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Research Article

A Decision Support System for Fertilization Recommendations for Oil Palm Using the AHP Method Based on Plant Vegetative Conditions

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Abstract: Palm oil is a vital commodity for the Indonesian economy, but improper fertilization often leads to waste, reduced yields, and negative environmental impacts. The objective of this research is to develop a Decision Support System (DSS) for palm oil fertilization recommendations using the Analytical Hierarchy Process (AHP) method, based on the plant's vegetative condition, soil condition, and climate. Therefore, a systematic, data-driven approach is needed for fertilization optimization. This DSS is designed to address these challenges by using three main kriteria: the plant's vegetative condition, soil condition, and climate condition. The AHP method is used to assess and prioritize these kriteria, resulting in more accurate fertilization recommendations that are tailored to the field conditions. This system is expected to assist farmers and plantation managers in making more informed, efficient, and effective fertilization decisions, which will ultimately increase crop productivity and reduce negative environmental impacts. This research successfully designed and implemented a DSS for oil palm fertilization recommendations. The AHP method was successfully applied to structure the problem, determine criteria weights, and provide agronomically valid recommendations through case study testing. The test results demonstrated that the system was capable of providing logical and useful recommendations for both nutrient deficiency conditions and optimal land conditions.

Keywords: Analytical Hierarchy Process; Decision Support System; Effective Fertilization Decisions; Fertilization; Palm Oil.

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1. Introduction

Oil palm (*Elaeis guineensis*) is a strategic plantation commodity that plays a vital role in the Indonesian economy, contributing significantly to Gross Domestic Product (GDP) and national exports. Increasing productivity has become a primary imperative in response to the high global demand for palm oil. One of the key factors that substantially influences crop yields is fertilization management. However, fertilization practices commonly applied in the field are often conventional or based on routine schedules that disregard the specific conditions of the land or plants. Inaccurate fertilization, whether due to excessive or insufficient dosages, can lead to several problems, such as the use of manual methods, inappropriate dosages, limited knowledge, and marginal soil conditions (Ayu, F., & Mustofa, A., 2021).

To address these challenges, a systematic, data-driven approach, as proposed by As-Siddiqi, et al., (2022), is required for fertilization optimization. Fertilizer application decisions must consider three primary interacting criteria, namely plant vegetative conditions, soil conditions, and climatic conditions.

The complexity of fertilization management in oil palm cultivation extends beyond the selection of fertilizer type because nutrient requirements are strongly associated with observable plant responses, soil characteristics, and management conditions. Ningsih et al. (2022) demonstrated the importance of systematic fertilization management in mature oil palm plantations, indicating that fertilizer application should be treated as an integrated managerial process rather than as an isolated agronomic activity. Likewise, the development of fertilization dose recommendation systems by Ginting and Uktoro (2018) reflects the growing need to translate field characteristics into structured decision parameters. This requirement becomes particularly important when farmers must simultaneously interpret multiple indicators whose relative importance may differ under specific plantation conditions. Research by Firmansyah et al. (2021) further reinforces the relevance of web-based recommendation systems as instruments for supporting fertilization decisions in smallholder oil palm plantations.

The increasing application of computational decision-support approaches in oil palm management demonstrates that agricultural decision-making can be strengthened through systematic processing of multiple criteria. Ayu and Mustofa (2021), for example, applied the Simple Additive Weighting approach to fertilizer-dose determination through an Android-based application, while Sitohang et al. (2026) developed a web-based decision support system for fertilizer selection using the same multicriteria decision-making framework. Other studies have broadened this computational orientation by employing Multi-Attribute Utility Theory for fertilizer selection, as reported by Khairani et al. (2019). These developments indicate that digital decision-support technologies offer substantial potential for transforming field observations into more transparent, consistent, and operational recommendations. Nevertheless, the appropriateness of a particular decision model depends on its capacity to represent hierarchical relationships among agronomic criteria and to distinguish their relative levels of importance.

Within this context, the Analytical Hierarchy Process provides a particularly relevant methodological framework because it enables complex decision problems to be decomposed into structured levels of objectives, criteria, subcriteria, and alternatives. Saaty et al. (2007) emphasized the analytical value of AHP in allocating priorities among competing factors, thereby providing a systematic basis for decisions involving multiple dimensions. In oil palm-related applications, As-Siddiqi et al. (2022) employed AHP to construct a fertilizer-type recommendation system, confirming the applicability of hierarchical multicriteria analysis to fertilization decisions. The method has also been extended to other oil palm decision domains, including the selection of superior parent trees, as shown by Amiroh (2026). Such applications illustrate that AHP is not merely a ranking mechanism but also a framework through which expert judgments can be formally organized, quantified, and subjected to consistency evaluation.

A further consideration concerns the need to integrate plant-based indicators with environmental characteristics rather than evaluating each component independently. Vegetative symptoms provide immediate visual information regarding plant performance, whereas soil conditions influence nutrient availability and the effectiveness of fertilizer uptake. At the same time, land suitability and environmental characteristics have increasingly been incorporated into decision-support applications for oil palm cultivation; Andreswari et al. (2023), for instance, applied a multicriteria approach to the selection of suitable plantation land, while Monalisa and Wahid (2021) developed a decision-support system for oil palm land selection using the SMARTER method. These studies collectively demonstrate the importance of representing heterogeneous field variables within a unified analytical structure. The integration of vegetative, soil, and climatic indicators therefore provides a more comprehensive basis for fertilizer recommendations than reliance on a single category of observation.

The advancement of fertilization decision support is also closely related to the broader objective of improving the precision, accountability, and practical usability of plantation management. Ezward et al. (2025) highlighted the relevance of fertilizer management within oil palm nursery technology, underscoring the continuing importance of appropriate nutrient management throughout different stages of crop development. From an information-system perspective, Lumbanraja and Lumbanraja (2024) further identified decision-system design as an alternative approach for addressing various issues in oil palm plantation management. Accordingly, a decision support system that combines hierarchical weighting with observable field conditions has the potential to bridge agronomic knowledge and operational decision-making in a form that is accessible to users. By structuring vegetative, soil, and climatic information within an AHP-based framework, the system can provide a more defensible basis for selecting fertilization alternatives while maintaining transparency in how each recommendation is generated.

This study aims to design and implement a Decision Support System (DSS) for oil palm fertilization recommendations using the Analytical Hierarchy Process (AHP). The AHP method was selected because of its capability to perform multicriteria assessments, prioritize the relative importance among criteria, and evaluate the consistency of decisions made by experts. This DSS is designed to provide fertilizer-type recommendations that are more accurate, efficient, and adaptive to field conditions, thereby increasing productivity and reducing adverse environmental impacts.

2. Literature Review

Decision Support Systems for Oil Palm Fertilization

A Decision Support System (DSS) constitutes a computer-based framework designed to assist decision makers in addressing semi-structured and multi-criteria problems by integrating data, analytical models, and explicit decision rules. Within oil palm cultivation, fertilization decisions are inherently complex because the selected fertilizer type and dose must correspond to heterogeneous field conditions rather than being determined solely through routine scheduling. Ayu and Mustofa (2021) demonstrated that computational decision models can translate agronomic variables into fertilizer-dose recommendations, thereby reducing dependence on purely intuitive judgments. A similar orientation is evident in the work of Firmansyah et al. (2021), who developed a web-based fertilization recommendation system for smallholder oil palm plantations to facilitate more systematic and accessible decision-making. More recently, Sitohang et al. (2026) applied a web-based Simple Additive Weighting model to fertilizer selection, further illustrating the relevance of multicriteria decision-support architectures in plantation management. From a broader plantation perspective, Lumbanraja and Lumbanraja (2024) contend that structured decision-system design offers a viable mechanism for addressing complex operational issues in oil palm management. These findings establish the theoretical foundation for positioning a DSS not as a substitute for agronomic expertise, but as an analytical instrument that structures multiple field indicators into transparent, consistent, and reproducible recommendations.

Analytical Hierarchy Process as a Multicriteria Decision-Making Method.

The Analytical Hierarchy Process (AHP) is a multicriteria decision-making method that decomposes a complex decision problem into a hierarchical structure consisting of objectives, criteria, subcriteria, and alternatives. The theoretical strength of AHP lies in its capacity to quantify subjective judgments through pairwise comparisons while simultaneously evaluating the logical consistency of those judgments. Saaty et al. (2007) explain that AHP enables decision makers to establish relative priorities among competing factors by deriving numerical weights from structured comparisons, thereby transforming qualitative preferences into measurable decision parameters. In the context of oil palm management, As-Siddiqi et al. (2022) applied AHP to fertilizer-type recommendations and demonstrated its suitability for organizing agronomic criteria into a systematic hierarchy. The adaptability of this approach is also evident in Amiroh (2026), who used AHP for the selection of superior oil palm parent trees, while Fazliani et al. (2017) employed the same method to support the selection of superior oil palm seedlings. These applications indicate that AHP is particularly appropriate when several criteria contribute unequally to the final decision. For fertilization recommendations, the method therefore provides a theoretically robust mechanism for assigning relative importance to vegetative, soil, and climatic conditions while maintaining consistency between expert judgment and the resulting priority structure.

Agronomic Indicators in Oil Palm Fertilization Decisions

Oil palm fertilization management requires an integrated interpretation of plant performance and environmental conditions because nutrient requirements cannot be evaluated independently from the physiological and edaphic context in which the crop develops. Ningsih et al. (2022) emphasize the importance of systematic fertilization management in mature oil palm cultivation, where nutrient application must be adjusted to plantation conditions and crop requirements to support sustained productivity. Observable vegetative characteristics, including leaf condition, frond development, and plant growth, can provide practical indications of nutritional status and therefore constitute relevant inputs for fertilizer recommendation systems. Firmansyah and Putra (2019), through the development of the Smartferti expert system, highlighted the potential of integrating agronomic knowledge into digital fertilization recommendations for oil palm. Soil-related variables are equally important because soil acidity, moisture, and physical condition directly influence nutrient availability and plant uptake; in this respect, Pasaribu (2025) demonstrates that land capability assessment provides an important basis for determining appropriate land-management recommendations. Environmental suitability has likewise been incorporated into computational plantation models, as Andreswari et al. (2023) used multicriteria analysis to identify suitable land for oil palm plantations. Accordingly, the simultaneous consideration of vegetative, soil, and climatic indicators provides a stronger theoretical basis for fertilization decisions than models relying on a single class of variables.

Digital and Web-Based Agricultural Recommendation Systems

The development of web-based agricultural recommendation systems represents an important transformation in the delivery of decision-support services because such systems enable analytical models to be accessed more efficiently by users operating under diverse field conditions. In oil palm cultivation, digital platforms can facilitate the conversion of field observations into structured inputs, automate multicriteria calculations, and present recommendations in a form that is readily interpretable by farmers or plantation managers. Firmansyah et al. (2021) demonstrated that web-based fertilization recommendation systems can extend decision support to smallholder plantations, while Sitohang et al. (2026) further showed how web architecture can be combined with multicriteria evaluation to determine appropriate fertilizers. The broader applicability of digital decision support is reflected in Monalisa and Wahid (2021), who implemented the SMARTER method for oil palm land selection, and Aelani et al. (2023), who developed a decision-support approach for selecting oil palm seedlings using the Preference Selection Index. Digital systems also contribute to greater transparency because users can trace how specific criteria influence the final ranking of alternatives rather than receiving recommendations without an explicit analytical basis. In this research context, integrating AHP within a web-based platform creates a conceptual bridge between agronomic knowledge and information-system functionality, enabling vegetative, soil, and climatic data to be processed through a hierarchical weighting mechanism and translated into practical fertilization recommendations.

3. Proposed Method

This research was conducted in Batu Menang Hamlet, Suka Karya Village, Ketapang Regency, West Kalimantan Province. The research objects were oil palm plants from the TBM (Immature Plants) phase to the TM (Mature Plants) phase. Data were obtained from Plant Vegetative Conditions, Soil Conditions, and Climate Data. The approach employed was a combination of qualitative and quantitative methods, integrating field data with AHP model analysis.

The process begins by determining the problem and the desired solution through the establishment of a priority scale for the criteria, namely a scale of 1–9 used to measure the relative importance among criteria. The next step is to construct a pairwise comparison matrix, in which each criterion is compared pairwise with the others based on validated expert assessments. Once the matrix has been constructed, the system mathematically calculates the criterion weights. This process involves matrix normalization and the calculation of the *eigenvector* to generate priority weights for each criterion. The subsequent step is a logical validity test, namely calculating the consistency value (CR). This CR value serves to validate the quality of the assessment. There is a decision point as to whether $CR \leq 0.1$; if yes, the assessment is considered logically consistent, and the resulting criterion weights are deemed suitable for use in the subsequent decision-making process. If not, the flow returns to the matrix construction stage, indicating that the pairwise comparison assessment must be revised because it contains inconsistencies. This process ensures that the resulting weights are not only based on preferences but are also logical and accountable.

AHP Method Flowchart

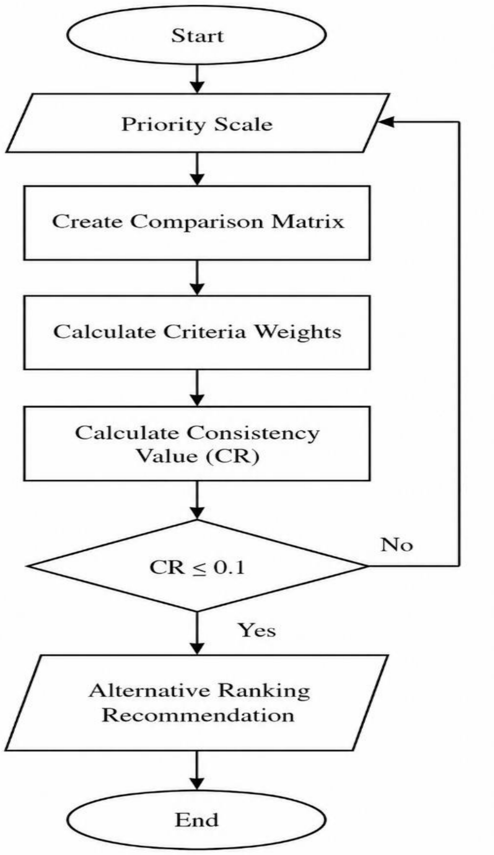

Figure 1. AHP Method Flowchart.

Decision Support System Hierarchical Structure

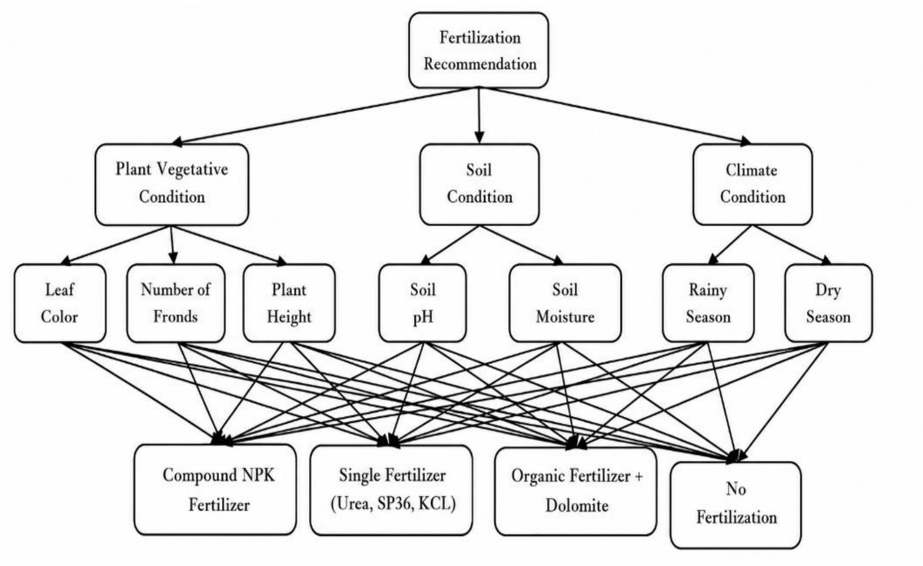

Figure 2. Decision Support System Hierarchical Structure.

The AHP hierarchy diagram illustrates the relationships among the objective, criteria, and sub-criteria. This structure helps visualize how each criterion contributes to the final objective. The hierarchical structure shown in Figure 2 explains the objective, criteria, sub-criteria, and alternatives used in this research.

Tools and Materials

The system was developed using server-side technologies integrated within the *XAMPP* package, including PHP as the primary programming language, *MySQL* for database management, and *phpMyAdmin* as the administrative interface. The development environment utilized *Visual Studio Code* and *Google Chrome*. The required data comprised primary data obtained from direct observations (vegetative conditions, soil, and climate) and secondary data derived from literature studies to establish the theoretical foundation and validate the AHP model.

AHP Analysis

The *Analytical Hierarchy Process* (AHP) is the primary method used to analyze and prioritize the criteria within the system. The stages of AHP in this research are as follows:

1. Hierarchical Structure: The fertilization problem is structured into a hierarchy consisting of the objective, main criteria, sub-criteria, and fertilizer alternatives.
   a. Objective: Oil Palm Fertilization Recommendation.
   b. Main Criteria: Vegetative Conditions, Soil Conditions, Climate Conditions.
   c. Sub-Criteria: Leaf Color, Number of Fronds, Plant Height, Soil pH, Soil Moisture, Season.
   d. Alternatives: Compound NPK Fertilizer (13-6-27), Single Fertilizer (Urea, SP-36, KCL), Organic Fertilizer + Dolomite, No Fertilization.
2. Pairwise Comparison: The system administrator, acting as the expert, performs pairwise comparisons among the criteria and sub-criteria using the Saaty scale (1–9).
3. Matrix Normalization: The comparison matrix is normalized to obtain priority weights (*eigenvector*). The normalization formula is:

$$\mathrm{b}ij = \frac{aij}{\sum_{n=1}^{k} akj} \quad (1)$$

   Description:

   b_{ij} = The normalized value in row i and column j

   a_{ij} = The value in row i and column j of the pairwise comparison matrix.

   $\sum_{n=1}^{k} akj$ = The total value in column j of the pairwise comparison matrix.

4. Consistency Test: The *Consistency Index* (CI) and *Consistency Ratio* (CR) are calculated to ensure that the assessments provided are logically consistent.

$$CI = \frac{\lambda\max - n}{\mathrm{n} - 1} \quad (2)$$

   Description:

   CI = Consistency Index

   λmax = Maximum eigenvalue

   n = Number of main criteria

Table 1. Established Random Index Values.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

5. Final Score Calculation: The suitability score of each alternative against the sub-criteria is multiplied by the priority weights of the sub-criteria and the main criteria to generate the final score.

4. Results and Discussion

The system developed has two access levels: administrator and user. The user interface is designed to be simple and intuitive, allowing users (farmers) to select field conditions from a dropdown list. Meanwhile, the administrator interface allows for the management of criterion weights and the suitability assessment matrix.

Interface Design

The developed system incorporates two distinct access levels, namely administrator and user, with each role assigned functions that correspond to its operational responsibilities. The user interface was deliberately designed to be straightforward and intuitive so that farmers can select actual field conditions through predefined *dropdown* menus without having to understand the mathematical procedures underlying the recommendation model. In contrast, the administrator interface provides facilities for managing criterion weights and suitability-assessment matrices that constitute the computational foundation of the system. This separation of access privileges is consistent with the development of web-based oil palm fertilization recommendation systems described by Firmansyah et al. (2021), in which digital interfaces function as a bridge between agronomic knowledge and practical decision-making. Lumbanraja and Lumbanraja (2024) similarly position decision-support system architecture as an alternative mechanism for addressing complex plantation-management issues, making the differentiation between managerial and operational access particularly relevant.

The initial point of interaction is the login interface, which displays the title "LOGIN SISTEM" and identifies the application as the Sistem Pendukung Keputusan Rekomendasi Pemupukan Kelapa Sawit. Two authentication fields, namely Username and Password, are provided, followed by a Login button that grants access to the system according to the authorized user role. The uncomplicated structure of this page minimizes unnecessary interaction before users reach the principal system functions. Ayu and Mustofa (2021) demonstrated the utility of application-based fertilizer-dose determination, while Mustofa (2017) also employed a decision-support approach for determining oil palm fertilizer doses, illustrating the importance of converting technical fertilizer calculations into accessible application interfaces. The development of *Smartferti* by Firmansyah and Putra (2019) further reflects the growing tendency to embed oil palm fertilization knowledge within digital systems that can be operated without requiring users to conduct complex calculations manually.

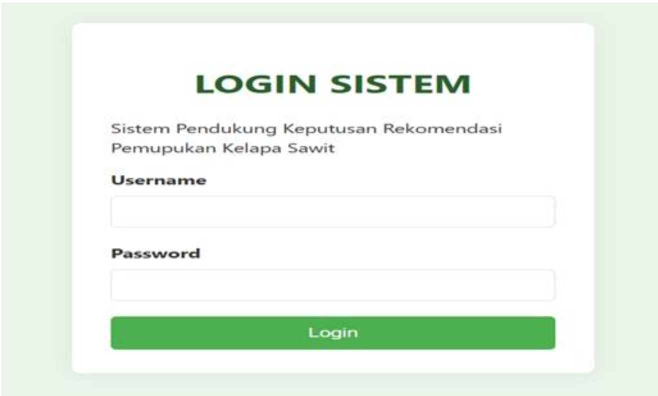

Figure 3. Login Page.

After successful administrator authentication, the system directs the authorized user to the Admin Dashboard. The navigation panel displays the system identity "SPK SAWIT" and provides four principal menus: Dashboard, Kelola Bobot, Kelola Matriks, and Logout, while the upper-right section presents a welcome notification for the administrator. This interface configuration centralizes the principal administrative functions and allows criterion-related information to be monitored from a single workspace. Such centralization is relevant to the broader application of decision-support technologies within the oil palm sector; for example, Karim (2023) applied a structured decision-support model within an oil palm research environment, demonstrating the value of systematic computational support for institutional decision processes. In another application domain, Aelani et al. (2023) employed decision-support techniques for selecting oil palm seedlings, reinforcing the usefulness of structured interfaces for transforming multiple assessment parameters into manageable decision information.

A central component of the administrator dashboard is the Analisis Bobot Kriteria (AHP) section, which explicitly displays the pairwise comparison matrix among Kondisi Vegetatif, Kondisi Tanah, and Kondisi Iklim. The matrix records values of 1.00, 1.67, and 2.50 for the Vegetative Condition row; 0.60, 1.00, and 1.50 for the Soil Condition row; and 0.40, 0.67, and 1.00 for the Climate Condition row, with column totals of 2.00, 3.33, and 5.00, respectively. These numerical relationships operationalize the principle of pairwise comparison central to AHP, whereby criteria are evaluated according to their relative importance rather than treated as equally influential. Saaty et al. (2007) explain that hierarchical decision analysis derives priorities through structured comparative judgments, while As-Siddiqi et al. (2022) specifically demonstrated the applicability of AHP to fertilizer-type recommendation problems in oil palm cultivation. The continued use of AHP in oil palm decision applications, including the selection of superior parent trees reported by Amiroh (2026), further supports the methodological appropriateness of displaying criterion relationships transparently within the administrator interface.

The dashboard also presents the Matriks Normalisasi & Hasil Bobot, allowing the administrator to examine how the initial pairwise comparisons are transformed into final priority coefficients. Vegetative Condition obtains normalized values of 0.50, 0.50, and 0.50, resulting in an AHP Weight of 0.500 and a Manual Weight of 0.500; Soil Condition records 0.30, 0.30, and 0.30, producing corresponding weights of 0.300; and Climate Condition records 0.20, 0.20, and 0.20, producing weights of 0.200. The identical AHP and manual weights shown on the dashboard facilitate direct verification of the weighting configuration implemented in the system. Fazliani et al. (2017) demonstrated that AHP can structure oil palm selection problems through hierarchical weighting, whereas Andika et al. (2023), using MOORA for oil palm seedling selection, illustrates the broader relevance of explicit criterion weighting and ranking within multicriteria plantation decision systems. The interface therefore makes the computational logic visible rather than concealing the weighting process behind the final recommendation.

Adjacent to the weighting analysis, the administrator dashboard includes an AHP Assessment Scale Guide that reproduces the pairwise-comparison scale used to determine the degree of relative importance. A value of 1 represents elements of equal importance, 3 indicates that one element is slightly more important, 5 denotes clearly greater importance, 7 represents very strongly greater importance, and 9 indicates absolute importance, while 2, 4, 6, and 8 represent intermediate values between adjacent judgments. Presenting this guide within the dashboard assists the administrator in entering or interpreting comparison values consistently and reduces dependence on external reference material during system operation. Sitohang et al. (2026) demonstrate how web-based multicriteria decision systems can operationalize fertilizer selection, whereas Andreswari et al. (2023) employ multicriteria processing for oil palm land suitability assessment. Monalisa and Wahid (2021) similarly show that structured weighting approaches can support oil palm land selection, indicating that transparent presentation of assessment scales is important when expert judgment must be converted into numerical decision parameters.

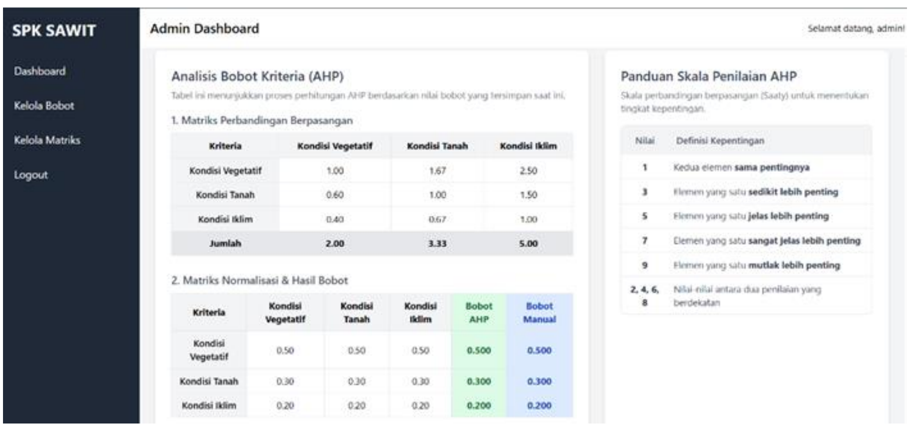

Figure 4. Admin Dashboard.

For ordinary users, the principal operational interface is the Analisis Kondisi Lahan page, which greets the user and provides a Logout facility in the upper-right section. The page instructs users to select the condition that most closely corresponds to the actual field situation for each available indicator. Six input variables are displayed through *dropdown* fields: Warna Daun, Jumlah Pelepah, Tinggi Tanaman, pH Tanah, Kelembapan Tanah, and Musim, with each field initially displaying the prompt "-- Pilih Kondisi --." Once these indicators have been completed, the user can initiate the decision process through the "Dapatkan Rekomendasi" button. The selection of field-oriented parameters reflects the practical nature of oil palm fertilization management described by Ningsih et al. (2022), while Ezward et al. (2025) emphasize the relevance of fertilizer management within oil palm cultivation practices. Earlier work by Ginting and Uktoro (2018) on fertilizer-dose recommendation systems likewise illustrates the need to translate plantation characteristics into structured inputs capable of supporting fertilizer decisions.

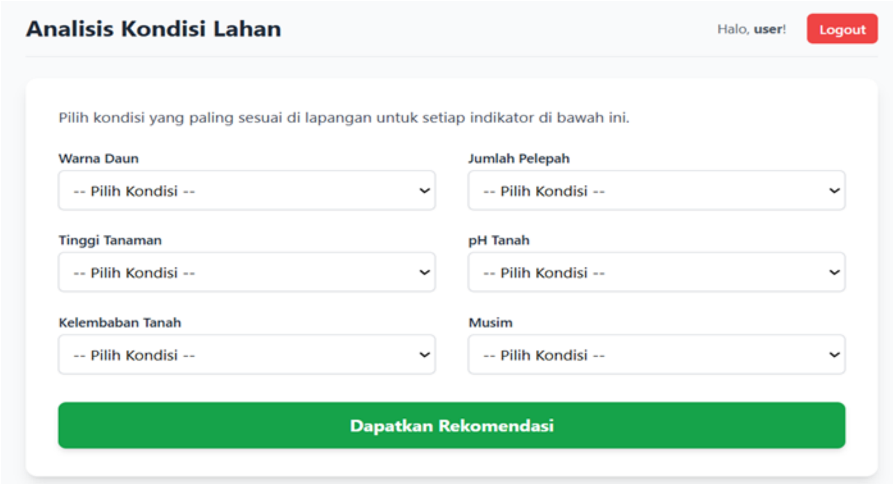

Figure 5. User Input Page.

The six input indicators demonstrate that the system does not treat fertilizer recommendation as a function of a single plant symptom. Vegetative observations represented by leaf color, number of fronds, and plant height are combined with environmental indicators consisting of soil pH, soil moisture, and season, thereby allowing the recommendation process to reflect both plant performance and growing conditions. This multidimensional design is agronomically meaningful because fertilizer effectiveness is associated not only with nutrient inputs but also with crop growth and the condition of the cultivation environment. Junenti et al. (2023), in examining NPK fertilization and plant growth, illustrate the relevance of nutrient management to vegetative development, while Suwarno et al. (2024) show that organic material inputs may contribute to crop growth and production responses. From the land-management perspective, Pasaribu (2025) emphasizes the importance of evaluating land capability as a basis for management recommendations, reinforcing the rationale for incorporating soil-related variables into the decision-support interface.

From a functional standpoint, the interface establishes a clear transition from qualitative field observation to quantitative decision processing. Farmers are only required to describe observable conditions using standardized choices, whereas the computational procedures involving criterion weights and decision matrices remain under administrator control. This arrangement minimizes the cognitive burden placed on users while preserving a transparent analytical structure at the administrative level. Khairani et al. (2019) similarly applied a multi-attribute decision framework for selecting fertilizer alternatives in oil palm cultivation, illustrating how several assessment dimensions can be converted into a comparative recommendation. The approach is also compatible with the broader principle demonstrated by As-Siddiqi et al. (2022), in which fertilizer selection becomes a multicriteria decision problem rather than a simple one-variable classification task.

Overall, the interface design demonstrates an integrated relationship between accessibility, data organization, and multicriteria decision logic. Figure 3 provides controlled system authentication through username and password fields; Figure 4 enables administrators to manage and verify the pairwise matrix, normalized values, AHP weights, manual weights, and Saaty assessment scale; and Figure 5 allows users to enter six field-condition indicators and request a fertilizer recommendation through a single operational command. The resulting structure reflects the progression of oil palm decision-support research from fertilizer-dose applications such as those developed by Ayu and Mustofa (2021) toward increasingly integrated web-based decision environments such as those reported by Sitohang et al. (2026). The inclusion of both administrator-level analytical transparency and farmer-oriented simplicity strengthens the practical function of the system because it preserves the mathematical basis of AHP while making the recommendation process accessible to field users. Thus, the interface is not merely a visual component of the application but an essential mechanism through which agronomic observations, criterion weighting, and computerized decision support are operationally connected.

Criteria Weights and System Validation Through Case Studies

The weighting stage establishes the relative contribution of the three principal criteria used by the system to generate oil palm fertilization recommendations. Based on expert assessment, Vegetative Condition received the highest weight of 0.50, followed by Soil Condition at 0.30 and Climate Condition at 0.20. The predominance of vegetative indicators reflects the assumption that nutritional deficiencies are most immediately manifested through observable plant characteristics, whereas soil properties determine nutrient availability and absorption and climatic conditions influence the effectiveness of fertilizer application. According to Saaty et al. (2007), differences in criterion weights within AHP represent the relative importance assigned to factors through structured comparative judgment rather than arbitrary numerical assignment. This hierarchy is consistent with the application of AHP to oil palm fertilizer recommendations by As-Siddiqi et al. (2022), while Amiroh (2026) further demonstrates the capacity of AHP to establish differentiated priorities among biological and agronomic attributes in oil palm decision problems.

The distribution of weights also provides an agronomically interpretable framework for translating field conditions into recommendations. A 0.50 weight for vegetative condition means that leaf color, number of fronds, and plant height exert the greatest influence on the final decision, whereas the 0.30 soil weight accommodates the effects of soil pH and moisture on nutrient availability. The remaining 0.20 climate weight captures seasonal conditions that may enhance or restrict the effectiveness of fertilizer application. Ningsih et al. (2022) emphasize the importance of systematic fertilizer management in mature oil palm plantations, and Ezward et al. (2025) similarly associate fertilizer management with the maintenance of appropriate crop development. From the soil-management perspective, Pasaribu (2025) demonstrates that land capability characteristics provide an important foundation for management recommendations, while Suwarno et al. (2024) show that organic amendments can influence soil-related conditions and crop performance.

To evaluate whether the weighting mechanism could generate meaningful recommendations under different field circumstances, three case studies were constructed. The first represents nutrient deficiency combined with acidic soil, the second represents optimal land conditions, and the third represents dry-season conditions accompanied by dry soil. This scenario-based testing approach enables the system to be examined not merely in terms of computational output but also in relation to whether its recommendations remain logically aligned with contrasting agronomic conditions. Ayu and Mustofa (2021) used a decision-support approach to translate oil palm fertilization parameters into fertilizer-dose recommendations, while Ginting and Uktoro (2018) similarly employed structured decision mechanisms for oil palm fertilizer recommendations. Such applications indicate that the usefulness of a fertilizer decision system depends substantially on its capacity to differentiate recommended actions across changing field conditions rather than repeatedly producing the same intervention.

In the first case study, Nutrient Deficiency and Acidic Soil, the input conditions consisted of yellow/pale leaves, an insufficient number of fronds, stunted plant height, acidic soil pH, dry soil, and the rainy season. Collectively, these conditions indicate substantial vegetative stress associated with nutrient limitation while simultaneously identifying soil acidity as an environmental constraint. The system designated Compound NPK Fertilizer (13-6-27) as the primary recommendation, with the case description recording a score of 3.97, while the result interface displays a final score of 3.9800. The interface also describes the recommended action as a fertilizer containing complete macronutrients and therefore suitable for the production phase. Firmansyah and Putra (2019), through the *Smartferti* expert system, demonstrated how observable oil palm conditions can be converted into digital fertilization recommendations, whereas Junenti et al. (2023) reinforce the agronomic significance of NPK nutrients for supporting vegetative plant development.

The detailed ranking displayed in the first case-study interface places Compound NPK Fertilizer (13-6-27) at 3.9800, followed by Single Fertilizer (Urea, SP-36, KCl) at 3.9800, Organic Fertilizer + Dolomite at 3.1000, and No Fertilization at 1.5200. Thus, the interface records identical numerical scores for the first two alternatives while still presenting Compound NPK Fertilizer as the best recommendation. The recommendation is logically associated with the combined symptoms of macronutrient deficiency, particularly those related to N, P, and K, because a compound fertilizer can simultaneously supply several major nutrients. Khairani et al. (2019) demonstrated the relevance of multi-attribute processing for selecting the best fertilizer for oil palm, while Mustofa (2017) showed how decision-support techniques can assist in determining fertilizer dosage. The broader development of web-based fertilizer recommendation systems reported by Firmansyah et al. (2021) likewise supports the conversion of multiple agronomic observations into ranked fertilizer alternatives.

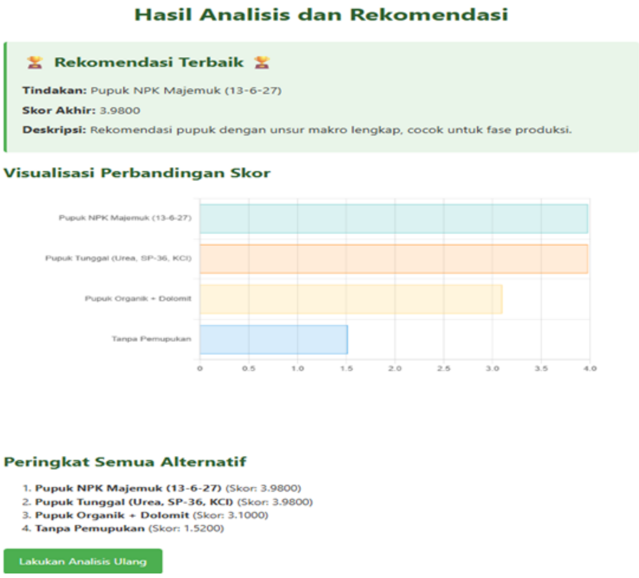

Figure 6. Result Page of the First Case Study Test.

The second case study, Optimal Land Conditions, was constructed using a markedly different input profile: dark green leaves, a healthy number of fronds, plant height appropriate for age, neutral soil pH, adequate soil moisture, and the rainy season. Under these conditions, the system recommended No Fertilization as the most appropriate option, with a score of 4.60. This result is significant because it demonstrates that the system is not inherently biased toward recommending fertilizer application in every situation. Rather, when the vegetative, soil, and climatic indicators collectively represent favorable conditions, the model is capable of confirming that additional fertilizer input is unnecessary. Sitohang et al. (2026) illustrate the value of web-based fertilizer decision systems in distinguishing among alternatives according to weighted conditions, while Lumbanraja and Lumbanraja (2024) emphasize that structured decision systems can assist in addressing plantation-management issues without relying exclusively on routine intervention.

The second case also demonstrates the economic and managerial relevance of the recommendation mechanism. By assigning No Fertilization the highest score under optimal conditions, the system can potentially prevent unnecessary fertilizer expenditure while avoiding nutrient application that is not supported by current field indicators. This interpretation aligns with the broader principle of matching interventions to actual land conditions rather than applying standardized treatments regardless of need. Andreswari et al. (2023), in their study of oil palm land suitability using MOORA, demonstrate the importance of environmental compatibility in plantation decision-making, while Monalisa and Wahid (2021) similarly employ multicriteria evaluation to determine appropriate oil palm land conditions. From the perspective of alternative decision-support techniques, Karim (2023) further illustrates how computational ranking methods can improve consistency in decision processes within the oil palm research context.

The third case study, Dry Season and Dry Soil, was characterized by yellow/pale leaves, an adequate number of fronds, plant height appropriate for age, acidic soil pH, dry/cracked soil moisture conditions, and the dry season. Although the yellow/pale leaves indicate a possible nutrient deficiency, the combination of acidic pH, dry soil, and seasonal water limitation causes soil condition to become a critical limiting factor. Under this scenario, the system recommends Organic Fertilizer + Dolomite as the primary alternative with a final score of 3.4000. The system description states that this alternative is intended to improve the physical and chemical properties of the soil, particularly by increasing soil pH and supplying micronutrients. Fazliani et al. (2017) demonstrate how AHP can prioritize alternatives on the basis of multiple oil palm attributes, whereas Aelani et al. (2023) and Andika et al. (2023) likewise show that multicriteria systems can differentiate agricultural alternatives when several decision variables must be considered simultaneously.

The complete ranking for the third scenario confirms the shift in priority caused by the dry and acidic soil conditions. Organic Fertilizer + Dolomite ranked first with a score of 3.4000, followed by Compound NPK Fertilizer (13-6-27) at 2.8800, Single Fertilizer (Urea, SP-36, KCl) at 2.6800, and No Fertilization at 2.3200. The recommendation indicates that, despite evidence of nutrient deficiency, immediate reliance on chemical fertilizer is not considered the most appropriate response when soil moisture and acidity substantially constrain fertilizer effectiveness. The preference for soil amendment reflects the model's ability to prioritize the most critical limiting condition before emphasizing direct nutrient supplementation. As-Siddiqi et al. (2022) similarly demonstrate the usefulness of hierarchical analysis for fertilizer-type selection, while Suwarno et al. (2024) provide supporting evidence concerning the role of organic amendments in improving crop-growth environments. The capacity to alter alternative rankings according to environmental limitations is also consistent with the general multicriteria decision logic described by Saaty et al. (2007).

Figure 7. Result Page of the Third Case Study Test.

Taken together, the three case studies indicate that the weighting configuration of 0.50 for Vegetative Condition, 0.30 for Soil Condition, and 0.20 for Climate Condition enables the system to produce different recommendations under contrasting agronomic situations. The first case directs the user toward Compound NPK Fertilizer under pronounced vegetative deficiency and acidic soil conditions; the second selects No Fertilization when all indicators represent an optimal condition; and the third prioritizes Organic Fertilizer + Dolomite when acidic, dry soil during the dry season becomes the dominant limitation. These variations demonstrate that the system operates as a contextual decision-support mechanism rather than as a fixed fertilizer-selection rule. The progression from digital fertilizer-dose systems developed by Ayu and Mustofa (2021) and Firmansyah et al. (2021) toward web-based multicriteria applications such as Sitohang et al. (2026) reflects this broader movement toward adaptive agricultural decision support. The present results also correspond with decision-support developments in oil palm seedling selection by Aelani et al. (2023) and Andika et al. (2023), land selection by Andreswari et al. (2023) and Monalisa and Wahid (2021), and plantation decision-system design by Lumbanraja and Lumbanraja (2024), collectively indicating that transparent multicriteria processing can provide a defensible basis for operational decisions in oil palm management.

Discussion

The analysis of the three case studies demonstrates that the developed system is capable of producing recommendations that are both agronomically valid and logically coherent. The principal strength of the model lies in its ability to transform qualitative observations obtained from field conditions into quantitative decision values through the Analytical Hierarchy Process (AHP). As-Siddiqi et al. (2022) demonstrated the applicability of AHP to fertilizer-type recommendations for oil palm, while Saaty et al. (2007) emphasized that hierarchical decision analysis enables qualitative judgments to be systematically converted into measurable priorities. This analytical mechanism is also consistent with the web-based fertilizer recommendation approach developed by Firmansyah et al. (2021), in which agronomic information is translated into structured recommendations. The results therefore indicate that the system does not merely digitize field observations but organizes them into a transparent multicriteria decision structure.

Input-Process-Output Model

The system mechanism can be explained through an input-process-output model, beginning with the acquisition of land-condition data entered directly by the user. The input component consists of observable field information, such as yellow/pale leaf color, which represents one of the vegetative indicators used to characterize the current condition of the oil palm. Ayu and Mustofa (2021) similarly incorporated field variables into an application-based fertilizer-dose determination system, while Ginting and Uktoro (2018) demonstrated the relevance of converting plantation conditions into decision variables for fertilizer recommendations. In the *Smartferti* system, Firmansyah and Putra (2019) also showed how agronomic knowledge can be represented digitally to support fertilization decisions. The present system adopts the same general principle while integrating field observations within an AHP-based hierarchical framework.

The *process* stage begins when the system maps the user-defined input into the assessment matrix, calculates the weighted scores, and aggregates those scores according to the priority weights assigned to the main criteria. Through this mechanism, each alternative is evaluated according to the contribution of vegetative, soil, and climatic conditions rather than through a single isolated indicator. Amiroh (2026) illustrates the usefulness of AHP for establishing differentiated priorities among oil palm characteristics, whereas Fazliani et al. (2017) similarly employed AHP to organize several criteria in the selection of superior oil palm seedlings. The pairwise and hierarchical structure described by Saaty et al. (2007) provides the mathematical foundation for such weighting, enabling expert judgments to be systematically represented in the final calculations. Consequently, the recommendation process remains traceable from the initial field input to the final alternative ranking.

Within the weighted model, Vegetative Condition carries a weight of 0.5, Soil Condition 0.3, and Climate Condition 0.2, thereby establishing the relative influence of each dimension on the final calculation. This structure gives the greatest contribution to visible plant conditions while still allowing soil and climatic factors to modify the final decision. Ningsih et al. (2022) emphasize that oil palm fertilization management should consider plant and plantation conditions systematically, while Ezward et al. (2025) similarly highlight the significance of fertilizer management within oil palm cultivation. The relevance of soil conditions is reinforced by Pasaribu (2025), whose land-capability assessment demonstrates the importance of soil characteristics in management recommendations. From the plant-growth perspective, Junenti et al. (2023) show the importance of nutrient inputs for vegetative development, while Suwarno et al. (2024) further illustrate how soil amendments and nutrient-related interventions may influence plant growth responses.

The detailed AHP calculation provides a transparent illustration of how these criterion weights are translated into final alternative scores. For Compound NPK Fertilizer, the vegetative score of 4.5600, soil score of 3.5000, and climate score of 3.2000 are multiplied by their respective weights of 0.5, 0.3, and 0.2, producing a final weighted score of 3.97 and placing the alternative in Rank 1. Khairani et al. (2019) similarly demonstrated that multiple attributes can be aggregated to identify the most appropriate fertilizer alternative for oil palm. The explicit numerical presentation also supports calculation transparency, an important characteristic of computerized decision systems in which users or administrators must be able to understand how recommendations are generated. The complete calculation is presented in Table 2.

Table 2. Details of AHP Method Calculation.

Recommendation Alternative	Criteria Score			Final Score (Total Weighted)	Rank
	Vegetative	Soil	Climate		
	0.5	0.3	0.2		
Compound NPK	4.5600	3.5000	3.2000	(4.560.5) + (3.500.3) + (3.20*0.2) =3.97	1
Single Fertilizer	4.1200	3.1000	3.0000	(4.120.5) + (3.100.3) + (3.00*0.2) =3.59	2
Organic + Dolomite	2.8000	4.8000	3.5000	(2.800.5) + (4.800.3) + (3.50*0.2) =3.54	3
No Fertilization	1.5000	1.2000	2.5000	(1.500.5) + (1.200.3) + (2.50*0.2) =1.61	4

The remaining alternatives demonstrate how differences among criterion scores affect the overall ranking. Single Fertilizer obtains vegetative, soil, and climate scores of 4.1200, 3.1000, and 3.0000, respectively, resulting in a final weighted score of 3.59 and Rank 2. Organic + Dolomite records scores of 2.8000, 4.8000, and 3.5000, yielding 3.54 and Rank 3, whereas No Fertilization receives scores of 1.5000, 1.2000, and 2.5000, producing a final score of 1.61 and Rank 4. Mustofa (2017) demonstrated how weighted decision models can distinguish fertilizer alternatives according to selected criteria, while Sitohang et al. (2026) further illustrate the effectiveness of web-based multicriteria systems for oil palm fertilizer determination. These results confirm that a relatively strong score in one dimension does not automatically determine the final position because the weighted total reflects the combined contribution of all criteria.

The output component consists of the final ranking of fertilization alternatives, which provides users with a structured basis for identifying the most appropriate action. Rather than displaying an isolated fertilizer recommendation, the system produces comparative rankings that allow the relative position of each alternative to be examined. Karim (2023) illustrates how ranked alternatives can strengthen decision consistency in computational decision-support applications, while Aelani et al. (2023) employed the Preference Selection Index to rank oil palm seedling alternatives. Similar ranking logic can be observed in the MOORA-based oil palm seedling decision model of Andika et al. (2023). In land-related decisions, Andreswari et al. (2023) and Monalisa and Wahid (2021) further demonstrate that systematic multicriteria ranking provides an explicit mechanism for comparing alternatives under different assessment variables.

System Advantages

The system possesses several operational advantages, including an attractive and user-friendly interface, centralized data management, calculation transparency, and weighting flexibility. The user-friendly interface reduces complexity for users who need to enter field conditions, while centralized data management supports systematic administration of criteria, matrices, and decision parameters. Calculation transparency allows the weighted contribution of each criterion to be examined directly, which is particularly important in AHP because decision priorities are derived from explicit comparative judgments. Lumbanraja and Lumbanraja (2024) identify structured decision-system design as an important mechanism for addressing oil palm plantation issues, and the web-based recommendation framework reported by Firmansyah et al. (2021) similarly demonstrates the practical value of centralized digital decision support. Sitohang et al. (2026) further reinforce the usefulness of web-based architectures for delivering fertilizer recommendations through a systematic computational process.

The flexibility of criterion weighting constitutes another important feature because the system permits the relative importance of decision variables to be represented numerically rather than assuming identical contributions for all factors. This characteristic is particularly relevant in agricultural decisions, where the importance of vegetative, soil, or climatic information may differ according to the structure of the problem being evaluated. AHP applications in oil palm research, including the work of Amiroh (2026), demonstrate how flexible priority structures can accommodate differences among biological and managerial criteria. The same multicriteria principle appears in seed-selection research by Fazliani et al. (2017), Aelani et al. (2023), and Andika et al. (2023), although the computational methods employed differ. Such flexibility strengthens the interpretability of the present system because the final ranking can be traced directly to the weighting configuration established within the model.

System Limitations

Despite its functional performance, the system retains several limitations, namely dependence on expert judgment, a simplified model that does not encompass all agronomic factors, and static data that are not integrated with real-time sensors. Dependence on expert judgment means that the quality of the final weighting remains closely associated with the quality and consistency of the evaluations used to construct the comparison matrix, an issue inherent in expert-based AHP applications described by Saaty et al. (2007). The simplified model also means that the decision structure represents only the variables incorporated into the current system and therefore cannot claim to capture the full complexity of oil palm agronomy. Pasaribu (2025), Andreswari et al. (2023), and Monalisa and Wahid (2021) demonstrate that land-related decisions may involve additional physical and environmental variables beyond those represented in the present model. The absence of real-time sensor integration further means that field conditions must remain dependent on manually entered, static observations rather than continuously updated measurements.

Taken collectively, the results demonstrate that the developed system successfully operationalizes an input-process-output mechanism in which qualitative field conditions are entered as input, transformed through assessment matrices, weighted scoring, and AHP aggregation as the process, and converted into ranked fertilizer alternatives as the output. The calculation example confirms a ranking of Compound NPK at 3.97, Single Fertilizer at 3.59, Organic + Dolomite at 3.54, and No Fertilization at 1.61, thereby making the computational pathway explicitly visible. The system's accessible interface, centralized management, transparent calculations, and flexible weighting strengthen its practical utility, although its dependence on expert judgment, simplified agronomic representation, and static data remain important constraints. Research ranging from fertilizer recommendation systems by Ayu and Mustofa (2021), As-Siddiqi et al. (2022), and Ginting and Uktoro (2018) to broader oil palm decision-support applications by Karim (2023), Lumbanraja and Lumbanraja (2024), and Khairani et al. (2019) collectively supports the relevance of structured multicriteria approaches for agricultural decision-making. Accordingly, the present system provides a logically organized and transparent foundation for oil palm fertilization recommendations while clearly retaining identifiable boundaries for further technological and agronomic refinement.

5. Conclusions

This study successfully designed and implemented a web-based Decision Support System (DSS) for oil palm fertilization recommendations using the *Analytical Hierarchy Process* (AHP) method. The system effectively integrates three main criteria plant vegetative condition, soil condition, and climatic condition as the basis for decision-making. The AHP method was successfully applied to structure the problem, determine criterion weights, and provide agronomically valid recommendations through case-study testing. The test results indicate that the system is capable of providing logical and beneficial recommendations for both nutrient-deficiency conditions and optimal land conditions. This system is expected to serve as an effective tool for farmers and plantation managers in improving fertilization efficiency and oil palm productivity.

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