RSF Conference Proceeding Series: Engineering and Technology Vol. 4 No. 1 (2025) https://doi.org/10.31098/cset.v4i1.1022

Research Paper

GIS-Based Spatial ID3 Analysis for Cocoa Land Suitability

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Received : Sept 27, 2025	Revised : Oct 6, 2025	Accepted : Oct 7, 2025	Online : October 14, 2025

Abstract
The decline in suitable cocoa land in Indonesia has led to reduced productivity and increased reliance on imports. This study addresses the gap for cocoa land suitability analysis by utilizing the Spatial ID3 algorithm, a method not previously applied in this region, to assess cocoa cultivation potential. A key contribution of this paper is the development of an interactive, web-based geographic information system tool that integrates spatial ID3 classification with mapping capabilities, providing decision-makers with a valuable tool for sustainable cocoa production and land management. The model used eight predictor variables, including soil, topography, and environmental factors, to generate 53 rules, which were then converted into interactive graphics. The tool consists of three main elements: an interactive Leaflet map for cocoa land suitability, detailed suitability classifications at the village level, and recommendations for five cocoa genotypes best suited to local conditions. Results indicate that the most significant area (231,018 ha) is classified as S3 (marginally suitable), followed by S2 (moderately suitable) with 16,443 ha. The unsuitable (N) land covers 49,253 ha, and the unclassified land accounts for 1,363 ha. No S1 (highly suitable) land was found, suggesting that ideal conditions may be absent in the region. This system equips decision-makers with evidence-based tools to prioritize sustainable cocoa production strategies, optimize land management in S2 zones, and implement adaptive interventions in S3 areas. Ultimately, this methodology supports sustainable agricultural development and aids Indonesia in its goal of cocoa self-sufficiency.

Keywords *cocoa, geographic information system, land suitability, spatial ID3*

INTRODUCTION

Cocoa (Theobroma cacao L.) is a significant crop and one of the major earners of foreign exchange worldwide, particularly in the tropical and subtropical regions (Terzungwe et al., n.d.). West Africa is the world's largest producer of cocoa, which is crucial for the economies of the countries in the region, the livelihoods of smallholder farmers, and the chocolate industry. Cocoa contains bioactive phytochemicals that are beneficial for health, making it more relevant not only for the chocolate and confectionery industry but also for the health and nutrition industry (Kongor et al., 2024).

Cocoa production in Indonesia has been declining in recent years. According to Badan Pusat Statistik (BPS), the import value of cocoa increased by 119% in January 2025 compared to December 2024, reaching US$304.41 million (Badan Pusat Statistik, 2025). Despite producing 667,300 tons of cocoa in 2022, over half of this amount — approximately 385,981 tons — was exported to other countries. While Indonesia remains one of the world's largest cocoa producers, it still relies on imports to meet the domestic demand of its industries. This indicates a gap in both the quantity and quality of cocoa produced within the country, signalling the need for improvements in cocoa cultivation and production practices.

One major cause is that the surface area of cocoa plantations is shrinking. It has declined by an average of 2.38% a year over the past decade. From 1.73 million hectares in 2014, the area decreased to 1.39 million hectares in 2023 (Pusat Data dan Sistem Informasi Pertanian, 2023). This decline is primarily due to the soil's unsuitability for cocoa cultivation (Djaenudin et al., 2011). In the quest for maximum yield, the land must possess specific characteristics similar to those of other types of crops (Nurkholis et al., 2020). When the selection of plants does not fit the soil condition, productivity decreases (Nurkholis & Sitanggang, 2020).

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For this, a land-suitability analysis is essential. Geographic information systems (GIS) are crucial to this process because they provide powerful analytics and visualizations for spatial data. Farmers and Policy-makers can make better decisions by identifying the best places to grow cocoa through GIS mapping (Adekunle & Chiekezie, 2024; Raihan, 2024). These tools help farmers manage their crops more effectively, enabling them to maximise their resources and use them more efficiently. In another way, GIS research also helps to show how crops are distributed over space, which is relevant for the future of cocoa production, where we want to promote sustainable activities. We need to move beyond that; to boost crop production in Indonesia, we must do more than increase production.

This study aims to develop a GIS-based cocoa land suitability system using the Spatial ID3 algorithm to support sustainable land-use planning in Indonesia. GIS research enhances understanding of agricultural spatial patterns, fostering sustainable practices essential for the future of cocoa production. Thus, strengthening cocoa production in Indonesia requires not only expanding cultivation but also integrating advanced spatial analysis. By aligning crop needs with land potential through GIS, it is possible to improve productivity, reduce reliance on imports, and secure Indonesia's role in the global cocoa industry.

LITERATURE REVIEW

Existing studies highlighted the crucial role of GIS in analyzing the viability of agriculture and the suitability of the land. Meanwhile, in the southern part of West Java, GIS mapping has been used to identify agribusiness opportunities in Growth Center zones, aiming to improve the quality of life for the local people (Maskun et al., 2021). Similarly, GIS and Analytic Hierarchy Process (AHP) were applied to analyze the landscape of smallholder oil palm estates in Kampar Regency, revealing that only a few individuals met the high suitability criteria. This approach combined GIS with AHP, providing a spatially explicit method for determining land suitability; however, it lacked further integration of predictive algorithms to enhance decision-making efficiency, a gap that this study aims to address.

The GIS and AHP were also employed in the analysis of the smallholder oil palm estate landscape in Kampar Regency. It was revealed that only a few individuals fulfilled high suitability criteria. This points to the need to enhance both the capacity and welfare of independent smallholders within the palm oil sector (Safriyana et al., 2021). In Yunnan, a MaxEnt model combined with AHP-GIS was used to evaluate the ecological suitability for Arabica coffee, with a focus on climatic factors and predicting the northward expansion of suitable regions under future climate scenarios (Zhang et al., 2021).

The result of this research builds upon the study on developing cocoa land suitability in Bogor Regency, utilising the Spatial ID3 algorithm. This approach differs from traditional methods, such as AHP-GIS or MaxEnt, in its ability to generate highly interpretable classification rules (Nurkholis et al., 2025). We applied these rules to local land characteristic data to generate a map indicating cocoa suitability, which can serve as a strategic framework for cocoa production. This paper extends the approach by developing a web-based GIS application using the Laravel framework and PostgreSQL with PostGIS. The model is not only analytical in nature but also provides farmers and policymakers with practical, easy-to-understand information that helps them make informed decisions, use the land more effectively, and manage agricultural resources in an environmentally beneficial manner.

RESEARCH METHOD

Study Area

This study focuses on Bogor Regency, which is strategically significant in West Java Province and plays a primary role within the agricultural sector. This regency comprises 40 sub-districts, covering 299,070 hectares, which indicates a significant agricultural potential in this region (BBSDLP, 2016b). Cibinong serves as the regency's administrative centre. The Indonesian Center for Agricultural Land Resources Research and Development (BBSDLP), as a government research institution under the Ministry of Agriculture, is tasked with mapping the suitability of land for various crops, including cocoa, rice, maize, soybeans, red chili, and elephant grass. BBSDLP has established its credibility over the years by conducting extensive research on land management, providing scientific recommendations for land use, and supporting the development of agricultural policies based on spatial data. With its expertise in land resource management and commitment to advancing sustainable agriculture, BBSDLP is a trusted authority in the field of land suitability assessments and agricultural land research (BBSDLP, 2016a).

The dataset is characterized by nine variables,, which are referred to to as two sub-groups: explanatory layers and target layers. The doctrine levels include eight soil properties and attributes related to the suitability of land for cocoa cultivation. These are: altitude, drainage, relief, base saturation (CEC), soil texture, soil pH, and mineral-soil depth. The target layer is the cocoa-land suitability data, derived from a field survey according to BBSDLP. Four land suitability classes have been defined in the land suitability classification system: S1 (high suitability), S2 (moderate suitability), S3 (marginal suitability), and N (not suitable).

Research Stage

This research builds upon previous studies that developed a spatial decision tree using spatial ID3 to generate a cocoa land suitability map. The two processes discussed in previous research are Stage 1, namely data preprocessing, and Stage 2, namely spatial ID3 classification, as well as Stage 3, which is partially evaluated, as shown in Figure 1. Meanwhile, the process that is the primary focus of this research is the final stage 3, namely the visualisation of the land suitability map in GIS, as shown in Figure 1.

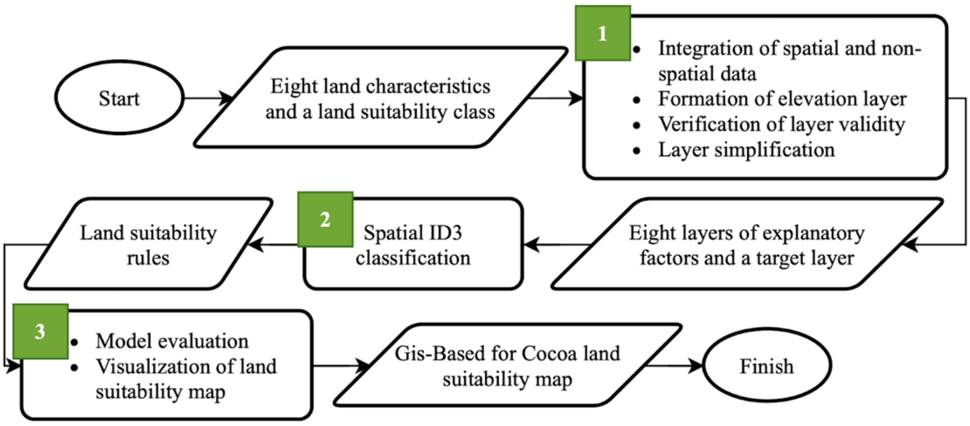


Figure 1. Research Stage

The visualization module of the spatial ID3 was developed to facilitate the generation of a comprehensive classification model that would be used to determine if a land is suitable for cocoa production. The system, with three core integrated functions acquired within the drive to promote cocoa cultivation, includes an interactive map that demonstrates the potential of each parcel of land for cocoa cultivation, the amount of information required for the land's potential, and the suggested cocoa varieties that can be planted. Some key technologies support it:

1. Competent backend (Laravel, Symfony, etc.) to handle database and interface integration, secure routing, and rapid data processing, ensuring everything is neat, tidy, and functional.
2. Bootstrap is a frontend framework that ensures responsive and dynamic interfaces with the help of pre-built components and a grid system. This ensures the interfaces are working on all devices.
3. Leaflet.js is a lightweight JavaScript library that enables the creation of interactive web maps. This module on the standing suitability of cocoa land clearly demonstrates that suitable cocoa land is in short supply, which facilitates interaction with a spatial project (Sitanggang et al., 2020).
4. PostgreSQL, in combination with its PostGIS extension, is an excellent database for spatial data. This enables to perform complex geospatial queries and conduct various types of analysis and visualisation.

These interrelated elements form a powerful web-based GIS system, which not only visualises data but also provides valuable information for enhancing cocoa cultivation. There are several key stages in the development of the system:

1. Creating an Interactive Cocoa Suitability Map: Utilising GIS and Leaflet.js to Display Cocoa Land Suitability on an Interactive Interface. Real-time presentation of land classes (S1, S2, S3, and N) for the suitability: stakeholders can observe how the land evolves. The tools utilize spatial ID3 rules based on precedents (Nurkholis et al., 2025) to simplify the identification and understanding of suitable areas for cocoa development.
2. Detailed Land Suitability Information: The system provides detailed information on each land class, including its administrative boundaries (village), geographical location (latitude and longitude), and total land area. This labelled data allowed users not just to see, but also to measure and locate exactly where regions were labelled as S1, S2, S3, or N.
3. Recommendation of the Best Cocoa Varieties: A suggestion model will be developed to help farmers and other interested users identify the most suitable cocoa variety for their specific land/soil conditions. These recommendations, tailored for use in context, link classification output to real-world potential, thereby improving yield and quality and supporting long-term, sustainable cocoa production.

FINDINGS AND DISCUSSION

We applied the Spatial ID3 algorithm to information on cocoa cultivation to create a spatial decision tree model for determining whether land is suitable. This approach consisted of eight explanatory layers that examined key environmental and agricultural factors, as well as a target layer that assessed the cocoa-friendliness of the region. The development and implementation assistance were performed using Laravel, Leaflet, and PostgreSQL technology stack. Laravel handled input/output of data with the user, Leaflet could display spatial data interactively, and PostgreSQL with PostGIS handled the tasks associated with managing and manipulating geospatial data. Combining these technologies makes the analysis easier and more accessible to everyone, enabling people to make informed decisions about how to utilize the land. This research offers valuable insights into sustainable cocoa production in Bogor, utilizing spatial algorithms on web-based tools. In Table 1 (Nurkholis et al., 2025), eight attributes can be divided into an explanatory and a target layer.

Table 1. Attribute Layer

Layer name	Class
Explanatory Layer	
Elevation (msal)	<100, 100-600, 601-700, 701-1600, 1601-1750, 1751-2000, >2000
Drainage	Swift, good, slightly hamper, hamper
Relief (%)	Flat (0), slightly flat (1–3), slightly slope (4–8), slope (9–15), slightly steep (16–25), steep (26–40), very steep (>40)
Base saturation (%)	Low (20–35), medium (36–60), high (61–80), very high (>80)
Cation exchange capacity (cmol)	Low (5–16), medium (17–24), high (24–40), very high (>40)
Soil texture	Very smooth, smooth, slightly smooth, medium, slightly rude, rude
Soil pH (°)	Acid (4.5–5.5), slightly acid (5.6–6.5), neutral (6.6–7.5)
Soil mineral depth (cm)	Very shallow (<25), shallow (25–50), medium (51-75), deep (76–100), very deep (>100)
Target layer	
Land suitability class of cocoa	S2 (moderately suitable), S3 (marginally suitable), and N (not suitable).

This research builds on previous work in GIS-based agricultural land suitability analysis, such as Maskun et al. (2021) and Safriyana et al. (2021). While these studies have successfully employed GIS to map land suitability for various crops, they primarily focused on traditional static maps or non-interactive platforms. In contrast, the novelty of this research lies in its integration of spatial decision trees with real-time interactive mapping tools. Nurkholis et al. (2025) laid the groundwork for cocoa land suitability modeling; however, the use of web-based GIS and the incorporation of Laravel and PostGIS into this study provide a more accessible and user-friendly platform. In a previous study, Spatial ID3 generated 53 rules. Here are five of them (Nurkholis et al., 2025):

1. IF Relief is Slope AND Soil Texture is Rude THEN Class is S3, Marginally Suitable
2. IF Relief is Slope AND Soil Texture is Slightly Smooth THEN Class is S3, Marginally Suitable
3. IF Relief is Very Steep AND Soil Texture is Slightly Smooth THEN Class is N, Not Suitable
4. IF Relief is Flat THEN Class is S3, Marginally Suitable
5. IF Relief is Slightly Flat AND Base Saturation is very high THEN Class is S2, Moderately Suitable

Here is an example of a menu display in a GIS application, based on the 53 rules that were made and turned into an interactive spatial map:

1. Dashboard: The dashboard menu is the overview of the cocoa land suitability analysis in Bogor Regency, as shown in Figure 2. Land classes spread out from Spatial ID3 results As shown in the line and pie charts, the land classes are spread for the Spatial ID3 results like below: S1 (Highly Suitable) = 0 ha, S2 (Moderately Suitable) = 16,443 ha, S3 (Marginally Suitable) = 231,018 ha, N (Not Suitable) = 49,253 ha, Unclassified = 1,363 ha. The prevalence of S3 suggests that there is no significant optimal amount of land, but S2 indicates that some improvement can be achieved through good management.

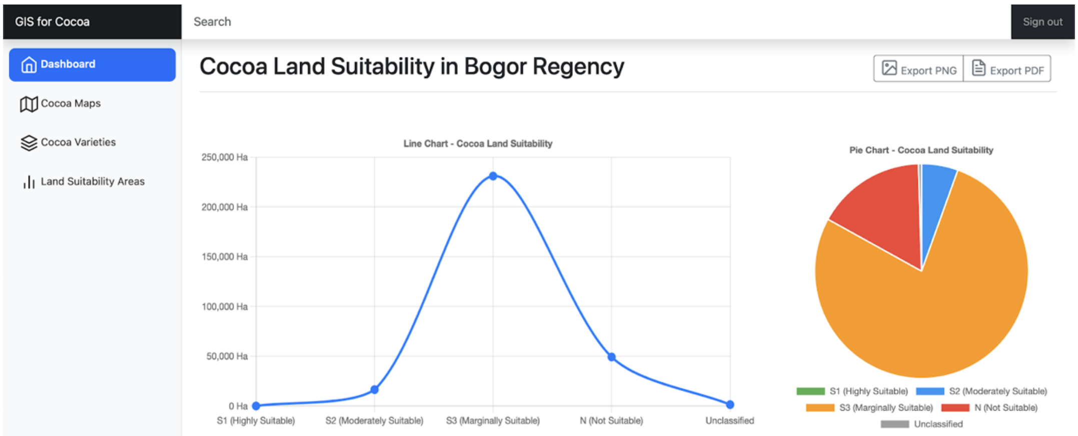


Figure 2. Dashboard Menu

2. Land Suitability Map for S2 Class: The Cocoa Map menu displays an interactive Leaflet.js map, allowing exploration of the area down to village level in Bogor Regency (Figure 3). Land suitability class, coordinates, and area of each soil pop-up in the different locations. It has a color legend — green (S2), orange (S3), red (N), and gray (Unclassified) — which helps. This map validates the Dashboard, such as for geographic analysis. For example, in Banyu Wangi Village, Cigudeg, there are more than 1,200 hectares of S2 class land, where cocoa can thrive if cultivated properly. This sort of information can help stakeholders determine which areas are most likely to be productive, even if biophysical conditions are not excellent.

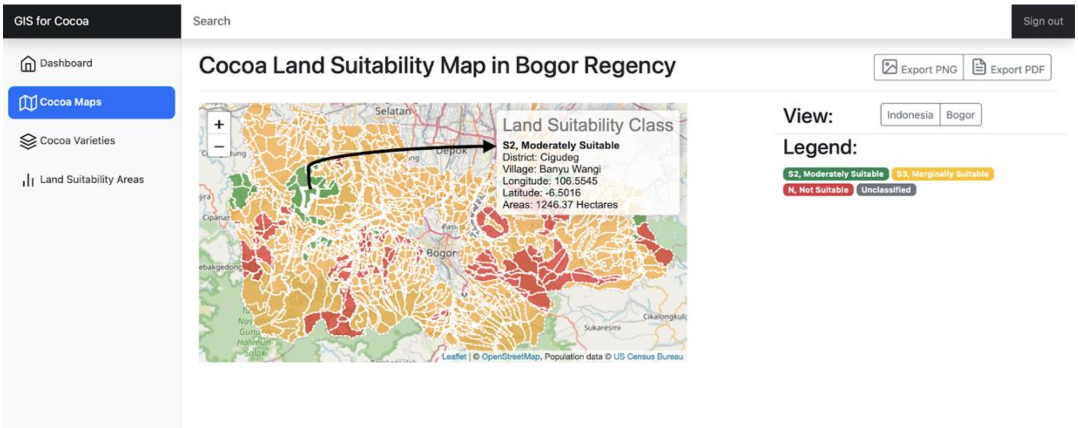


Figure 3. Cocoa Map for S2

3. Land Suitability Map for S3 Class: The S3 class represents the most frequent type of cocoa land in Bogor Regency, as shown in orange in the majority of the district. Sukamulya Village of Rumpin Subdistrict is found to contain more than 2,000 hectares of S3 land, as indicated in Figure 4. In these regions, marginal land with limited suitability for cocoa production can be utilized, with improvements such as enhanced drainage, improved soil fertility management, and optimized S3 distribution. In this manner, S3 demonstrates the need for more adaptive strategies to maximize resource utilization, despite physical limits. That information is vital for aiding development projects on land that is not as good as S2 class.

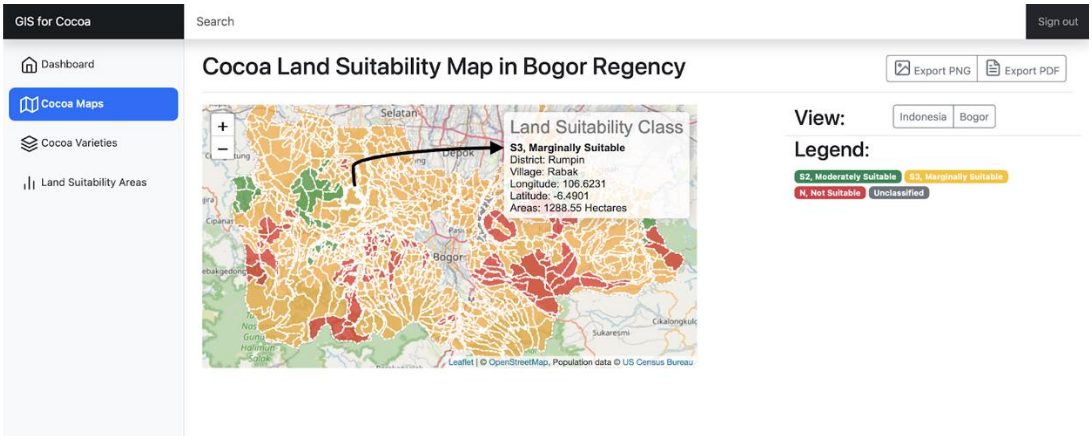


Figure 4. Cocoa Map for S3

4. Land Suitability Map for N Class: Shown in red, this category is where you cannot do cocoa. Figure 5, for example, features Banyuasih Village in Cigudeg District, which has some 800 hectares classified as N. The constraints are predominantly biophysical, i.e., steep slopes and rocky soils that neither technology nor management can address well. The existence of N class provides an early warning signal to policy- and decision-makers that investments should not be directed to these areas.

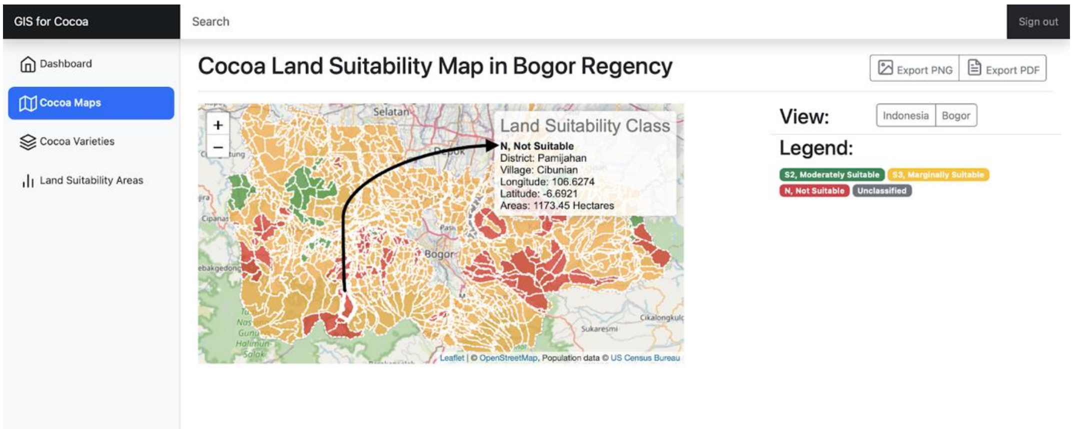


Figure 5. Cocoa map for N

5. Land Suitability Map for Unclassified Class - The Spatial ID3 model cannot predict these areas, so we do not know if they are suitable (S1, S2, S3, or N). For example, Figure 6 shows that 217.19 hectares of land in Leuwinutug Village, Citeureup District, are not classified. The presence of this class highlights the model's limitations in accurately capturing specific patterns from the input data. As a result, these areas require either additional field testing or adjustments to the analysis parameters to achieve more accurate results.

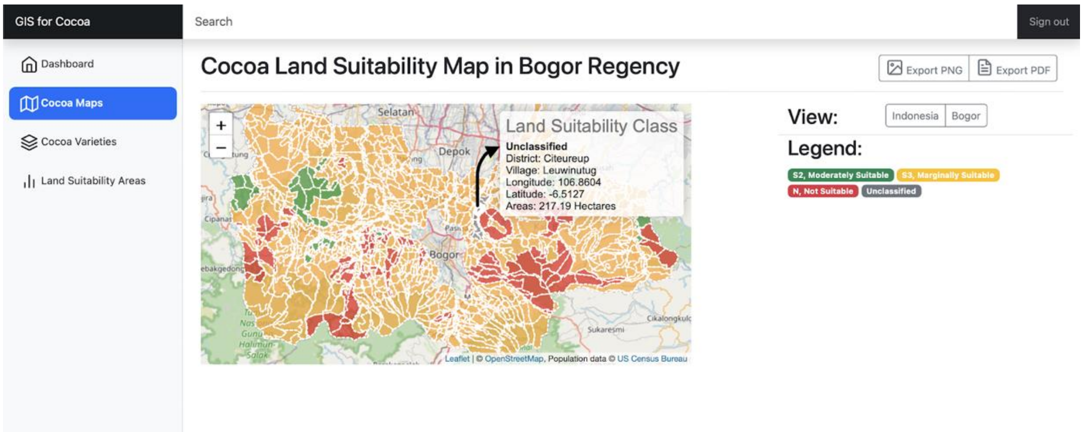
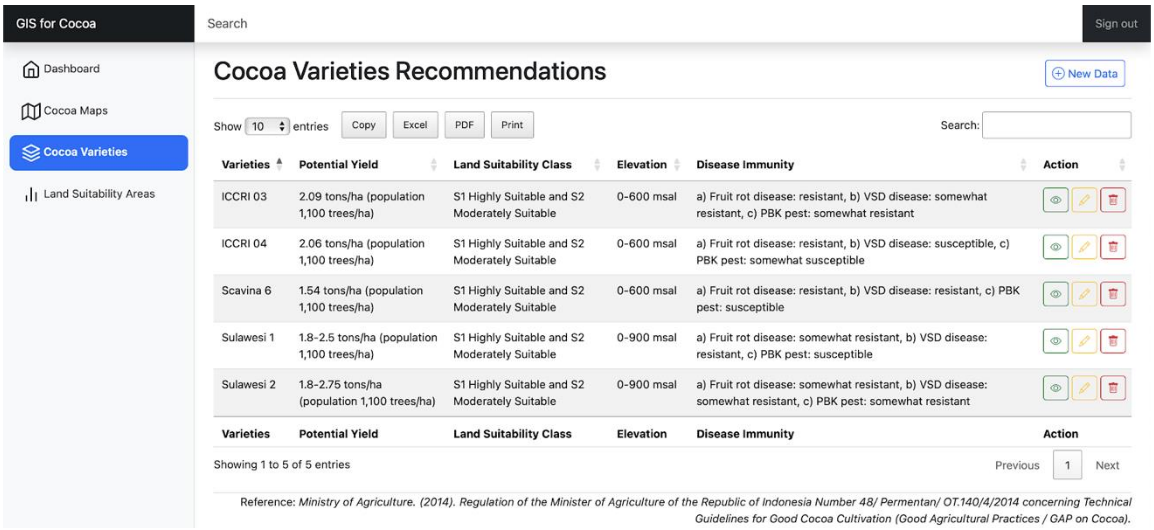


Figure 6. Cocoa map for Unclassified

6. Recommended cocoa varieties: This menu provides helpful guidance by pairing the appropriate cocoa varieties with the corresponding land types, as illustrated in Figure 7. The latter presents the top five varieties: ICCRI 03, ICCRI 04, Scavina 6, Sulawesi 1, and Sulawesi 2. It also provides details on their yield potential, ideal elevation, and degree of resistance to major diseases such as fruit rot, VSD, and PBK. This information enables users not only to determine where cocoa can be cultivated but also to identify which varieties are the most adaptable. For instance, Sulawesi 2 shows the highest productivity, and ICCRI 03 exhibits better resistance to diseases. This is how scientific analysis meets real-world use, as the recommendation module will assist people in making informed, long-term decisions about how to grow things.



Varieties	Potential Yield	Land Suitability Class	Elevation	Disease Immunity	Action
ICCRI 03	2.09 tons/ha (population 1,100 trees/ha)	S1 Highly Suitable and S2 Moderately Suitable	0-600 msal	a) Fruit rot disease: resistant, b) VSD disease: somewhat resistant, c) PBK pest: somewhat resistant	
ICCRI 04	2.06 tons/ha (population 1,100 trees/ha)	S1 Highly Suitable and S2 Moderately Suitable	0-600 msal	a) Fruit rot disease: resistant, b) VSD disease: susceptible, c) PBK pest: somewhat susceptible	
Scavina 6	1.54 tons/ha (population 1,100 trees/ha)	S1 Highly Suitable and S2 Moderately Suitable	0-600 msal	a) Fruit rot disease: resistant, b) VSD disease: resistant, c) PBK pest: susceptible	
Sulawesi 1	1.8-2.5 tons/ha (population 1,100 trees/ha)	S1 Highly Suitable and S2 Moderately Suitable	0-900 msal	a) Fruit rot disease: somewhat resistant, b) VSD disease: resistant, c) PBK pest: susceptible	
Sulawesi 2	1.8-2.75 tons/ha (population 1,100 trees/ha)	S1 Highly Suitable and S2 Moderately Suitable	0-900 msal	a) Fruit rot disease: somewhat resistant, b) VSD disease: somewhat resistant, c) PBK pest: somewhat resistant	
Varieties	Potential Yield	Land Suitability Class	Elevation	Disease Immunity	Action

Figure 7. Cocoa Varieties Recommendation Menu

7. Land Suitability Areas: These are Spatial ID3 model classification area results, presented in a tabular format for easy readability (Figure 8). For each group (N, S3, S2, Unclassified), data is available on constraints to cultivation, areas, and villages with the largest class. In the example, Megamendung has the largest area of inappropriate land (N). In contrast, Malasari has the largest S3 area, and Singasari has the S2 potential, indicating that some space remains to be managed.

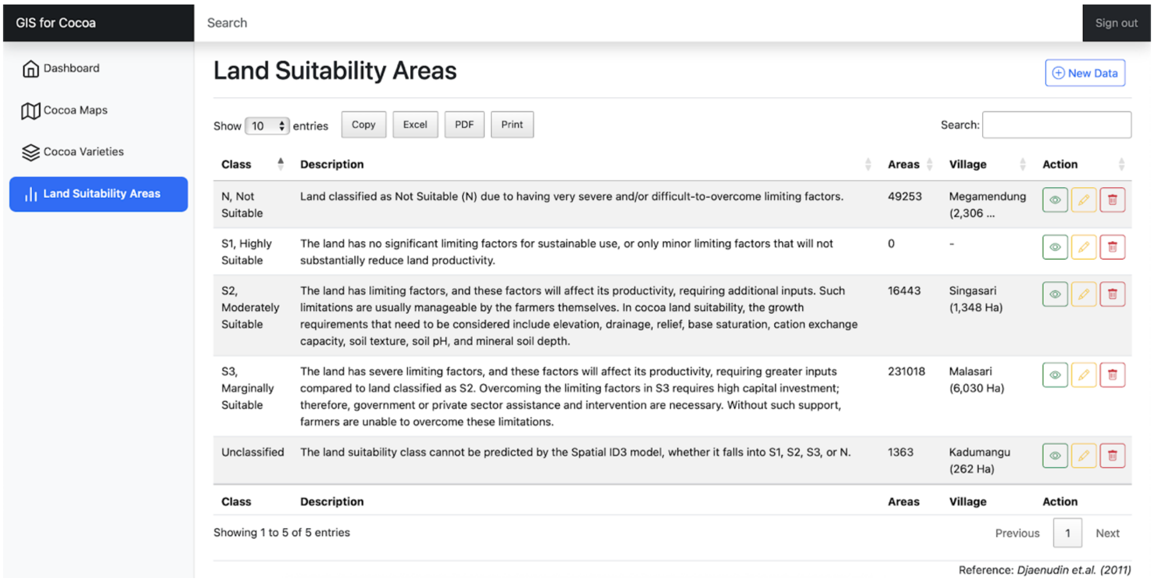


Figure 8. Land Suitability Areas Menu

The development of GIS for cocoa land suitability in this study aims to provide an interactive mapping platform that is accessible to the public. This system could significantly contribute to Indonesia's goal of achieving cocoa self-sufficiency by 2033. One of the key strategies to reach this goal is expanding the land dedicated to cocoa cultivation. The GIS application developed in this study is designed to assist in identifying the most suitable land for cocoa farming, particularly in Bogor Regency. By offering detailed insights into land suitability classes, the system aims to minimize errors in land selection, which is crucial for maximizing cocoa production.

A significant advantage of this system is its ability to provide specific land suitability information down to the village level. The findings from this study also reveal that a single village can contain more than one land suitability class. To address this, the developed system includes the ability to present detailed data on the area of each land suitability class within a village. As a result, users can gain precise information about the distribution of land suitability classes (S1, S2, and S3) within each village. For instance, Figure 2 illustrates that Garabak Data village contains two distinct land suitability classes: S1 (represented by the blue legend) and S2 (represented by the green legend). In this case, S1 spans an area of 3,774.49 hectares. The system is further enhanced by the inclusion of longitude and latitude information, allowing users to pinpoint the exact location of suitable land with greater accuracy.

This GIS-based approach aims to support sustainable agricultural practices by providing farmers, policymakers, and stakeholders with detailed, accessible, and up-to-date information on land suitability for cocoa cultivation. By making this information readily available, the system empowers users to make informed decisions that can enhance agricultural productivity and contribute to the country's long-term goal of self-sufficiency.

CONCLUSIONS

This study employed the Spatial ID3 algorithm to assess cocoa land suitability in Bogor Regency and integrated the results into a web-based GIS system. The platform was developed using Laravel for backend logic, Leaflet.js for interactive mapping, and PostgreSQL with PostGIS extension for spatial data management. It integrates visualisation of suitability classes, village-level information, and cocoa variety recommendations, providing a practical decision-support tool. The results show that S3 (marginally suitable) dominates, covering more than 231,000 hectares, while S2 (moderately suitable) spans approximately 16,400 hectares, presenting opportunities for productivity improvement. No S1 (highly suitable) land was identified, and the presence of N and Unclassified areas highlights both biophysical constraints and model limitations. By combining algorithmic rules with interactive GIS, the system enhances accessibility to spatial data. It supports adaptive strategies for sustainable cocoa development, contributing to broader sustainable agricultural practices and food security.

LIMITATIONS & FURTHER RESEARCH

The presence of N and Unclassified areas highlights both biophysical constraints and model limitations. Future work should incorporate weather and climate datasets, such as rainfall and temperature, to capture dynamic conditions more accurately. Field validation and model refinement are also essential. This study contributes to academic research by advancing spatial land suitability modelling techniques and demonstrating the integration of GIS with decision-support systems, which could be applied to other agricultural sectors and regions. The framework and technology stack can further be extended to different crops and regions, broadening its role as a spatial decision-support system in sustainable agriculture.

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