to 32°C. Relative humidity during the period showed figures ranging from 73% to 80%, with a peak in 2016. Annual rainfall varied, reaching 2,718 mm in 2016, and decreasing in 2018 by 1,914 mm. Other challenges, such as dependence on fluctuating weather patterns and drought risk, are the main concern that must be addressed. Low and uneven rainfall can lead to soil dryness, hindering the optimal growth of cassava plants. Difficulty in accessing distant water sources is an obstacle in meeting irrigation needs, while the use of less efficient irrigation technology and unwater-friendly planting patterns can exacerbate the problem [9], [10], [11]. The content of soil essential nutrients, such as phosphorus (P), nitrogen (N), and potassium (K), must be maintained at levels sufficient to support optimal plant growth in different ways [12]. Improper or excessive use of fertilizers can damage the quality of the soil and the surrounding environment and disrupt the nutritional balance of cassava plants [13]. This has an impact on the lack of information about fertilizer dosage causing the application of fertilizer to be inappropriate because it has not been scientifically proven [14], [15].

Cassava is a fairly flexible plant, but the result is greatly influenced by the planting location factor. Climate with rainfall: 1,500-2,500 mm/year, minimum air temperature: 10 °C, optimal temperature: 27-32 °C, optimal air humidity: 60-65% and solar irradiation duration: 10 hours/day. The soil type is crumbly structured, loose, not too clayy, and not too porous and rich in organic matter (≥ 2%). The soils that correspond to this type of plant are alluvial, latosol, red-yellow, mediterranean, grumosol, andosol, and ultisol, with an acidity degree (pH): 4.5-8.0 with (pH) an ideal of 5.8. Ideal place height: 10-700 (masl), with tolerances of 10-1500 (masl). In addition to having optimal growing conditions, cassava is also known as a plant that is tolerant of less fertile soil conditions and resistant to drought. Cassava tubers are an important source of carbohydrates for most populations in tropical and subtropical regions. Cassava plants also have potential in food diversification and as raw materials for the food and non-food industries. With these diverse benefits, cassava is an important crop in supporting food security and economies in various countries [16], [17]. Therefore, the maintenance needs to be improved properly, one of the solutions is to implement an IoT-based treatment system to monitor plant conditions in real-time, optimizing its growth by watering and fertilizing precisely using a drip irrigation system.

The emergence of the Internet of Things (IoT) in the agricultural sector provides great benefits for farmers. This technology is not only user-friendly and economical in connecting various devices, but it also allows users to access and manage devices from remote locations whenever needed. In addition, IoT also improves the quality of services in line with user needs [18]. The IoT-based drip irrigation system implemented on the Jonggol land is a pioneering implementation designed with the needs of two actors in mind, and implements two modes of action, namely automatic and manual. In automatic mode, the system works based on scheduling, i.e. field conditions reported from the sensor when moisture or nutrient levels are reduced from a predetermined threshold value. Meanwhile, in manual mode, the user directly interacts with the control of the control of the unit's hed system, regulating the flow of water and fertilizer by performing every function that has been programmed on the control of the system. This process allows users to manually adjust irrigation based on soil conditions, plant types, as well as other environmental factors that affect the water needs of cassava plants.

A study on precision agriculture that integrates Internet of Things (IoT) technology to improve soil nutrient analysis and crop recommendations was pioneered by Senapty in [19]. However, there is no in-depth information on how the IoT Enabled Soil Nutrient Analysis and Crop Recommendation (IoTSNA-CR) model is integrated with fertilization and irrigation systems. It is important to clarify how soil nutrient data collected by sensors and measurable groundwater availability data to provide appropriate fertilization and irrigation recommendations. A good integration between soil nutrient analysis, groundwater availability analysis as well as its recommendations can improve efficiency based on needs [20]. Lean in [21] developing a smart farming system using the Raspberry Pi. The system is designed to monitor and control crucial plant growth factors such as irrigation, temperature, humidity, soil moisture, and light intensity. They connect these sensors to the GrovePi board, making it easy to integrate multiple sensors at once. The system also includes a smartphone app built with MIT App Inventor to simply monitor sensors and control drip irrigation. One of its excellent features is its ability to automatically adjust watering based on soil conditions in real-time, reducing water wastage and supporting healthy plant growth. However, the study focuses on small-scale prototypes and will probably face some challenges such as network connectivity, power management, and data security in a real farm environment. Nguyen in [22] working on a system called the Internet of Plants (IoP) to remotely monitor environmental factors for plant growth such as soil moisture, water level, temperature, and humidity. They used a simple microcontroller called ESP32, which has built-in Wi-Fi and Bluetooth, to create a small IoP system for organic gardens in a small environment. The data they collect is sent to an open-source IoT platform like Thingsboard for storage and display. However, indoor testing with wired power makes it difficult to use the system in actual outdoor farming. On a real farm, they need to think about things like resource availability, wireless connections, and how well the system can handle complex outdoor conditions.

This research aims to design and implement an IoT system integrated with sensor technology to improve the efficiency of resource use in precision agriculture, especially in cassava plants in an area of 10 hectares of land in Jonggol. The developed system will utilize sensor data to monitor and control the supply of water and fertilizer automatically and precisely based on soil conditions and plant needs. Thus, it is hoped that this research can contribute to the development of intelligent systems that can increase agricultural productivity and resource management efficiently in the context of technology-based agriculture.

RESEARCH METHODS

A. System description

Mapping plantation land is the first step to find out the characteristics of the land to be planted with the right crops, especially in this case cassava plants as food commodity crops. Land mapping is carried out by measuring soil content with data parameters in the form of:

- The content of N, P, K in the soil.
- Temperature and Humidity in the soil.
- Coordinates of the location of plantation land (Longitude, Latitude).
- Land level above sea level (masl).

The autonomous nutrient sensor system that was built is a system located in an area or land of cassava plants located in the Jonggol germplasm plantation with an area of 10 hectares, which is designed based on a number of criteria and reasons for use that are adjusted to needs. The location of the research can be seen in Figure 1.

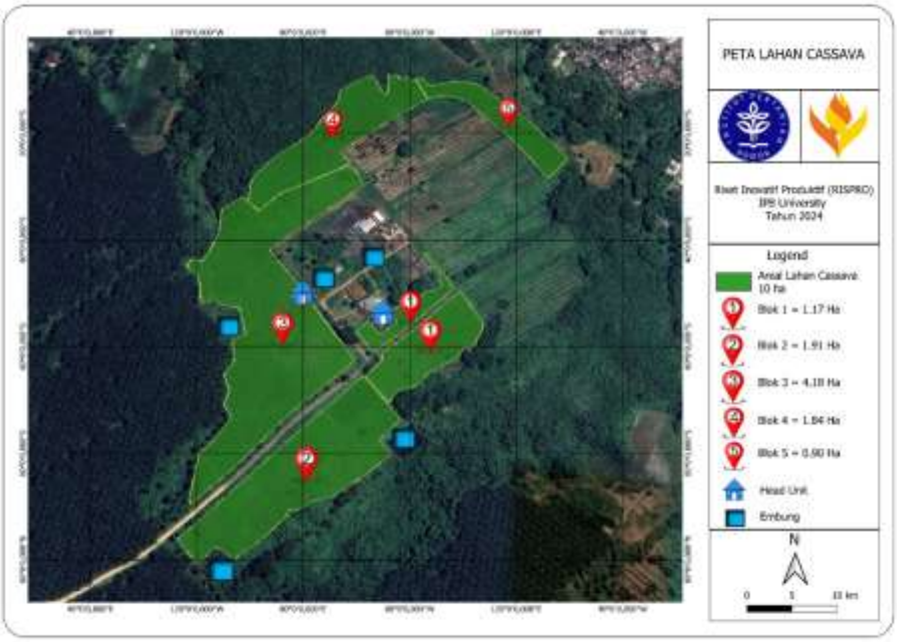


Figure 1 Research location

In the context of research focused on the utilization of IoT technology, the research location map not only serves as a visual representation of the study area, but also serves as a starting point that guides the design of an optimal system architecture. The integration of spatial information from location maps with system architecture elements such as network infrastructure, sensors, and user interfaces is crucial in ensuring that the developed system is able to cope with diverse environmental challenges [23]. As illustrated in Figure 2.

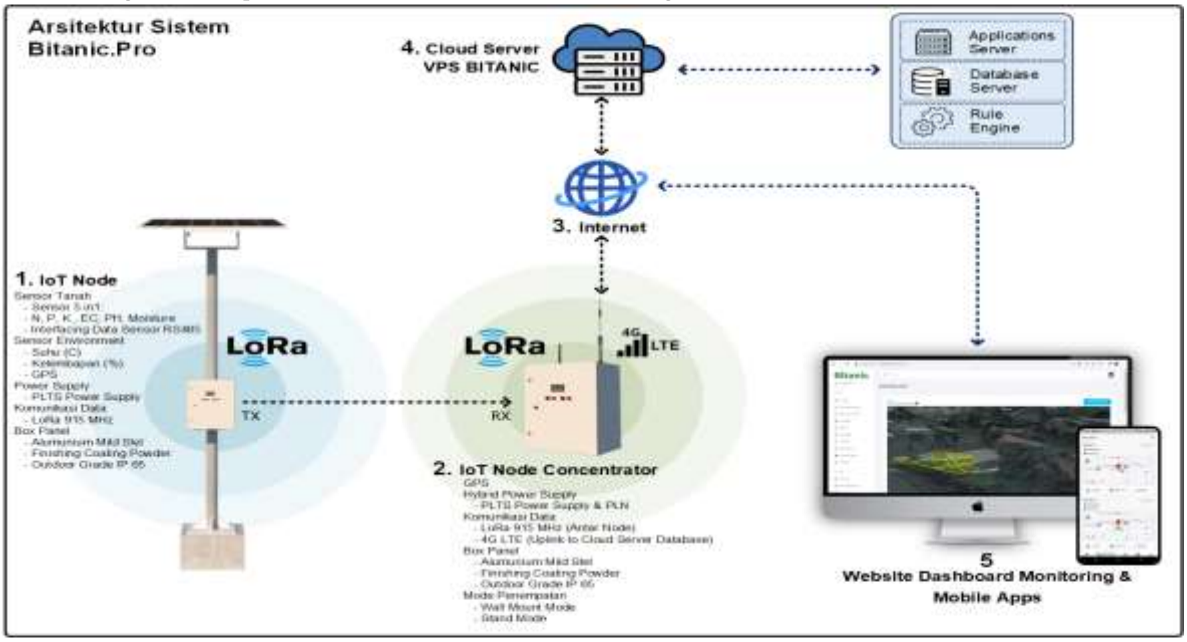


Figure 2 System architecture

The system consists of various components such as IoT nodes as the starting point responsible for collecting data from various sensors by using LoRa as a data communication network. IoT node concentrators are connected via the internet to servers in the cloud. This server is used to store soil condition data entered by users and also as an application server that provides appropriate fertilizer recommendations. Websites and mobile applications act as a link between users and devices, allowing them to remotely control the pump according to a schedule set through the website or mobile application. The website provides information about soil and crop conditions based on reports from sensors. With a mobile application, users can control watering and fertilization based on a schedule that has been created. The explanation of each system is explained in Table 1 as follows:

Table 1 System and subsystem functions.

Yes	Part	Feature	Detail
1	IoT Node	a. Equipped with 7 in1 soil sensor for N, P, K, EC, PH, Moisture. b. Equipped with temperature, environmental humidity sensors. c. Equipped with GPS. d. Solar panel voltage source with battery *back up*. e. Installation mode on poles with a concrete cast foundation. f. Integrated with IoT Node *concentrator*. g. Communication via LoRa 915 MHz.	1. Soil temperature value input 2. Input value of soil acidity level (soil pH) 3. Input soil moisture value 4. Input values of nitrogen (N), phosphorus (P), potassium (K)
2	IoT Node Concentrator	a. Downlink communication via LoRa 915 (up to 16 nodes). b. DC voltage source from PLN's solar panel/AC. c. Solar energy source management with battery backup. d. Uplink based on GSM 4G Industrial modem. e. Mounting mode on a wall or pole.	As an IoT unit that traps data transmission between data communication from IoT Nodes in the form of Radio communication (downlink) to Bitanic Cloud Server VPS and 4G GSM data communication as (uplink).
3	Internet	Connectivity and data transfer between devices.	Provide a communication path between sensors, microcontrollers, and cloud platforms or applications. The internet plays a role in sending sensor data in real-time to servers, as well as allowing farmers to access and control the system remotely through web-based or mobile applications.
4	Cloud Server VPS Bitanic	Server virtualization services can divide the resources of a physical server into parts virtually.	Store website hosting files and host website traffic and mobile apps.

From the previous exposure to system architecture, then how these concepts are implemented in the use case diagram in Figure 3 which will be explained further. The use case diagram provides a visual representation of the interaction between the user and the system, which will help in a deeper understanding of the overall functionality of the system [24]

Figure 3 Use case diagram

First, in the user management feature , the admin can add, edit, or delete farmer and operator accounts. The admin is also responsible for managing access rights and resetting passwords if necessary. In the device activation feature , the admin is tasked with registering sensors or IoT devices into the system so that they can start sending data. The admin also monitors the device's connectivity status, including monitoring whether the device is functioning properly or not. Through this feature, the admin can also perform regular device system updates. The system interpretation and control feature allows the admin to view data from all fields connected to the system, both in the form of soil fertility information and plant health. The admin has the authority to set system parameters such as nutrient thresholds, default watering settings, or automatic fertilization schedules. In addition, through the fertilization schedule and watering settings module, the admin can test the functionality of the automation system for all fields. In the fertilizer recommendation feature, the admin has a role in adjusting the formula or recommendation algorithm based on soil type, sensor results, and fertilization history. This feature is usually managed with a team of experts or based on the results of ML model training. Finally, through the dashboard and reports, the admin can monitor the performance of system usage, create statistical reports, and evaluate the efficiency of technology implementation in the field. Farmers, on the other hand, can use the device activation feature to activate the farming device connected to the app. They can also access fertilizer application schedules that are tailored to the type of plant and its growth stage, as well as arrange plant watering arrangements according to plant water needs and environmental conditions.

In application development, device control mechanisms can be designed to flexibly manage system activation (Figure 4). This allows the user to determine whether the watering system will run automatically based on specific parameters, such as soil moisture or a preset schedule, or be operated manually according to specific needs.

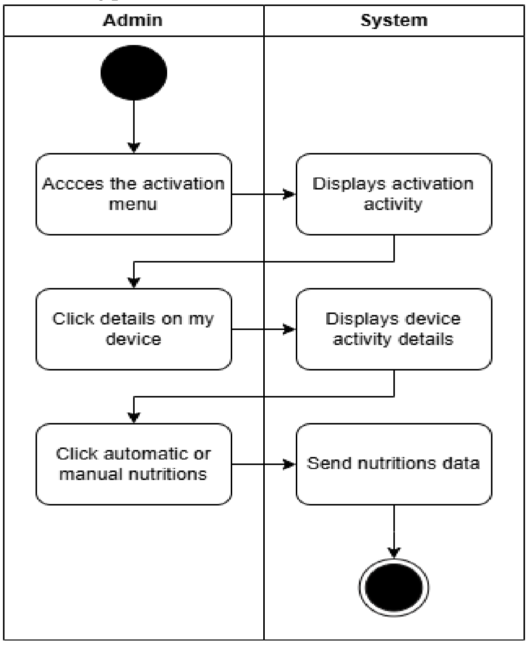


Figure 4 Irrigation control activity diagram

RESULTS AND DISCUSSION

B. Process and implementation of the system

Based on the image in (Figure 5) that has been presented,it can be seen that the installation of an irrigation system has been carried out on the land in Jonggol. The pipes and other components are seen to be connected to a power source and arranged in a certain pattern. The pipes are used for the purpose of watering or irrigating agricultural land in the area. The work process related to the installation of this system involves several stages. First, the pipes must be installed correctly according to the planned pattern to distribute water evenly throughout the land area. Next, the system must be tested to ensure that the pipes are properly installed and do not leak. After that, the system must be activated and run to ensure that the water flows smoothly and according to the needs of the plants based on the results of the water calculations that have been calculated and programmed for the land. This system allows watering and fertilization to be carried out in two ways, which are automatic or manual. In the automatic working section, the machine will turn on to water the plants or nourish the soil with water and liquid fertilizer according to the schedule that has been determined by the farmer through the website or application on the mobile phone. On the other hand, in the manual way of working, the farmer will control the pump directly by turning it on or off himself.

The app's website provides farmers with information on important matters related to soil conditions, which will later have an impact on the needs of water and fertilizer use. This information helps farmers in providing fertilizer to plants according to the needs of plants and the type of soil on their land. Figure 5 shows the system used to drain water and fertilizer in cassava farming.

(a) (b)

Figure 5 Cassmatech module (a) pump installation module and integration, (b) device testing (automatic and manual mode)

C. Apps and websites

The web view in Figure 6 shows an interface for a soil monitoring system called CassMaTech. This interface has several different parts, such as a dashboard, control unit, soil monitoring system through soil monitoring system (SMS), and other functionality. The main function of this web view is to provide information related to soil conditions, garden management, crop varieties, agricultural equipment, and others (Figure 6a). The web view on (Figure 6b), users can also view historical data related to daily irrigation, such as watering frequency, amount of water used, and water use efficiency. With this information, users can analyze effective watering patterns, evaluate water use efficiency, and make the necessary adjustments to improve overall farm productivity. The web view on (Figure 6c) related to the report on plant fertilization in the jonggol agricultural area, users can obtain important data to manage the fertilization aspect more efficiently. The data presented, such as the type of fertilizer used, the amount of fertilization, the dose administered, and the effect of fertilization on the plant, provide a clear picture of the successes and shortcomings in the fertilization practices carried out.

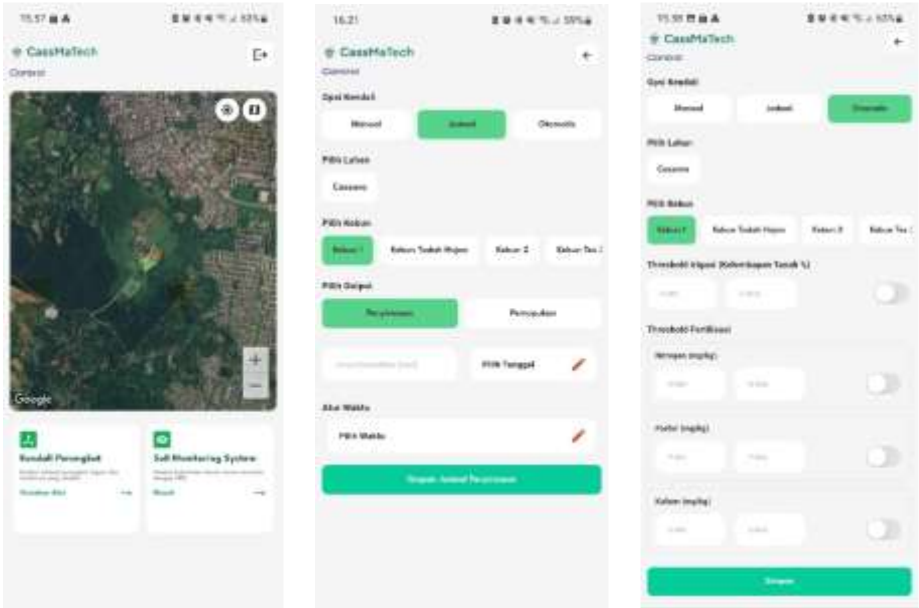
(a) (b)

(c)

Figure 6 Applications and websites (a) dashboard view, (b) daily irrigation view, (b) fertilization report view

D. Mobile app

This mobile application serves as a simple screen display that makes it easier for farmers to control the watering and fertilization process of plants remotely. Remote connectivity is especially important here, where the application needs to connect to a CassaMaTech device over the internet using a specific means of communication. The app also comes with a control feature that allows farmers to set watering and fertilizing schedules and monitor plant conditions, and receive instant notifications. Figure 7 is a general form of view, which is the general user interface that the user usually sees when opening the application. This general view (Figure (7a)) may include a variety of features and information that are generally available to users. (Figure (7b),(7c)) shows a special display showing how to manage watering and fertilizing plants through a detailed app. In this section, the farmer can also turn on or off the automatic or scheduled watering mode as needed.



(a) (b) (c)

Figure 7 Mobile app view (a) app general view, (b) scheduled irrigation and fertilization, (c) automatic irrigation and fertilization

CONCLUSION

The CassMaTech system is the first breakthrough that provides innovative solutions for farmers in Jonggol regarding the more efficient use of water and fertilizers. The presence of this system is very important considering the challenges faced by farmers in Jonggol, especially related to the limited availability of water during the dry season. With the help of CassMaTech, farmers can better manage resources to care for cassava plants. In operation, the CassMatech system offers two modes, namely manual and automatic modes, which provide farmers with flexibility in managing cassava land. In manual mode, the farmer has direct control over the frequency and amount of water and fertilizer given to the crops. They can adjust watering and fertilization patterns according to the specific needs of cassava plants. On the other hand, the automatic mode allows the CassMaTech system to automatically set the watering and fertilization process based on a predetermined schedule. This schedule can be programmed through the website or mobile application provided, making it easier for farmers to plan plant care more efficiently. With these two modes, farmers can utilize the CassMaTech system according to their preferences and needs. This system not only helps to improve the efficiency of the use of resources such as water and fertilizer, but also makes it easier for farmers to manage cassava land more effectively.

REFERENCES

1. R. R. D. Pertami dan A. SALIM, "Optimasi penggunaan lahan berdasarkan kelas kesesuaian lahan untuk pengembangan tanaman cabai merah di Kabupaten Jember," 2022.
2. R. Taisa dkk., "Ilmu Kesuburan Tanah dan Pemupukan," 2021, Yayasan Kita Menulis.
3. G. Byju dan G. Suja, "Mineral nutrition of cassava," Advances in Agronomy, vol. 159, hlm. 169–235, 2020.
4. R. Wulansari, "KAJIAN STATUS HARA TANAH DAN TANAMAN DI PERKEBUNAN TEHJAWA BARAT DAN SUMATERA UTARA," Creative Research Journal, vol. 1, no. 01, hlm. 16–30, 2015.

5. E. Handayanto, N. Muddarisna, dan A. Fiqri, Pengelolaan kesuburan tanah. Universitas Brawijaya Press, 2017.
6. D. Sara, G. Herdiansyah, A. Nuraini, A. Ismail, dan E. Suminar, "Evaluasi Kesesuaian Lahan untuk Budidaya Pisang di Jawa Barat Selatan," Agrologia, vol. 8, Jan 2020, doi: 10.30598/a.v8i2.1013.
7. Akhmad Musyafak, "Outlook Komoditas Tanaman Pangan Ubi Kayu Tahun 2020." [Daring]. Tersedia pada: https://satudata.pertanian.go.id/details/publikasi/225
8. F. G. Bilkis, M. A. Chozin, dan D. Guntoro, "Pergeseran dominasi gulma kebun kelapa sawit IPB Jonggol, dan kemungkinan resistensi terhadap herbisida glifosat," Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy), vol. 50, no. 1, hlm. 115–122, 2022.
9. S. Suwarto dkk., "Standar Operasional Prosedur Teknologi IPB Prima-Cassava," hlm. 1–42, 2022.
10. D. Rey, I. P. Holman, dan J. W. Knox, "Developing drought resilience in irrigated agriculture in the face of increasing water scarcity," Reg Environ Change, vol. 17, hlm. 1527–1540, 2017.
11. G. Gardner dan G. S. Sampson, "Groundwater quality vs. groundwater quantity. Combining information on irrigator concerns with past water use and cropping behavior.," Water Resour Econ, vol. 47, hlm. 100246, 2024, doi: https://doi.org/10.1016/j.wre.2024.100246.
12. S. N. Shylaja dan M. B. Veena, "Real-time monitoring of soil nutrient analysis using WSN," dalam 2017 International Conference on Energy, Communication, Data Analytics and Soft Computing, ICECDS 2017, 2018, hlm. 3059–3062. doi: 10.1109/ICECDS.2017.8390018.
13. H. N. Saha, R. Roy, M. Chakraborty, dan C. Sarkar, "Chapter 7 - Crop management system using IoT," dalam Intelligent Data-Centric Systems, A. Abraham, S. Dash, J. J. P. C. Rodrigues, B. Acharya, dan S. K. B. T.-A. I. Pani Edge and IoT-based Smart Agriculture, Ed., Academic Press, 2022, hlm. 125–141. doi:https://doi.org/10.1016/B978-0-12-823694-9.00022-0.
14. C. O. Adetunji, D. I. Hefft, dan O. T. Olugbemi, "Chapter 17 - Agribots: A gateway to the next revolution in agriculture," dalam Intelligent Data-Centric Systems, A. Abraham, S. Dash, J. J. P. C. Rodrigues, B. Acharya, dan S. K. B. T.-A. I. Pani Edge and IoT-based Smart Agriculture, Ed., Academic Press, 2022, hlm. 301–311. doi: https://doi.org/10.1016/B978-0-12-823694-9.00007-4.
15. O. Kurniadinata, R. Poerwanto, dan A. Susila, "The Determination of Phosphor Status in Leaf Tissues to Make a Fertilizer Recommendation and Predict Mangosteen Yield," Journal of Tropical Horticulture, vol. 1, hlm. 7, Nov 2018, doi: 10.33089/jthort.v1i1.5.
16. M. Abajue dan M. Ogwu, "Morphological features, physicochemical and microbial characterization of cassava, and its products in the tropics," 2024, hlm. 19–38. doi:10.1016/B978-0-443-21747-0.00023-0.
17. R. Bayitse, F. Tornyie, dan E. B. Ali, "Chapter 19 - Food and feed potentials of cassava peels using fermentation technologies," dalam Plant Biology, sustainability and climate change, M. Chidozie Ogwu, S. Chibueze Izah, A. A. Cunha Alves, dan S. B. T.-S. C. Chandra Babu, Ed., Academic Press, 2024, hlm. 345–359. doi:https://doi.org/10.1016/B978-0-443-21747-0.00002-3.
18. S. Premkumar dan A. N. Sigappi, "Chapter 5 - Functional framework for edge-based agricultural system," dalam Intelligent Data-Centric Systems, A. Abraham, S. Dash, J. J. P. C. Rodrigues, B. Acharya, dan S. K. B. T.-A. I. Pani Edge and IoT-based Smart Agriculture, Ed., Academic Press, 2022, hlm. 71–100. doi:https://doi.org/10.1016/B978-0-12-823694-9.00029-3.
19. M. K. Senapaty, A. Ray, dan N. Padhy, "IoT-enabled soil nutrient analysis and crop recommendation model for precision agriculture," Computers, vol. 12, no. 3, hlm. 61, 2023.
20. H. Yang, M. Zhang, N. Xiao, dan Y. Li, "The Integration of Water and Fertilizer Regulated Soil Nutrients and Enzyme Activities of Greenhouse Tomato (Solanum lycopersicum) by Moistube Irrigation," Phyton-International Journal of Experimental Botany, vol. 93, no. 11, hlm. 2813–2836, 2024, doi: https://doi.org/10.32604/phyton.2024.057795.
21. C. Lean, G. Krishnan, C. Li, K. Yuan, P. K. Ng, dan M. R. Basir Khan, "A Raspberry Pi-Powered IoT Smart Farming System for Efficient Water Irrigation and Crop Monitoring," Malaysian Journal of Science and Advanced Technology, hlm. 149–158, Mar 2024, doi: 10.56532/mjsat.v4i2.295.
22. V. K. Nguyen, Q. Z. Sheng, A. Mahmood, W. E. Zhang, M.-H. Phan, dan T. D. Vo, "Demo abstract: an internet of plants system for micro gardens," dalam 2020 19th ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN), IEEE, 2020, hlm. 355–356.
23. A. Patel, K. Ajaykumar, A. Naorem, M. Jagadale, S. Radhakrishnan, dan R. p.s, "Review of artificial

intelligence and internet of things technologies in land and water management research during 1991-2021: A bibliometric analysis," Eng Appl Artif Intell, vol. 123, Apr 2023, doi: 10.1016/j.engappai.2023.106335.

24. J. Hassine, A. Hamou-Lhadj, dan L. Alawneh, "A framework for the recovery and visualization of system availability scenarios from execution traces," Inf Softw Technol, vol. 96, hlm. 78–93, 2018, doi: https://doi.org/10.1016/j.infsof.2017.11.007.