Enabling Precision Agriculture through a Web-Based Fertilization Management System for Nawungan Selopamioro Fruit Orchards

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Abstract: Precision Agriculture (PA) is an integrated farming system based on information and technology for managing agriculture to identify, analyze, and manage spatial and temporal diversity information in specific locations to obtain optimum and sustainable benefits while minimizing unwanted environmental impacts. Fertilization is one of the crucial phases in agricultural production process considering technical cultivation aspects, costs, and environmental impacts. The current fertilization process at Kebun Buah Nawungan Selopamioro (KBNS) is still conventional, so there is no standard rule in determining the fertilization dose. Therefore, a PA approach is needed to provide suitable fertilizer doses for agricultural production needs. This objective of this study was to develop of a web-based fertilizer management system, integrating with orchard management to enhance accessibility and decision-making. The system calculates fertilizer requirements by analyzing soil nutrient availability (N, P, K), cultivation area, crop type and age, and available fertilizer types. The development followed the waterfall methodology, encompassing stages from requirement analysis to system maintenance. The outcome is a web application that manages land assets, administrative activities, and fertilizer needs tailored to specific land blocks, crop characteristics, and nutrient inventories. Subsequent validation against field conditions ensures the accuracy of its recommendations. Although comprehensive testing confirmed a 100% success rate in functionality, the system currently operates within a limited scope of variables. Future enhancements are planned to incorporate broader agronomic factors, such as soil pH and texture, to augment the system's precision. Despite its limitations, this system represents a significant technological advance in precision agriculture, promising to improve fertilizer application efficiency and support sustainable farming practices.

Keywords: decision support system; fertilizer management; precision agriculture; smart agriculture, smart farming

INTRODUCTION

Background

The advent of precision agriculture has transformed the landscape of agricultural production, especially in regions with tropical climates, where the variability of conditions presents unique challenges and opportunities. Precision agriculture is an integrated farming system that utilizes information and technology to manage agricultural processes by identifying, analyzing, and managing spatial and temporal variability at specific locations to achieve optimal and sustainable benefits while minimizing negative impacts on the environment (Karydas et al., 2023; Monteiro et al., 2021; Nugroho et al., 2013; Vishwajith et al., 2014). A vital component of this approach is the strategic use of fertilization, which is essential for bountiful harvests. The application of precision fertilization strikes a delicate balance between environmental stewardship and cost efficiency, ensuring that crop cultivation remains both successful and sustainable (Lu et al., 2022).

Despite the proven benefits of this approach, the Nawungan Selopamioro Fruit Orchard (Kebun Buah Nawungan Selopamioro - KBNS) has adhered to traditional methods for fertilizer management. At KBNS, tropical fruits such as avocado, durian, longan, rambutan, and soursop are grown, each with unique nutrient requirements due to their varying characteristics. With diverse land conditions, special attention is required for optimal plant growth and development (Atalla et al., 2023). Considering the current fertilization process at KBNS that has no standard rules in determining the fertilizer dose, this reliance on conventional practices has limited the orchard's potential to optimize yield and sustainability. Therefore, the implementation of a Precision Agriculture (PA) approach is necessary to provide an appropriate fertilizer dose according to the agricultural production needs (Colaço & Molin, 2017; Erickson & Fausti, 2021; Pandey Amit Kumar and Mukherjee, 2022).

The application of precision agriculture for managing fertilizer management is essential to enhance the efficiency and effectiveness of nutrient application. Considering the first attempt on the development of fertilizer management system, web-based application is preferred. Web-based management systems offer advantages such as real-time data accessibility, remote monitoring, and ease of collaboration among stakeholders(He et al., 2011; Nugroho et al., 2016). By utilizing web-based technologies and data analysis, the proposed Fertilization Management System aims to provide a comprehensive solution for precise fertilization in the fruit orchard(Tagliavini et al., 1995). Some related research about fertilization management systems in precision agriculture has been conducted, indicating the feasibility and potential benefits of such systems. For example, a study about Fertilization Decision Support Systems has focused on the design and implementation of decision support algorithms and systems for optimal fertilization in precision agriculture (Ahmad et al., 2022a; Musanase et al., 2023; Zeng Linaand Lin, 2020). These systems aim to determine the ideal amount of fertilizer and its application rate, considering varying rates and mixtures as needed in the field (Beneduzzi et al., 2022; He et al., 2011; Wiratmoko et al., 2023). Other research is CropManage is an online database-driven tool that assists growers and farm managers in determining water and nitrogen fertilizer applications on a field-by-field basis(Na & Kang, 2023). Smart fertilizer management, enabled by information/data, sensors, and smart tools, plays a crucial role in precision agriculture, allowing for correct fertilization and improved efficiency(Ahmad et al., 2022b). The use of web-based tools for nutrient planning is driven by the complexity and time-consuming nature of the nutrient management process, which involves collecting extensive farm information, making diverse decisions and calculations about crops, fertilizers, and manure management, and communicating the completed plan to various stakeholders(Zhong et al., 2022).

Web-based fertilizer management systems have seen significant advancements. For instance, a fuzzy inference system for orchards was introduced by Hong et al. (2018), focusing on laboratory-scale simulations and implementing simple scenarios for calculations. An IoT-based management system for field crops and orchards was also developed for research (Nie Pengchengand Zhang, 2021). However, this system did not mention site-specific locations or suitable scenarios. A more advanced approach is the fertilization control system based on the PSO-BP-PID control algorithm, as presented by Wan (Wan et al., 2022). While this control system is precise, the scenario in Kebun Buah Nawungan only requires a simple decision support system. For effective management, it is crucial to consider site-specific conditions and appropriate scenarios.

Objective

The objective of this study was to develop of a web-based fertilizer management system tailored for KBNS, aimed at enhancing accessibility and integration with existing orchard management information systems. The system calculates fertilizer requirements by analyzing soil macronutrients levels (Nitrogen, Phosphorus, Potassium), land area, plant species, maturity, and available fertilizer types. Nitrogen, phosphorus, and potassium are essential nutrients for plant growth. Nitrogen is crucial for photosynthesis and the creation of amino acids, proteins, and DNA, promoting lush foliage and stem growth. Phosphorus is vital for energy transfer and supports strong root systems, flowering, and fruiting. Potassium helps plants withstand stress, aids in protein and starch synthesis, and facilitates water and nutrient movement. These nutrients are extensively studied because they are fundamental to plant health and productivity. Understanding their roles helps develop effective fertilization strategies, enhancing crop yields and ensuring sustainable agricultural practices. Employing the waterfall model, the system's design progressed through stages of requirements gathering, design, programming, testing, and maintenance.

In this paper, we detail the system's architecture and operational mechanics, which encompass asset (land) management, administrative functions, activity logging, and precise fertilizer need assessments based on a range of variables including land block location, area, plant specifics, and fertilizer inventory. Subsequent field validation is conducted to align the system's estimations with actual agronomic conditions, thereby calibrating the predicted dosages. The deployment of this system is intended to streamline KBNS's farm input management, enhancing profitability and environmental sustainability.

MATERIALS AND METHODS

Study Site and Data Collection

This study was conducted at Nawungan Selopamioro fruit orchard in Selopamioro village, Imogiri district, Bantul Regency, Yogyakarta Special Region Province (DIY), and for system development, it was carried out at Smart Agriculture Research, Agricultural Energy and Machinery Laboratory, Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, Yogyakarta. The research was conducted from January 1, 2018, to August 1, 2018.

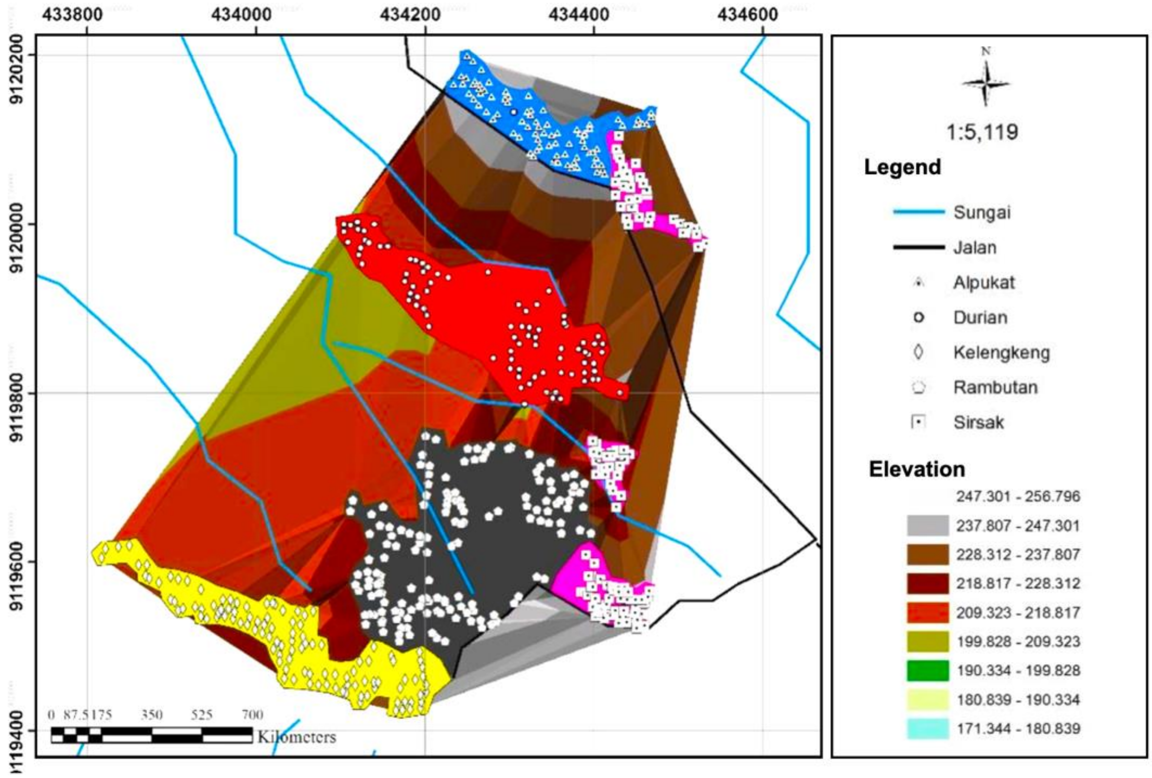


Figure 1. Distribution of fruit commodities in Kebun Buah Nawungan Selopamioro (KBNS)

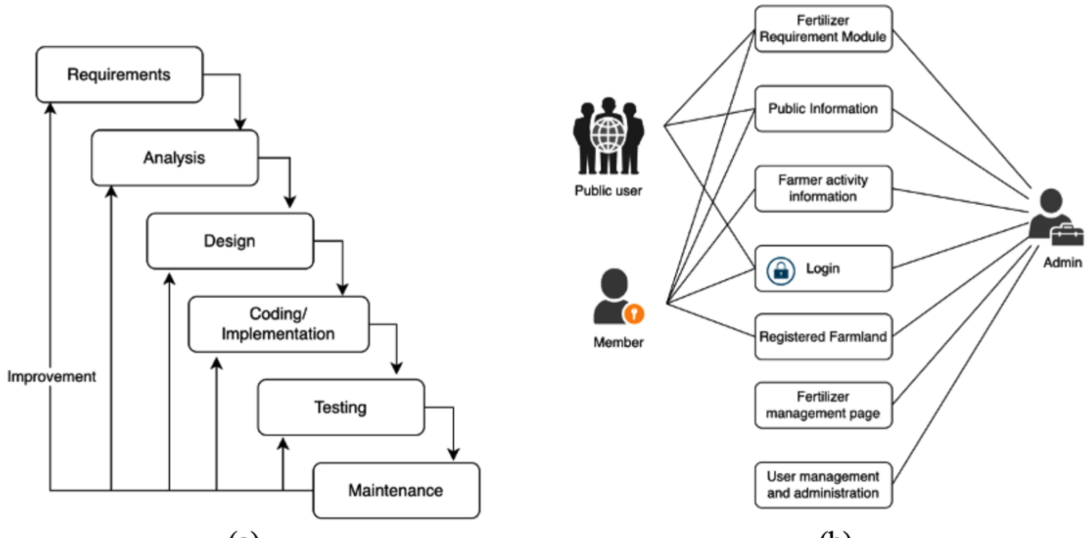
Figure 1 illustrates the spatial distribution of key fruit commodities within KBNS and correlates their positioning with the site's topographical elevation variation. The selected fruit species, which include avocado (Persea americana), durian (Durio zibethinus), longan (Dimocarpus longan), rambutan (Nephelium lappaceum), and soursop (Annona muricata L.), are differentially distributed across a gradient of elevations, ranging from 171.344 to 256.796 meters above sea level. The elevation not only influences the microclimate conditions, such as temperature and humidity, which are critical to the fruiting patterns and health of these species but also affects soil properties and water drainage patterns, directly impacting nutrient availability and fertilizer uptake.

The soil variability across this elevation range necessitates a tailored approach to fertilizer management, as the requirements for each crop can significantly differ due to changes in soil composition, pH, and organic matter content with elevation. Other factors influencing plant needs include climate, water availability, and specific nutrient requirements. These elements affect a plant's ability to grow and thrive by determining temperature and light conditions, ensuring adequate hydration for nutrient uptake, and meeting unique physiological needs for processes like root development and disease resistance. The soil characteristics in the area are Mediterranean. The bulk density ranges from 1.26 to 1.46 g/cm^3, while the particle density is between 2.04 and 2.10 g/cm^3. The moisture content ranges from 36.90% to 42.00% by mass, and the content of organic material (COM) is between 1.16% and 1.78% (Sagung Esya Maharani et al., 2020). For instance, lowland areas, where rambutan and soursop are more prevalent, may have richer organic matter and require different nutrient management compared to the higher elevation zones where avocado, and durian thrive. The system's algorithm takes into account these elevation-dependent variables to estimate precise fertilizer needs, ensuring that the application is optimized for each plant type and maturity stage. This elevation-sensitive approach aims to improve the efficiency of resource use and enhance the overall productivity and sustainability of KBNS.

System Design and Development

During the process of system development, the methodology used is known as Software Development Life Cycle (SDLC) of the waterfall model, which involves several stages as displayed in **Figure 2(a)**. The first stage is requirement analysis, which includes collecting data and identifying the needs of all system elements. The second stage is system design, where the analyzed data and requirements are translated into a format that can be easily understood by users. Next is the development stage, where the designed problem-solving data is translated into a computer programming language that has been predetermined. The fourth stage is testing, which involves evaluating the software that has been created. Finally, the maintenance stage is where the completed software is subject to modifications or additions as needed. By following this methodology, the development of the web-based fertilization management system for Nawungan Selopamioro fruit orchard in Bantul, Yogyakarta was able to progress in an organized and efficient manner.

The process of designing the system began in the system design stage. This included designing aspects that would make it easier to create the system, such as Entity Relation-ship Diagrams, Activity Diagrams, User Case Diagrams, and determining the system model to be developed. After that, the system was constructed by creating a database to be used in the system. During the coding stage of the system, a web-based system was developed using the CodeIgniter framework. The CodeIgniter framework was used to simplify the web development process by reducing the amount of code that the developer needed to write. The framework uses the M-V-C (Model-Views-Controller) method in web development.



(a) (b)

Figure 2. Software Development Life Cycle (SDLC) using waterfall method for system development.

This system's output requirements illustrate how the system's needs align with the users' expertise level, which falls into two categories. First, the admin user, responsible for processing data comprehensively, requires advanced computer skills. Second, the general users and members need basic computer skills to access the available features on the system. The use case diagram can be seen in Figure 2 (b). The admin interface provides the highest level of access as it enables the user to view the entire system interface, including member data, and manage the database by adding, deleting, or editing data. The Hierarchical structure menu for Administrator can be seen at Figure 3. The main menu consists of seven components: Profile of Selopamioro, Profile of KBNS, Land list, Database management, Activity list, Instruction for fruit cultivation, and Fertilizer Requirement estimation. Each main menu has sub-menu for details information and more specific contexts related to public information and daily management for KBNS. The next step for system development is the creating the database.

The database is designed using an Entity Relationship Diagram (ERD) to depict the interconnected entities and their relationships, as seen in Figure 4. The system comprises several entities, including users, lands, and activities, which are interrelated to facilitate the recording of farmers' activities on their land. The user entity contains various attributes that represent user data. Additionally, the relationships between the entities of user, fertilizer, fertilizer type, fruit, fruit nutrition, input, and fertilization contribute to a fertilizer dosage estimation system. Each relationship has multiple secondary keys, which serve the purpose of linking two entities in the system. The relational database system facilitates relation of each entity with specified cardinality (one to one, one to many, and many to many relationship). For each relation also has meaning that represents the overall function of database for supporting the fertilizer and daily management.

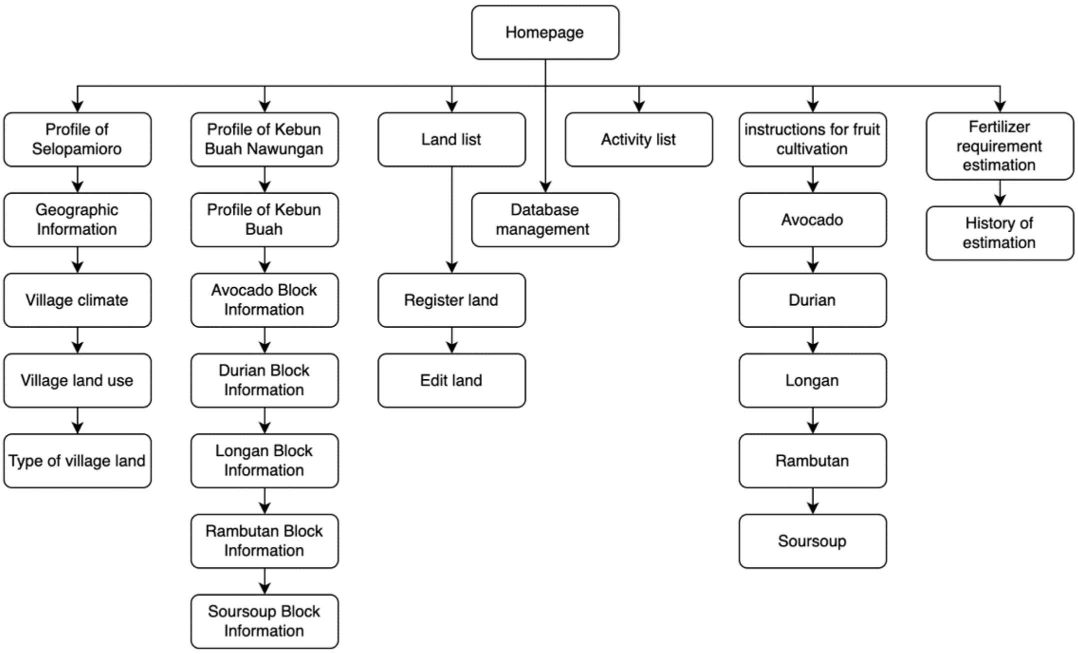


Figure 3. Hierarchical structure menu for Administrator

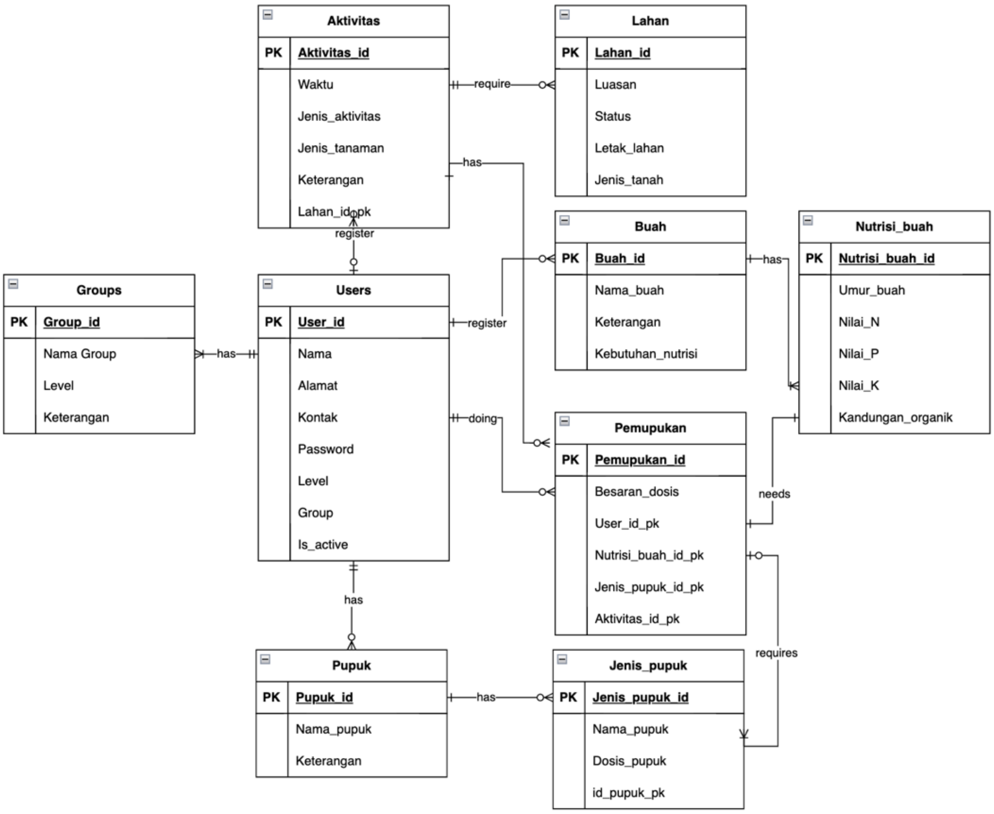


Figure 4. Entity Relationship Diagram for fertilization management

Fertilizer Requirement Estimation Model

Fertilizer requirement estimation model is the model for calculating the dose of fertilizer provided as a function embedded in web application as tools that can be accessed via the main menu. The process of calculating fertilizer dosage provides information on the amount of fertilizer needed for fruit plant by following the procedures as follows:

1). Determine the nutrient dosage required for the plant based on the type and age of the fruit.
2). Determine the type and nutrient content of the fertilizer based on the selected fertilizer.
3). Determine the number of plants to be fertilized based on the area, using Equation 1.

$$Np = A \times Pp \tag{1}$$

where *Np* is the number of plants, *A* is the land area in hectares, and *Pp* is the number of plants per hectare.

4). Convert the soil nutrient content data inputted in % unit to a kg unit.
5). Retrieve the required plant and fertilizer nutrient data from the database based on the selected category.
6). Calculate the required fertilizer dosage using Equation (2):

$$Fd = f(A, H, P, Ut, Jp, Sp) \tag{2}$$

where:
A = Land area (m^2),
H = Nutrients contained in the soil (kg),

P = Type of plant,
Ut = Plant age (years),
Jp = Type of fertilizer,
Sp = Plant condition.

Some variables are interrelated, creating new variables such as the age and type of plant that determine the required nutrient dosage. A mathematical formula is derived from Equation (2) to determine the fertilizer dosage, presented in Equation (3):

$$Df = \frac{((Hp \times Sp) - Hs) \times Np}{Hf} \tag{3}$$

where:
Df = Fertilizer dosage (Kg),
Hp = Nutrient required by the plant, whose value corresponds to the selected type and age of the plant (kg),.
Sp = Plant condition value (good=1, not good=1.2). The categorization of plant conditions is based on the percentage of plants in the block. If the number of plants with poor condition > 50%, the plants are classified as being in poor condition,
Hs = Nutrient available in the soil (kg),
Np = Number of plants, and
Hf = Nutrient provided by the fertilizer in units per kg whose value corresponds to the selected fertilizer type.

The final step is to display the calculation results of the total fertilizer requirement in units of kg/year and the unit dosage in kg/tree/year and gram/tree/year.

The value of standard and nutrient requirement is following the reference from the government (Kementerian Dalam Negeri Direktorat Jenderal Bina Pembangunan Daerah, 2013)and related research in location (Sagung Esya Maharani et al., 2020; Wibawati et al., 2024). The final step is to display the calculation results of the total fertilizer requirement in units of kg/year and the unit dosage in kg/tree/year and gram/tree/year.

As an embedded function in web application, the flow chart process for estimating the fertilizer dosage using web can be seen in Figure 5**.** From user side, user select the commodity, determining the age of plants, type of fertilizer, area of application, inputting soil nutrient condition. The system will process by filtering the data to ensure that the input is valid and completed. If the data is completed, then performing data calculation following the reference database and resulting a fertilizer dose. The system replies to the fertilizer dose and the user considering the result, does it suitable or not according to experience, if so then user can save the result that may be used for future recommendation.

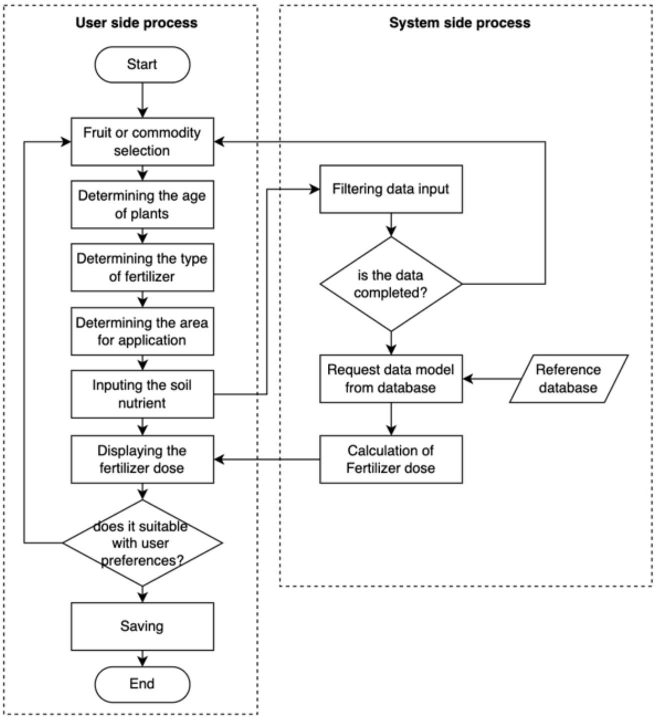


Figure 5. Entity Relationship Diagram for fertilization management

System Testing and Validation

The system's functionality was tested using the black box testing method. This involved creating scenarios to be tested in the system, which were categorized as negative test case and positive test case. Negative test cases were designed to evaluate the system's performance in situations where users behaved in ways that deviated from the system. On the other hand, positive test cases were designed to test the system's response to user behaviors that aligned with the system's requirements. Each scenario included expected results from the system. The inspections for testing the system are listed in Table 1.

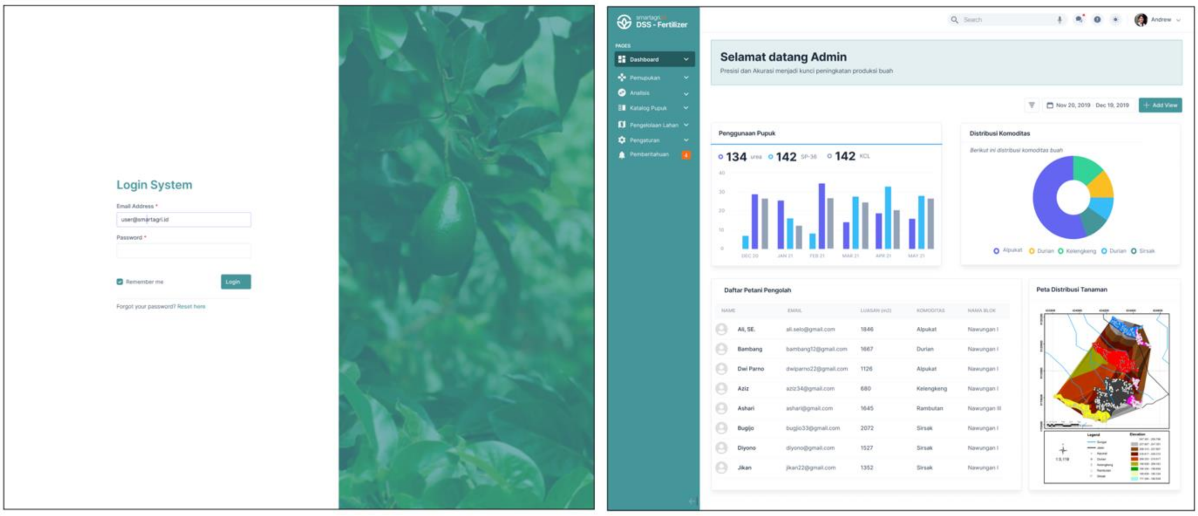
Table 1. List of inspection for testing the system

Inspection	***Negative test***	***Positive test***	**Total** ***test***
Login	4	3	7
Registration	8	2	10
Public Home	-	3	3
Home Member	-	4	4
Home Admin	-	14	14
Profile of Village	-	2	2
Profile of KBNS	-	2	2
Fruits cultivation	-	6	6
Registered Land	-	7	7
Registration of land	3	1	4
List of activities	-	2	2
Add new activities	4	1	5
Navbar	-	2	2
Table	-	5	5
Calculate Fertilizer	4	4	8
Estimation Result	-	5	5
Fertilizer Manager	-	4	4
Total	**23**	**67**	**90**

RESULT AND DISCUSION

Web-based Fertilizer Management System

Web-based fertilizer management system for managing the KBNS, aimed at enhancing accessibility and integration with existing orchard management information systems. The software assesses fertilization needs through a systematic evaluation of key parameters with inputs: soil nutrient profiles (including nitrogen, phosphorus, and potassium), the expanse of the arable land, crop species, developmental stages, and the range of available fertilizers. The development adhered to the sequential phases of the waterfall model, which involved meticulous requirement elicitation, systematic design, precise programming, rigorous testing, and ongoing maintenance.



Email Address *
user@smartagri.id

Password *

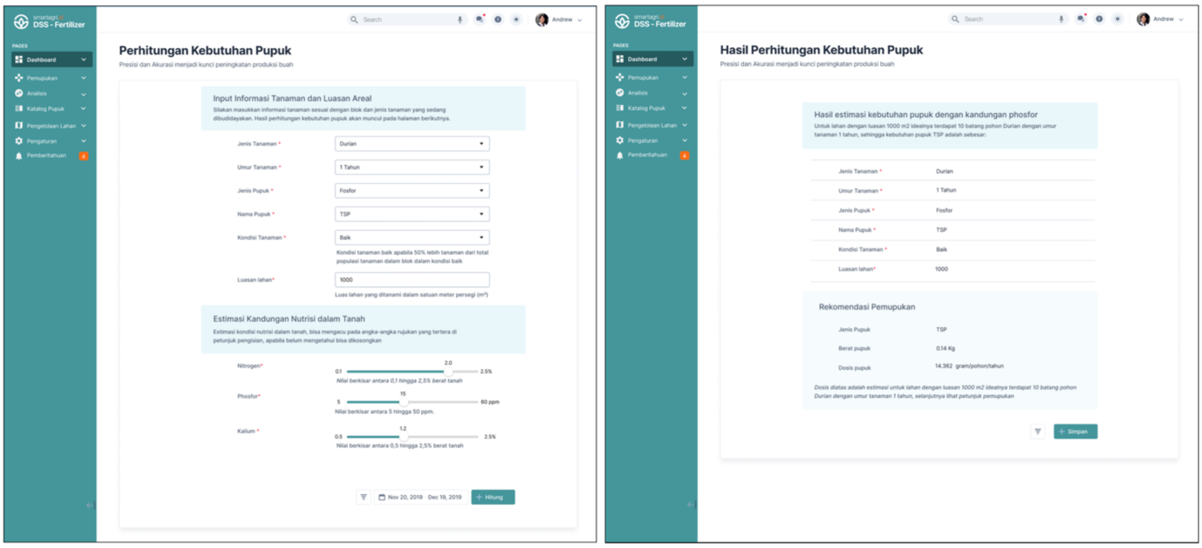
☑ Remember me

Daftar Petani Pengolah

NAME	EMAIL	LUASAN (m2)	KOMODITAS	NAMA BLOK
Ali, SE.	ali.selo@gmail.com	1846	Alpukat	Nawungan I
Bambang	bambang12@gmail.com	1667	Durian	Nawungan I
Dwi Parno	dwiparno22@gmail.com	1126	Alpukat	Nawungan I
Aziz	aziz34@gmail.com	680	Kelengkeng	Nawungan I
Ashari	ashari@gmail.com	1645	Rambutan	Nawungan III
Bugijo	bugijo33@gmail.com	2072	Sirsak	Nawungan I
Diyono	diyono@gmail.com	1527	Sirsak	Nawungan I
Jikan	jikan22@gmail.com	1352	Sirsak	Nawungan I

Figure 6. User interface design for Login System (left) and Personal Dashboard (right)

The login and dashboard for Web-based Fertilizer management system can be seen in Figure 6. The developed web interface serves as a fertilizer calculation tool, guiding users through the process of determining precise fertilizer quantities for various fruit plants. Users are prompted to input specific data, including the type and age of the fruit, chosen fertilizer, land attributes, and soil nutrient content. The 'Calculate' function processes this information to yield a recommended fertilizer regimen. Should there be any discrepancies or omissions in the input, the system is designed to prompt an error notification, ensuring the accuracy of data entry. Upon submission, the system delineates the appropriate fertilizer dosage according to the reference from the fertilizer guidelines (Kementerian Dalam Negeri Direktorat Jenderal Bina Pembangunan Daerah, 2013; Sagung Esya Maharani et al., 2020; Wibawati et al., 2024)reflecting inputs such as the plant type, age, quantity, and total required fertilizer, down to the individual dosage per plant. This actionable information is presented on a subsequent interface. Moreover, the system offers a section dedicated to specific fruit varieties—avocado, durian, longan, rambutan, and soursop—each with a direct link to a maintenance page providing detailed, fruit-specific fertilization guidelines. This feature facilitates informed decision-making, allowing for customized nutrient management tailored to the unique needs of each fruit type.



Perhitungan Kebutuhan Pupuk

Presisi dan Akurasi menjadi kunci peningkatan produksi buah

Input Informasi Tanaman dan Luasan Areal

Silakan masukkan informasi tanaman sesuai dengan blok dan jenis tanaman yang sedang dibudidayakan. Hasil perhitungan kebutuhan pupuk akan muncul pada halaman berikutnya.

Jenis Tanaman *: Durian
Umur Tanaman *: 1 Tahun
Jenis Pupuk *: Fosfor
Nama Pupuk *: TSP
Kondisi Tanaman *: Baik
Kondisi tanaman baik apabila 50% lebih tanaman dari total populasi tanaman dalam blok dalam kondisi baik
Luasan lahan*: 1000
Luas lahan yang ditanami dalam satuan meter persegi (m²)

Estimasi Kandungan Nutrisi dalam Tanah

Estimasi kondisi nutrisi dalam tanah, bisa mengacu pada angka-angka rujukan yang tertera di petunjuk pengisian, apabila belum mengetahui bisa dikosongkan

Nitrogen*: 0.1 — 2.0 — 2.5%
Nilai berkisar antara 0,1 hingga 2,5% berat tanah
Phosfor*: 5 — 15 — 60 ppm
Nilai berkisar antara 5 hingga 50 ppm.
Kalium *: 0.5 — 1.2 — 2.5%
Nilai berkisar antara 0,5 hingga 2,5% berat tanah

Hasil Perhitungan Kebutuhan Pupuk

Presisi dan Akurasi menjadi kunci peningkatan produksi buah

Hasil estimasi kebutuhan pupuk dengan kandungan phosfor

Untuk lahan dengan luasan 1000 m2 idealnya terdapat 10 batang pohon Durian dengan umur tanaman 1 tahun, sehingga kebutuhan pupuk TSP adalah sebesar:

Jenis Tanaman *	Durian
Umur Tanaman *	1 Tahun
Jenis Pupuk *	Fosfor
Nama Pupuk *	TSP
Kondisi Tanaman *	Baik
Luasan lahan*	1000

Rekomendasi Pemupukan

Jenis Pupuk	TSP
Berat pupuk	0.14 Kg
Dosis pupuk	14.362 gram/pohon/tahun

Dosis diatas adalah estimasi untuk lahan dengan luasan 1000 m2 idealnya terdapat 10 batang pohon Durian dengan umur tanaman 1 tahun, selanjutnya lihat petunjuk pemupukan

Figure 7. User interface design for Fertilizer requirement calculation (left) and Result of fertilizer requirement calculation (right)

Figure 7 shows the user interface for calculation of fertilizer requirements. On the left, the 'Fertilizer Requirement Calculation' interface is designed for user interaction and data entry. Users begin by entering specific details about their fruit crops. The required fields include the fruit type and age, the type of fertilizer desired, and the size of the land area where the crops are grown. Additionally, users must input soil nutrient estimates, including levels of nitrogen, phosphorus, and potassium, which are critical for determining the right fertilizer mix. The default value for the estimated macronutrient levels is set to 0. The system provides a slider for easy selection of N, P, and K values based on soil type references. The ranges are as follows: Nitrogen (N) from 0.1% to 2.5%, Phosphorus (P) from 5 ppm to 60 ppm, and Potassium (K) from 0.5% to 2.5%. If users do not have reference values for these parameters, they can leave them at the default setting of 0. Once all data is entered, the 'Calculate' button will initiate the system to process the inputs and produce an output.

The right side of the image showcases the 'Result of Fertilizer Requirement Calculation' interface. After the data is processed, this interface displays the calculated fertilizer needs. It provides a detailed breakdown of the fertilizer recommendation, including the type of fertilizer, total dosage for the land area, and individual dosage per plant. This information is crucial for farmers and agricultural managers to accurately distribute fertilizers across their crops.

The system's design prioritizes user-friendliness and precision in fertilizer management. It reflects an understanding of the critical role accurate data plays in agricultural success. By simplifying the calculation process and providing clear results, the interface aims to support better decision-making in fertilizer application, potentially leading to increased crop yield and more sustainable farming practices. The system's user interface is a key feature discussed in this section, highlighting its potential impact on agricultural productivity.

Estimation of Fertilizer Requirements

Fertilizer requirements are computed through a precision agriculture framework, ensuring an accurate alignment of fertilizer application with plant-specific needs. Critical factors influencing these requirements encompass plant species, developmental stage, chosen fertilizers, soil nutrient composition, land extent, and the health of the plant. The system adopts the 2013 fertilizer application protocols issued by the Ministry of Internal Affairs as a benchmark, due to the paucity of research on the fertilization of certain fruit trees such as avocado, durian, longan, rambutan, and soursop. These protocols provide categorizations for fertilizer requirements that account for the age of the plant, the type of fertilizer, and the necessary quantities, offering a structured approach to nutrient management amidst data scarcity.

Table 2. Results of fertilizer dose requirement testing for the system

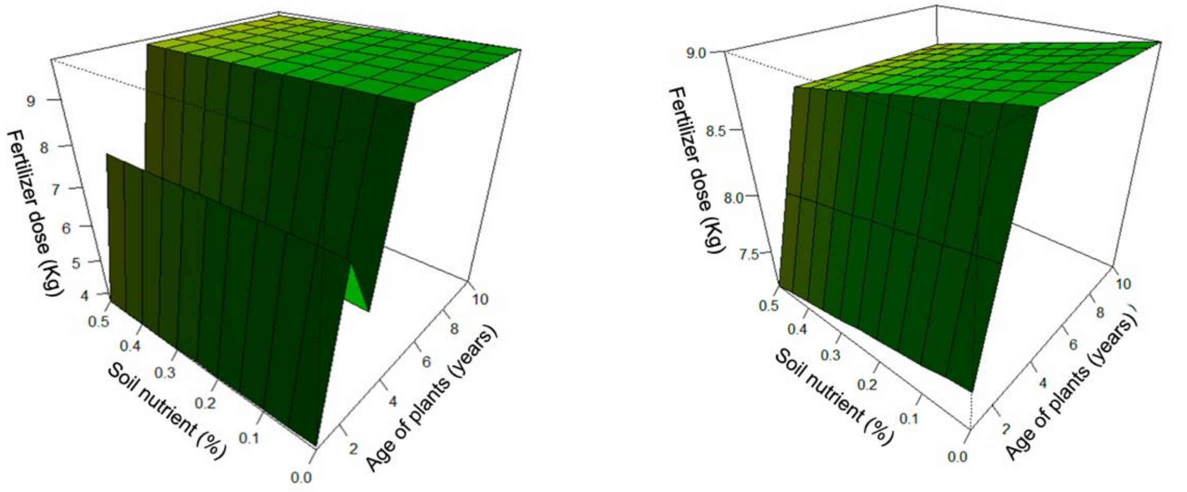
Id	Fruits	Age	Frt. Type	Frt. name	Plant condition	Area (m^2)	N	P	K	NP	Dose (g/tree/yr)
1	Durian	5	Nitrogen	Urea	Good	100	0	0	0	1	1410
2	Durian	5	Nitrogen	Urea	Good	100	0.3	0.3	0.3	1	1403
3	Durian	5	Nitrogen	Urea	Not good	100	0	0	0	1	1692

Table 2 shows the variations in fertilizer dosages for durian trees as influenced by soil nutrient concentrations and plant health conditions, according to tests conducted using the system. Test 1, which assumed a lack of soil nutrients (0% N and P, 1% K), resulted in a fertilizer requirement of 1410 grams per tree annually. Conversely, Test 2, with a slight increase in soil nutrients to 0.3% for both N and P, recorded a marginally lower fertilizer requirement of 1403 grams per tree per year. This slight reduction suggests that even minimal increases in soil nutrient levels can slightly reduce the fertilizer needed. Test 3 highlights a significant increase in fertilizer requirement (1692 grams per tree per year) under the 'Not good' plant condition, suggesting that stressed or unhealthy plants might require a greater quantity of nutrients to recover, approximately 1.2 times the dosage compared to plants in 'Good' condition. Achieving optimum plant conditions still depends on the farmer's observations of physical appearance (leaves, growth, stem diameter) and adherence to government fertilization standards (Kementerian Dalam Negeri Direktorat Jenderal Bina Pembangunan Daerah, 2013). The assessment remains subjective and may vary among farmers.

The system's algorithm appears to account for the plant's health as a critical variable, adjusting fertilizer dosages accordingly to support plant recovery and growth(Beneduzzi et al., 2022). It's essential to note that any increased fertilizer dosage for plants in suboptimal health should be administered over multiple applications rather than a single treatment to avoid the risks associated with over-fertilization, such as nutrient runoff, soil degradation, and potential harm to the plant itself.

Table 3. Simulated data for calculating fertilizer doses.

Fruit type	Plant condition	Age (yr.)	Fertilizer Name	Soil nutrient (n/p/k)	Area (m^2)
Longan	Good	1 – 10	TSP	0 – 0.3	1000
Soursop	Good	1 – 10	Urea	0 – 0.3	1000



(a) Characteristic TSP Fertilizer dose for Longan.

(b) Characteristic UREA Fertilizer dose for Soursop

Figure 8. Characteristic of TSP and UREA for fertilizer dose of longan (a) and soursop (b)

Figure 8 illustrates the simulation outcomes for fertilizer dosage requirements using a three-dimensional graph, which conveys the complex relationship between plant age, soil nutrient levels, and the quantity of fertilizer needed for longan and soursop trees. To develop a simulation model, we simulate the input parameters for the characteristic fertilizer application of TSP and UREA. The input parameters include soil nutrient levels (ranging from 0% to 0.5%) and the age of plants (0 to 10 years). Calculations are performed using spreadsheet tools, and the results are displayed in a three-dimensional chart, illustrating the different characteristics for various applications. The data used for this simulation, as outlined in Table 3, includes plants in good condition, aged between 1 to 10 years, growing in soil with nutrient levels ranging from 0 to 0.3%, and spanning an area of 1000 square meters. For longan trees, the requirement for TSP fertilizer shows a fluctuating pattern: it rises from the first to the second year, dips in the third year, and then surges once more in the fourth year. This variability suggests that TSP needs are not linear and are influenced by factors beyond just plant age. As for the soil nutrient influence, the graph reveals a slight decline in TSP dosage as soil nutrient percentages increase, indicating that soil richness can slightly reduce the need for additional fertilization.

Conversely, the urea requirement for soursop displays a linear escalation from the first through the fourth year, stabilizing from the fourth year onwards, irrespective of incremental changes in soil nutrient content. This consistent demand suggests a sustained need for nitrogen as provided by urea, which is not significantly impacted by the soil's existing nutrient levels. The graph also notes the effect of plant density on the dosage required per plant. With longan plots hosting 10 plants and soursop plots accommodating 30, the graph underscores the inverse relationship between plant density and individual plant fertilizer needs.

Additionally, our study identifies plant density as a crucial variable in determining fertilizer dosage, highlighting its practical significance and contribution to agricultural practices. Previous research has demonstrated that plant density significantly influences the optimal amount of fertilizer required (Fang et al., 2018; Karydogianni et al., 2022; Xu et al., 2017). Our results demonstrate that the number of plants per unit area can inversely affect the amount of fertilizer required per plant, an insight that can significantly impact fertilizer management practices, especially in densely planted orchards. In conclusion, the simulation outcomes from our system provide a granular perspective on fertilizer management that, when compared to existing research, underscores the importance of tailored fertilization protocols. Future studies should continue to explore the multi-dimensional factors affecting fertilizer needs to refine the recommendations further and validate them in diverse agricultural settings.

Performance Evaluation of web-based Fertilizer Management System

The system's robustness was evaluated using negative test case scenarios to assess its response to deviations in user interactions within the login interface, detailed in Table 3. Four scenarios were tested, each confirming that the system reliably generates appropriate error messages corresponding to user input errors. Complementary to this, positive test case scenarios, outlined in Table 4, examined the system's response to standard user behaviors during login. Across three tested scenarios, the system consistently functioned correctly, directing users appropriately based on their actions. The tables collectively summarize the system's dependable performance in handling both typical and atypical user interactions.

Table 3. Negative test result for login page test

Id	Test Case	Expected output	Result	Status
1	Only the username field is filled with a valid value: "unity".; The password field is not filled. - Login	Notification appears: Password cannot be empty.	ok	Success
2	Only the password field is filled with a valid value: "44minute". The username field is not filled. - Login	Notification appears: Username cannot be empty.	ok	Success
3	The password field is filled with a valid value: "44minute". The username field is filled with an invalid value: "bukanuser1". - Login	Notification appears: Username not found.	ok	Success
4	The username field is filled with a valid value: "unity". The password field is filled with an invalid value: "22minute". - Login	Notification appears: Incorrect password.	ok	Success

Table 4. Positive test result for login page test

Id	Test Case	Expected output	Result	Status
1	Username is filled with a valid value: "unity." Password is filled with a valid value: "44minute." Click the login button	Go to the member homepage	Ok	Success
2	Username is filled with a valid value: "admin." Password is filled with a valid value: "pas" Click the login button	Go to the admin homepage	Ok	Success
3	Click the registration button.	Go to the registration page	Ok	Success

The comprehensive black box testing regimen, which examined a broad spectrum of operational aspects of the web-based fertilizer management system, corroborated its dependability through 90 varied scenarios. Detailed in Table 5, each scenario was precisely crafted to scrutinize the system's effectiveness, encompassing vital processes such as login, registration, land registration, and the computation of fertilizer needs. This approach catered to both expected (positive) and unexpected (negative) user interactions, thus validating the system's resilience and applicability in real-world contexts. When juxtaposed with the results from similar systems evaluated in research by (Godinho Antónioand Rosado, 2024), which reported a success rate of the tested system under comparable testing conditions, the performance of our system is particularly impressive. (Alsaleh et al., 2017) utilized a smaller set of test scenarios and encountered several issues in user interaction sequences that our system successfully navigated without error. This comparison not only demonstrates the robustness of our system but also indicates its advanced readiness and potential for a positive impact on agricultural management practices.

Table 5. Overall black box test result for the system using several scenarios.

Inspection section	Negative	Positive	Total	Success
Login	4	3	7	7
Register	8	2	10	10
Public homepage	-	3	3	3
Home Member	-	4	4	4
Home Admin	-	14	14	14
Profile of village	-	2	2	2
Profile of KB	-	2	2	2
Fruits cultivation	-	6	6	6
Registered Land	-	7	7	7
Registration of land usage	3	1	4	4
List of activities	-	2	2	2
Add. new act.	4	1	5	5
Navbar	-	2	2	2
Table	-	5	5	5
Calculation of Fertilizer	4	4	8	8
Result calculation	-	5	5	5
Fertilizer management	-	4	4	4
Total	**23**	**67**	**90**	**90**

Discussion and limitation

The web-based fertilizer management application presented in this manuscript offers a flexible and accessible platform for managing agricultural data, accessible globally with an internet connection. The application's performance in testing scenarios was exemplary, achieving a 100% success rate, signifying that it operates as intended. It serves as a repository of extensive information about Selopamioro village and Nawungan fruit orchard, including detailed accounts of fruit cultivation practices, land management, and farmer activities. The inclusion of an administrative dashboard significantly simplifies data management, allowing for efficient updates and edits within the database. Nevertheless, the application's dependency on a restricted selection of literature for determining fertilizer needs constitutes a considerable limitation. This reliance may not fully reflect the extensive body of contemporary research in agricultural science, potentially constraining the application's precision and adaptability to current farming methods and region-specific conditions.

For a more comprehensive validation of the system's recommendations, a field-based assessment is imperative. This would involve correlating the application’s fertilizer guidelines with actual crop yield data and soil health metrics post-fertilization. To enhance the system's robustness and reliability, it is recommended to integrate a broader spectrum of peer-reviewed agricultural research, such as the findings by(Karydas et al., 2023) and (Lu et al., 2022)which investigate the impact of precise fertilizer application on crop yield and soil conservation. Comparing the system's outputs with these established studies can provide a benchmark for accuracy and offer opportunities for refinement. Future iterations of the system should also prioritize user feedback from field tests to fine-tune its algorithms to the intricacies of real-world agricultural settings.

CONCLUSION AND SUGGESTIONS

Conclusion

The development of a fertilizer requirement information system tailored for an array of fruit plants—including avocado, durian, kelengkeng, rambutan, and soursop has been successfully established. This system adeptly computes the fertilizer needs based on critical parameters such as plant type, age, fertilizer category, land area, and soil nutrient levels. Rigorous testing through the Black Box methodology has yielded a 100% success rate, underscoring the system's functional efficacy across all operations. Nonetheless, the current version of the system is constrained by the scope of its variables. Expansion to include additional factors like soil pH, texture, specific fruit cultivars, and more could greatly enhance its precision. Validation through empirical research monitoring soil nutrient dynamics and correlating them with actual field conditions is essential to refine the system's recommendations.

Suggestions

Further development, the system's reliance on a limited range of literature for determining fertilizer needs points to an opportunity for improvement; incorporating findings from broader agronomic research would solidify its scientific underpinning. Future work should focus on expanding the range of variables considered and reinforcing the system's algorithm with comprehensive, research-based agronomic data. Despite these areas for enhancement, the system stands as a testament to the potential for technology to facilitate more informed and efficient agricultural practices.

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CONFLICT OF INTEREST

All authors declare that there is no conflict of interest.

REFERENCES

Ahmad, U., Alvino, A., & Marino, S. (2022a). Solar Fertigation: A Sustainable and Smart IoT-Based Irrigation and Fertilization System for Efficient Water and Nutrient Management. *Agronomy*, *12*(5). https://doi.org/10.3390/agronomy12051012

Ahmad, U., Alvino, A., & Marino, S. (2022b). Solar Fertigation: A Sustainable and Smart IoT-Based Irrigation and Fertilization System for Efficient Water and Nutrient Management. *Agronomy*, *12*(5). https://doi.org/10.3390/agronomy12051012

Alsaleh, M., Alomar, N., Alshreef, M., Alarifi, A., & Al-Salman, A. M. (2017). Performance-Based Comparative Assessment of Open Source Web Vulnerability Scanners. *Security and Communication Networks, 2017*. https://doi.org/10.1155/2017/6158107

Atalla, S., Tarapiah, S., Gawanmeh, A., Daradkeh, M., Mukhtar, H., Himeur, Y., Mansoor, W., Hashim, K. F. Bin, & Daadoo, M. (2023). IoT-Enabled Precision Agriculture: Developing an Ecosystem for Optimized Crop Management. *Information (Switzerland)*, *14*(4). https://doi.org/10.3390/info14040205

Beneduzzi, H. M., de Souza, E. G., Moreira, W. K. O., Sobjak, R., Bazzi, C. L., & Rodrigues, M. (2022). Fertilizer recommendation methods for precision agriculture – a systematic literature study. *Engenharia Agricola*, *42*(1). https://doi.org/10.1590/1809-4430-ENG.AGRIC.V42N1E20210185/2022

Colaço, A. F., & Molin, J. P. (2017). Variable rate fertilization in citrus: a long term study. *Precision Agriculture*, *18*(2), 169–191. https://doi.org/10.1007/s11119-016-9454-9

Erickson, B., & Fausti, S. W. (2021). The role of precision agriculture in food security. *Agronomy Journal*, *113*(6), 4455–4462. https://doi.org/10.1002/agj2.20919

Fang, X. M., She, H. Z., Wang, C., Liu, X. B., Li, Y. S., Nie, J., Ruan, R. W., Wang, T., & Yi, Z. L. (2018). Effects of fertilizer application rate and planting density on photosynthetic characteristics, yield and yield components in waxy wheat. *Cereal Research Communications*, *46*(1), 169–178. https://doi.org/10.1556/0806.45.2017.058

Godinho António and Rosado, J. and S. F. and C. F. (2024). Method for Evaluating the Performance of Web-Based APIs. In I. M. and L. N. V. Coelho Paulo Jorge and Pires (Ed.), *Smart Objects and Technologies for Social Good* (pp. 30–48). Springer Nature Switzerland.

He, J., Wang, J., He, D., Dong, J., & Wang, Y. (2011). The design and implementation of an integrated optimal fertilization decision support system. *Mathematical and Computer Modelling*, *54*(3–4), 1167–1174. https://doi.org/10.1016/j.mcm.2010.11.050

Karydas, C., Chatziantoniou, M., Stamkopoulos, K., Iatrou, M., Vassiliadis, V., & Mourelatos, S. (2023). Embedding a precision agriculture service into a farm management information system - ifarma/PreFer. *Smart Agricultural Technology*, *4*. https://doi.org/10.1016/j.atech.2023.100175

Karydogianni, S., Roussis, I., Mavroeidis, A., Kakabouki, I., Tigka, E., Beslemes, D., Stavropoulos, P., Katsenios, N., Tsiplakou, E., & Bilalis, D. (2022). The Influence of Fertilization and Plant Density on the Dry Matter Yield and Quality of Black Mustard [Brassica nigra (L.) Koch]: An Alternative Forage Crop. *Plants*, *11*(20). https://doi.org/10.3390/plants11202683

Kementerian Dalam Negeri Direktorat Jenderal Bina Pembangunan Daerah. (2013). *Pedoman Budidaya Tanaman Buah-buahan*. Kementerian Dalam Negeri.

Lu, Y., Liu, M., Li, C., Liu, X., Cao, C., Li, X., & Kan, Z. (2022). Precision Fertilization and Irrigation: Progress and Applications. In *AgriEngineering* (Vol. 4, Issue 3, pp. 626–655). MDPI. https://doi.org/10.3390/agriengineering4030041

Monteiro, A., Santos, S., & Gonçalves, P. (2021). Precision agriculture for crop and livestock farming—Brief review. In *Animals* (Vol. 11, Issue 8). MDPI AG. https://doi.org/10.3390/ani11082345

Musanase, C., Vodacek, A., Hanyurwimfura, D., Uwitonze, A., & Kabandana, I. (2023). Data-Driven Analysis and Machine Learning-Based Crop and Fertilizer Recommendation System for Revolutionizing Farming Practices. *Agriculture (Switzerland)*, *13*(11). https://doi.org/10.3390/agriculture13112141

Na, H., & Kang, J. (2023). Research on the impact of internet use on fertilizer and pesticide inputs: Empirical evidence from China. *Heliyon*, *9*(10). https://doi.org/10.1016/j.heliyon.2023.e20816

Nie Pengcheng and Zhang, Q. and H. Y. (2021). IoT Management of Field Crops and Orchards. In P. and Z. Q. and L. F. He Yong and Nie (Ed.), *Agricultural Internet of Things: Technologies and Applications* (pp. 291–303). Springer International Publishing. https://doi.org/10.1007/978-3-030-65702-4_10

Nugroho, A. P., Okayasu, T., Hoshi, T., Inoue, E., Hirai, Y., Mitsuoka, M., & Sutiarso, L. (2016). Development of a remote environmental monitoring and control framework for tropical horticulture and verification of its validity under unstable network connection in rural area. *Computers and Electronics in Agriculture*, *124*, 325–339. https://doi.org/10.1016/j.compag.2016.04.025

Nugroho, A. P., Okayasu, T., Inoue, E., Hirai, Y., & Mitsuoka, M. (2013). Development of actuation framework for agricultural informatization supporting system. *IFAC Proceedings Volumes*, *46*(4), 181–186.

Pandey Amit Kumar and Mukherjee, A. (2022). A Review on Advances in IoT-Based Technologies for Smart Agricultural System. In R. and P. S. Pattnaik Prasant Kumar and Kumar (Ed.), *Internet of Things and Analytics for Agriculture, Volume 3* (pp. 29–44). Springer Singapore. https://doi.org/10.1007/978-981-16-6210-2_2

Sagung Esya Maharani, A. A., Ngadisih, Tirtalistyani, R., Mawardi, M., Alviandy, D., & Rahmadi, N. A. (2020). Evaluation of soil characteristics and infiltration capacity under Dimocarpus Longan Fruit-tree based agroforestry in Selopamioro, Imogiri, Bantul, D.I.Yogyakarta. *IOP Conference Series: Earth and Environmental Science*, *451*(1). https://doi.org/10.1088/1755-1315/451/1/012089

Tagliavini, M., Scudellazi, D., Marangoni, B., & Toselli, M. (1995). Nitrogen fertilization management in orchards to reconcile productivity and environmental aspects. *Fertilizer Research*, *43*(1), 93–102. https://doi.org/10.1007/BF00747687

Vishwajith, K. P., Bhat, A., Ashalatha, K. V., & Sahu, P. K. (2014). Decision support system for fertilizer recommendation–a case study. *Indian Journal of Agronomy*, *59*(2).

Wan, C., Yang, J., Zhou, L., Wang, S., Peng, J., & Tan, Y. (2022). Fertilization Control System Research in Orchard Based on the PSO-BP-PID Control Algorithm. *Machines*, *10*(11). https://doi.org/10.3390/machines10110982

Wibawati, W., Mulyanto, D., & Munawar, A. (2024). Status Hara N, P Dan K Pada Tanah Sawah Irigasi di Kapanewon Prambanan, Kabupaten Sleman, Daerah Istimewa Yogyakarta. *Jurnal Tanah Dan Sumberdaya Lahan*, *11*(1), 215–222. https://doi.org/10.21776/ub.jtsl.2024.011.1.23

Wiratmoko, A., Nugroho, A. P., Muna, M. S., Syarovy, M., Suwardi, Sukarman, & Sutiarso, L. (2023). Development of Cloud-Based Decision Support System for Fertilizer Management - A Case Study in Wilmar Oil Palm Plantation. *Proceedings of the International Conference on Sustainable Environment, Agriculture and Tourism (ICOSEAT 2022)*, *26*. https://doi.org/10.2991/978-94-6463-086-2_69

Xu, C., Huang, S., Tian, B., Ren, J., Meng, Q., & Wang, P. (2017). Manipulating planting density and nitrogen fertilizer application to improve yield and reduce environmental impact in Chinese Maize production. *Frontiers in Plant Science*, *8*. https://doi.org/10.3389/fpls.2017.01234

Zeng Lina and Lin, H. and L. T. and Z. D. and Y. J. and Y. Z. and W. Q. (2020). Research on Integrated Management System of Water and Fertilizer Based on Internet of Things. In J. and F. Y. and Y. M. and Y. Z. Li Bo and Zheng (Ed.), *IoT as a Service* (pp. 318–325). Springer International Publishing.

Zhong, X., Wang, Y., Wen, X., & Liao, J. (2022). An Ontology-Based Automation System: A Case Study of Citrus Fertilization. *International Journal on Semantic Web and Information Systems*, *18*(1). https://doi.org/10.4018/IJSWIS.295946