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Evaluation of Land Suitability for Cocoa (*Theobroma cacao* L.) Cultivation in Wotu Subdistrict, Luwu Timur Regency

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ABSTACT

This study aims to evaluate the actual and potential land suitability for cocoa (*Theobroma cacao* L.) cultivation in Wotu District, East Luwu Regency, and identify its limiting factors. Conducted from April to July 2022, the research involved field surveys and soil analysis at the Soil Science and Environmental Conservation Laboratory, Faculty of Agriculture, Universitas muslim Indonesian, Makassar. Data used included rainfall records, administrative maps, land cover maps, soil type maps, and slope maps (1:50.000 scale). Using the FAO method with a limiting factor approach, results showed that actual land suitability in Land Unit 2 (36 and 37) is marginally suitable (S3), while Representative Land Unit 2 (12, 15, and 07) is not suitable (N1). Land Unit 3 (16, 25, 17) is also marginally suitable (S3). Potential suitability for Land Units 1, 2, and 3 increases to moderately suitable (S2). Limiting factors include water availability, nutrient retention, and rooting depth.

INTRODUCTION

Cocoa (*Theobroma cacao* L.) in Wotu Subdistrict, Luwu Timur Regency, is one of the cocoa-producing areas in Indonesia. Cocoa plays an important role in the economy, both as a source of income for farmers and as an export commodity that contributes to the country's foreign exchange. In recent years, global demand for cocoa products has continued to increase, making the development of sustainable cocoa cultivation very important. However, the success of cocoa cultivation is greatly influenced by land suitability factors, which include physical, chemical, and biological soil aspects, as well as climatic conditions that support plant growth. (Indla et al., 2024).

Wotu Subdistrict has significant potential for cocoa development, however, the challenges faced in cocoa cultivation in this area cannot be ignored. Previous studies have shown that the characteristics of the soil and climate in the region can affect cocoa productivity. Soil conditions are mostly Ultisol, having diverse physical and chemical properties, which can affect land suitability for cocoa plants (Ali et al., 2019; Hati et al., 2023). Besides that, climatic factors such as rainfall and temperature also play an important role in determining the suitability of land for this plant (Du et al., 2022).

Although there have been several studies on land suitability for cocoa in other regions, specific research on Wotu Subdistrict is still limited. Existing research tends to be general and does not consider unique local characteristics. Therefore, it is important to conduct a more in-depth evaluation using an integrated approach, such as spatial analysis using Geographic Information Systems (GIS), to get a more accurate picture of land suitability in this area (Odiwe et al., 2012).

Therefore, the results of this research are expected to provide valuable information for the development of sustainable cocoa cultivation in Wotu Subdistrict. Existing research is lacking in studies that integrate land suitability analysis with local climate data and soil characteristics comprehensively in Wotu Subdistrict. This study aims to fill this gap by conducting an evaluation of land suitability for cocoa plants, and providing data-based recommendations for more effective and sustainable cocoa farming development. Thus, this research will not only contribute to scientific knowledge, but also provide direct

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benefits to cocoa farmers in Wotu Subdistrict in improving their productivity and income (Agwupuye et al., 2019).

MATERIALS AND METHODS

This research was conducted from April to July 2022 in Wotu Subdistrict. Soil analysis was carried out at the Soil Science and Environmental Conservation Laboratory, Faculty of Agriculture, Universitas Muslim Indonesia. Materials used in this study included rainfall data for the past five years obtained from the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG), administrative maps, land cover maps, soil type maps, and slope maps with a scale of 1:50.000. Equipment used included measuring tapes, plastic bags, machetes, cameras, soil borers, labels, and stationery.

Research employed a survey method to determine land suitability class based on the FAO (1976) methodology with an emphasis on limiting factors and land characteristics. The research was conducted in four stages as follows:

1. **Data Collection Stage**

   Data collection involved gathering information on land resources from various relevant agencies, including annual average temperature data, water availability (average rainfall for the past five years obtained from the Indonesian Agency for Meteorology, Climatology, and Geophysics - BMKG), administrative maps, land use maps, soil type maps, and slope maps.

2. **Implementation Stage**

   A composite map, or land unit map, was generated by overlaying land use, soil type, and slope maps at a 1:50.000 scale. The resulting map was used to determine the spatial coordinates for soil sampling.

   Field observations focused on vegetation cover, soil drainage profile, effective soil depth, flood susceptibility, slope angle, sulfidic depth, and the presence of surface and subsurface rock constraints.

3. **In-situ Sampling**

   Soil samples were collected from each land unit using a soil auger to a depth of 100 cm for subsequent physical and chemical analyses.

Table 1. Soil Types and Land Units in Wotu Subdistrict, Luwu Timur Regency

Soil Type	Land Unit
Entisol	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15
Inseptisol	16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34
Oxisol	35,36,37

4. **Soil Sample Analysis**

   Soil samples required for the analysis of physical and chemical soil properties were first air-dried. The soil properties analyzed were tailored to the information needed for land suitability assessment based on the FAO methodology.

Table 2. Parameters and Measurement Methods for Biophysical Land Analysis in Wotu Subdistrict, Luwu Timur Regency

No.	Variable	Method
1.	Soil Texture	Hydrometer
2.	Cation Exchange Capa (CEC)	NH_4OAc pH 7.0 Extract
3.	Soil pH	pH meter electrode glass
4.	Total Nitrogen	Kjehdahl
5.	Phosphorus Pentoxide (P_2O_5)	Olsen
6.	Potassium Oxide (K_2O)	HCl 25% Extract
7.	Salinity	1:25 Extract
8.	C-Organic	Walkley and Black

5. Interpretation of Data for Land Suitability Classification

Land suitability class determination using land characteristics through evaluation, namely annual average temperature, dry months, annual average rainfall (mm), drainage class, soil texture, effective soil depth (cm), Cation Exchange Capacity (CEC), soil pH, total N (%), available P_2O_5, available K_2O, slope gradient (%), erosion hazard, surface rock and rock outcrops. Then it is linked to the determining factors of land suitability class for cocoa plants. This land suitability class determination is based on the FAO method using a limiting factor approach.

RESULTS AND DISCUSSION

1. Limiting Factor

Limiting factors affecting actual land suitability and improvement efforts that can be done to increase land potential. This includes the identification of limiting factors, the types of recommended improvement efforts, and the potential results that can be achieved after the improvement is done.

Table 1. Limiting Factors in Actual Land Suitability

Land Unit	Actual Land	Limiting Factors
7	S3wfn	- Rainfall - Soil pH - P_20_5 - K_20
12	S3wfn	- Rainfall - Soil pH - P_20_5 - K_20
15	S3wfn	- Rainfall - Soil pH - P_2O_5 - K_2O
16	N1f	- Soil pH
17	N1f	- Soil pH
25	N1f	- Soil pH
36	S3wfn	- Rainfall - CEC (Cation Exchange Capacity) - Soil pH - Total N - K_2O
37	S3wfn	- Rainfall - CEC (Cation Exchange Capacity) - Soil pH - Total N - K_2O

Note: S1: Very suitable, f: Nutrient retention, S2: Fairly suitable, r: Root medium, S3: Marginally suitable, n: Nutrient availability, N: Unsuitable, w: Water availability.

The actual and potential land suitability of several land units is very important in the context of agricultural development, especially for cacao (*Theobroma cacao* L.) cultivation. In this study, the analyzed land units include units 7, 12, 15, 16, 17, 25, 36, and 37, with actual land classifications such as S3wfn and N1f. Several major limiting factors were found, including rainfall, soil pH, nutrient content such as P_2O_5, K_2O, total nitrogen (total N), and cation exchange capacity (CEC) (Aini, 2024).

Limiting factors in the actual land suitability for cacao cultivation encompass several important aspects that affect crop productivity. Insufficient rainfall is one of the primary factors, especially in regions with low water availability. This condition can hinder the growth of cacao plants, which require adequate water supply to support photosynthesis and metabolism. Other limiting factors in cacao cultivation include increasing water availability through the implementation of efficient irrigation systems and liming to neutralize acidic soil pH, thereby creating optimal conditions for cacao plant growth (Sariani et al., 2023).

Acidic soil conditions with low pH can pose a significant challenge to the growth of cacao plants (*Theobroma cacao* L.). Low pH soils not only reduce the availability of essential nutrients such as phosphorus (P), but can also increase the toxicity of heavy metals like aluminum, which is detrimental to plant roots (Faradilla et al., 2023; Pane et al., 2022). Phosphorus is crucial for root development, while potassium (K) plays a role in seed filling and plant resistance to environmental stress. Additionally, nitrogen (N) is a primary component for vegetative plant growth (Syamsia, 2023; Yusnaweti et al., 2023). Research indicates that soils with low pH are often bound with Al-P and Fe-P compounds, resulting in decreased phosphorus availability for plants (Faustina et al., 2024).

Low levels of nutrients, such as P2O5, K2O, and total nitrogen, are also limiting factors that hinder the growth and production of cacao. Research shows that the use of organic fertilizers, such as bat guano and compost, can increase the availability of nutrients in the soil, thus supporting plant growth (Marian & Tuhuteru, 2019; Naim, 2022). In addition, the application of arbuscular mycorrhizal fungi (AMF) can enhance nutrient uptake by plant roots, thereby mitigating the negative impacts of acidic soils (Nurlaili et al., 2021; Pattirane et al., 2022).

Another critical factor is the low cation exchange capacity (CEC) of the soil. Low CEC indicates the soil's limited ability to retain and exchange nutrients with plant roots, resulting in nutrient deficiencies in cacao plants, even with fertilization (Setiawati et al., 2023). Research indicates that the addition of organic matter can increase the soil's cation exchange capacity (CEC), which in turn enhances nutrient availability for plants (Fahyu et al., 2020). Overall, these limiting factors have resulted in several land units being categorized as unsuitable (N) or marginally suitable (S3), necessitating improvement efforts to enhance land productivity and support optimal cacao plant growth (Syamsia, 2023; Yusnaweti et al., 2023).

2. Improvement Efforts

The table below outlines the specific improvement measures that can be implemented.

Table 2. Tailored improvement measures for each land unit.

Land Unit	Improvement Effots		Improvement Types	Potential Land
	Medium (+)	High (++)		
7	-	++	Irrigation	S2r
	-	++	Liming	
	-	++	Fertilization	
	-	++	Fertilization	
12	-	++	Irrigation	S2r
	-	++	Liming	
	-	++	Fertilization	
	-	++	Fertilization	
15	-	++	Irrigation	S2r
	-	++	Liming	
	-	++	Fertilization	
	-	++	Fertilization	
16	-	++	Liming	S2r
17	-	++	Liming	S2r
25	-	++	Liming	S2r
36	-	++	Irrigation	S2r

Land Unit	Improvement Effots		Improvement Types	Potential Land
	Medium (+)	High (++)		
	-	++	Fertilization	
	-	++	Liming	
	-	++	Fertilization	
	-	++	Fertilization	
37	-	++	Irrigation	S2r
	-	++	Fertilization	
	-	++	Liming	
	-	++	Fertilization	
	-	++	Fertilization	

To address limiting factors in the actual suitability of land for cocoa cultivation, various improvements can be implemented. One crucial step is the application of an efficient irrigation system, especially in areas with low rainfall. A well-designed irrigation system can ensure adequate water availability for the plants throughout the growing season, particularly in regions with prolonged dry seasons or uneven rainfall distribution (Aini, 2024). Research has shown that the use of drip irrigation technology can significantly improve water use efficiency and enhance plant growth (Fahrudin et al., 2023; Tenggara et al., 2022).

Liming is also a strategic step to improve soils with low pH. The application of agricultural lime, such as dolomite or calcite, can neutralize soil acidity, increase the availability of nutrients like phosphorus, and reduce the toxicity of heavy metals such as aluminum and manganese (Marasabessy et al., 2023). In addition, liming contributes to increased soil microbial activity, which supports soil fertility (Yuniati et al., 2024). Studies have found that adding lime can make land better for growing cocoa, moving it from a not very good category (S3) to a good enough category (S2). (Aini, 2024).

Fertilizing is a very important way to add more nutrients to the soil. We need to give the right amount of fertilizer with phosphorus (P_2O_5), potassium (K_2O), and nitrogen to cocoa plants. Phosphorus helps the roots grow strong, potassium helps the cocoa beans grow well, and nitrogen helps the plant grow leaves and stems (Pattirane et al., 2022). Studies have found that giving cocoa plants the right fertilizer can make them produce more and better cocoa beans (Managanta, 2020).

To fix the problem of low CEC, we can add organic things like compost, green manure, or biochar to the soil. These organic things help the soil hold onto nutrients better and let plants take up those nutrients through their roots (Fahyu et al., 2020; Setiawati et al., 2023). Adding things like zeolites or special types of clay can also make the soil healthier by improving its chemistry and increasing its ability to hold onto nutrients (Yuniati et al., 2024).

Using good irrigation, adding lime, giving the right fertilizer, and adding organic materials can help make land better for growing cocoa. This can change the land from being not good or only a little good to being good enough or even very good for cocoa. We can do many things to improve the land for cocoa, like using better ways to water the plants and adding lime to make the soil less acidic, so the cocoa plants can grow well (Sariani et al., 2023). Also, when we give the right amount of fertilizer at the right time, it helps to add important nutrients like phosphorus (P_2O_5), potassium (K_2O), and nitrogen to the soil. These nutrients are really important for cocoa plants to grow well. (Hazriani & Krisnohadi, 2021). By doing these things together, like using irrigation, adding lime, and giving the right fertilizer, we can help cocoa plants produce more cocoa beans over a long time (Sunil et al., 2023).

Checking how good the land is for growing cocoa and trying to make it better are very important to get more cocoa from farms in Wotu. Using technology from space to watch over the farms can help us use the land and other resources better (Singh et al., 2021). If we figure out what is stopping the farms from doing well and do something about it, we can grow more food and help the farmers make more money (Ardhianto et al., 2021; Wahyu et al., 2023).

CONCLUSIONS

Land suitability evaluation for cocoa cultivation has revealed several major limiting factors, including low rainfall, acidic soil pH, low nutrient content (P_2O_5, K_2O, total nitrogen), and low cation exchange capacity (CEC). These factors have resulted in many land units being classified as not suitable (N) or marginally suitable (S3). Improvement efforts, such as the implementation of efficient irrigation, liming to neutralize soil pH, balanced fertilization, and the addition of organic matter, can enhance soil quality and cocoa productivity. The combination of these measures can transform unsuitable land into moderately suitable (S2) or even highly suitable (S1) categories.

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