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Quality Index and Land Suitability for Cocoa Plants in Bandar District, Pacitan Regency, East Java

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ABSTRACT

Cocoa (Theobroma cacao L.) is an Indonesian plantation crop that has potential for agricultural development. The goal of this study was to evaluate the relationship between soil quality index (SQI) and land suitability in Bandar District, Pacitan Regency, East Java for cocoa plants, as well as to identify the limiting variables and inputs used to boost cocoa plant production. This study used a descriptive survey and purposive soil sampling methods. Land Map Units (LMUs) were created by overlaying maps of soil type, land use, slope, and rainfall. To generate Principal Component (PC) data, SQI calculations utilized the expert judgement and Principal Component Analysis (PCA) methodologies. PC was utilized to select the Minimum Data Set (MDS); the PC chosen as the MDS had an eigenvalue near to 1 or −1 or a p-value less than 0.05 or 5%, and the SQI value was determined. Land suitability was assessed using the FAO land evaluation framework (1976). The study site SQI ranged from very low (1.76) to low (3.14), with a land suitability class of S3 (marginally suitable). association study revealed a substantial positive association between SQI and land suitability (r = 0.688, p = 0.000). The correlation test's limiting indicator, P, was available. Liming, adding organic materials, and fertilization are all recommended improvements.

Keywords: cocoa, land suitability evaluation, soil quality index

INTRODUCTION

Cocoa cultivation can promote the development of agro-industrial areas, and it is the third largest provider of foreign exchange in the plantation subsector, following palm oil and rubber. This is demonstrated by the rising cost of cocoa in both domestic and international markets. According to the International Cacao Organization (2009), global cocoa demand increases by approximately 2−4% per year. Despite increased plantation area and cocoa production, cocoa production has been insufficient to meet market demand. Pacitan Regency's cocoa plantation area in 2018 was 5,559 hectares, with a cocoa production of 399.43 tons. In 2019, the cocoa plantation area was 5,694 hectares, and the cocoa production was 399.63 tons (BPS 2020).

Soil and land information are required for crop commodity planting to ensure success and reduce the chance of failure. Several reasons contribute to Bandar District's low cocoa productivity, including pest and disease infestations, improper handling, inappropriate land use and land conditions, and inappropriate cocoa cultivation practices. Crop commodity development requires an understanding of land conditions and limiting factors. This can be evaluated by evaluating land suitability and analyzing the Soil Quality Index (SQI). The FAO uses land suitability evaluations to provide information on the potential profitability of crop commodities businesses. Proper land use guidelines based on land suitability evaluation can be utilized as a reference to increase crop production (Ma'sum *et al.* 2020). Land suitability evaluation is an assessment of a plot of land's appropriateness for cultivating a certain commodity based on biophysical parameters, resulting in land suitability levels of highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and unsuitable (N). This classification is based on the elements that limit a plant's growth.

The SQI can also be used to predict whether a commodity will succeed or fail. SQI classification categories include very good, good, moderate, low, and very low. Classification is based on potential and limiting variables. Soil quality includes physiography (morphological characteristics and slope gradient), soil development (parent material characteristics and weathering), physical properties (particularly texture), chemical properties (such as pH, organic matter content, and nutrient concentration), and soil biology (Syaf 2014). Abid *et al.* (2011) found that soil quality has a substantial positive connection with crop productivity. The land suitability evaluation and the SQI both employ the same classification basis, which are limiting factors. This highlights the significance of examining the link between SQI and land suitability within the same land map unit (LMU). The analysis of the relationship between the two will provide information on attempts to develop specific agricultural

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commodities correctly as well as boost commodity cultivation success rates by identifying efforts to improve current restricting factors.

Bandar District, Pacitan Regency, has the potential to be an agricultural and plantation producing area, cultivating food crops, vegetables, and fruits. The cocoa plant (*Theobroma cacao* L.) is one of the agricultural items with promising development potential. Cocoa is a member of the Sterculiceae family that originated in tropical climates (Roesmanto 1991). Cocoa thrives in soil with clay loam texture, organic matter content >3.5%, cation exchange capacity (CEC) >15 cmol(+)kg^{-1}, base saturation (KB) >35%, pH 6.0−7.0, available P 32 ppm, rainfall 1500−2500 mm/year, temperature 25−26°C, and humidity 80% (Firdausil *et al*. 2008). The district has a tropical climate with a rainfall of 1200−2000, soil types in the form of Inceptisols and Entisols, and a pH range of 5.0−7.0, all of which are favorable for cocoa commodity development. Cocoa cultivation requires information support in terms of land appropriateness or SQI to enhance commodity development and increase cocoa yield. As a result, the findings of this study will contribute to the understanding of the relationship between land suitability evaluation and SQI for cocoa plants, as well as the limiting variables and inputs used to boost production.

METHODS

This study was conducted in 2020 in Bandar District, Pacitan Regency, East Java, with laboratory analysis performed at the Physics & Soil Conservation Laboratory and the Chemistry & Soil Fertility Laboratory, Faculty of Agriculture, Sebelas Maret University. The materials used in this study were KCl solution, H_2O, H_2O_2 10%, HCl 1.2 N, KCNS 10%, $K_4Fe(CN)_6$ 0.5%, $K_2Cr_2O_7$, concentrated H_2SO_4, $CuSO_4$, K_2SO_4, Olsen solution, ammonium molybdate, $SnCl_2$, ammonium acetate, alcohol, NaCl, concentrated NaOH, Zn granules, H_3BO_3 reservoir solution, and 0.1 N HCl.

The research was carried out using a descriptive survey method. The location of soil sampling was determined using a purposive sampling method based on overlaying land use maps, soil type distribution maps, rainfall maps, and slope maps, resulting in 15 land map units (LMU), and the soil sample points in each land use unit were determined using a purposive sampling technique. In this study, land suitability was evaluated using a matching approach between land features and cocoa plant requirements as defined by Ritung *et al*. (2011). The FAO land evaluation framework (1976) served as the basis for land suitability classes. The SQI was calculated using two methods: expert judgement and principal component analysis (PCA) (Laishram *et al*. 2012). The expert judgement method uses experts' experience and literature to determine indicators and scores, whereas the PCA method is a statistical test of data from the analysis of physical, chemical, and biological soil indicators (Martunis *et al*. 2016). PCA employs the Minitab data processing tool to generate Principal Component (PC) data. PC was used to select the Minimum Data Set (MDS), which was a selected indicator representing soil function. The PC chosen as MDS has an eigenvalue close to 1 or −1, or a *p*-value less than 0.05 or 5% (Supriyadi *et al*. 2016). The weight index (Wi) was then determined by selecting the indication with the highest value in each selected PC column. The Wi value was calculated from the results of the PCA test, which was the division of proportion by the number of data appearing in the selected PC divided by the cumulative, whereas Si was the indicator score value. The requirements for the SQI value are shown in Table 1.

$$\text{SQI} = \sum_{i=1}^{n} Wi \ x \ Si^{n}$$

where:
SQI = Soil quality index
Si = Score on selected indicators
Wi = Weighting factor (index weight)
n = Number of soil quality indicators

RESULTS AND DISCUSSION

Bandar District, Pacitan Regency, East Java covers an area of 11,735 ha, with 1,677.30 ha of paddy fields and 10,059.40 ha of dry land. The district is located between 0 and 946 masl and is divided into eight villages: Petungsinarang, Ngunut, Bandar, Kledung, Tumpuk, Watupatok, Bangunsari, and Jeruk. The district is located near the equator, hence it has two seasons: rainy (October−April) and dry (April−October). Based on rainfall data from the previous ten years, rainfall was 1769.20 mm/year,

Table 1 Soil quality index (SQI) criteria

Soil quality	SQI rating scale	Class
Very good	0.80−1.00	1
Good	0.60−0.79	2
Currently	0.40−0.59	3
Low	0.20−0.39	4
Very Low	0.00−0.19	5

Source: Lal (1994).

resulting in a Q value of 68.12% and a Schimdt-Ferguson classification of climatic type D (moderate). The average maximum temperature is 23.56°C, while the average low is 22.71°C. In the last ten years, humidity has ranged between 75% and 86%. This study was carried out by dividing 15 LMU based on the use of plantation and dry land in the research location and their respective characteristics (Table 2).

Table 3 shows the findings of the indicator analysis. Microorganisms' activity in breaking down organic matter, evapotranspiration, and erosion all influence soil carbon content. Organic C at the research site is characterized as low-to-high. Microbial biomass C at the research site is classified as low. According to Saraswati *et al*. (2007), soil microbial C content is relatively small compared to the overall soil C but plays an important role in the nutrient cycle. Kapli *et al*. (2017) stated that microbial C is a representative of microbial biomass as a component of organic matter consisting of living things measuring ≤ 5−10 μm^3.

According to Hermiyanto *et al*. (2016), the CEC value at the research location is moderate−rather high, indicating that the soil has a high capacity to provide cationic nutrients to plants, such as K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}, MO^{2+}, Cu^{2+}, and Zn^{2+}. A higher CEC value results in lower base saturation, and vice versa

Table 2 Characteristics of each land use unit

LMU	Village	Sampling point coordinates		Land use	Soil type	Slope (%)	Area (Ha)	Height (masl)
1	Kledung	111° 17' 7.143" E	7° 59' 52.569" S	Plantation	Inceptisols	0-8	272.72	840
2	Orange	111° 15' 18.742" E	7° 57' 48.653" S	Plantation	Inceptisols	25-40	133.83	478
3	port	111° 15' 52.443" E	7° 57' 41.524" S	Plantation	Inceptisols	25-40	69.86	456
4	port	111° 13' 55.885" E	7° 56' 54.392" S	Plantation	Inceptisols	8-15	112.81	816
5	Petungsinarang	111° 14' 38.396" E	8° 3' 58.835" S	Plantation	Entisols	15-25	49.21	647
6	Petungsinarang	111° 14' 6.516" E	8° 4' 9.334" S	Plantation	Entisols	8-15	15,16	565
7	port	111° 16' 41.088" E	7° 56' 27.59" S	Dry Land	Inceptisols	>40	168.80	463
8	Ngunut	111° 13' 26.03" E	8° 1' 45.403" S	Dry Land	Inceptisols	0-8	17.74	532
9	port	111° 13' 15.745" E	8° 1' 49.458" S	Dry Land	Inceptisols	15-25	1134.06	624
10	Stack	111° 15' 24.669" E	7° 57' 24.165" S	Dry Land	Inceptisols	15-25	129.49	612
11	Orange	111° 14' 16.222" E	7° 57' 26.618" S	Dry Land	Inceptisols	15-25	321.34	643
12	port	111° 19' 12.117" E	7° 56' 56.781" S	Dry Land	Inceptisols	25-40	631.57	482
13	Kledung	111° 18' 20.91" E	8° 1' 44.113" S	Dry Land	Inceptisols	8-15	332.63	587
14	Petungsinarang	111° 13' 1.008" E	8° 4' 7.733" S	Dry Land	Entisols	15-25	278.25	658
15	port	111° 12' 58.33" E	8° 3' 20.895" S	Dry Land	Entisols	8-15	92.07	572

Description: LMU = Land Map Units

Table 3 Indicator/parameter analysis

LMU	C-organic (%)	C-biomass ($\mu g\ g^{-1}$)	CEC (cmol(+) kg^{-1})	KB (%)	pH	P-Available (ppm)	K Available (cmol(+) kg^{-1})	N total (%)	BV (g cm^{-3})	Porosity (%)	Texture
1	1.10 S	0.96 R	21.48 AT	37.71 S	5.16	2.61 R	1.30 T	0.19 S	1.39 S	35.31 AT	silty clay
2	0.79 R	0.52 R	19.37 AT	53.18 AT	5.25	2.60 R	0.28 S	0.15 S	1.49 S	34.32 AT	sandy loam
3	0.79 R	0.54 R	19.38 AT	53.37 AT	5.24	2.59 R	0.28 S	0.15 S	1.52 R	28.64 S	sandy clay loam
4	0.85 R	0.21 R	20.82 AT	44.46 AT	5.07	2.64 R	0.22 S	0.18 S	1.58 R	31.55 AT	clay loam
5	1.18 S	0.73 R	29.46 AT	46.16 AT	5.22	4.34 R	0.23 S	0.16 S	1.46 S	33.81 AT	silty loam
6	1.19 S	0.69 R	29.56 AT	46.31 AT	5.24	4.13 R	0.23 S	0.16 S	1.50 S	31.10 AT	silty clay
7	1.65 S	0.85 R	20.46 AT	45.00 AT	5.56	5.55 R	0.94 T	0.20 S	1.32 AT	47.97 T	clay
8	2.26 AT	0.85 R	20.83 AT	30.28 S	6.14	6.42 R	0.68 T	0.30 AT	0.78 T	56.12 T	clay loam
9	1.20 S	0.76 R	18.90 AT	52.40 AT	5.42	2.05 R	1.23 T	0.20 S	1.57 R	29.37 S	silty clay
10	1.21 S	0.77 R	18.96 AT	51.22 AT	5.43	2.06 R	1.23 T	0.21 AT	1.61 R	26.84 S	silty clay
11	1.20 S	0.76 R	18.92 AT	53.85 AT	5.42	1.96 R	1.23 T	0.20 S	1.62 R	26.92 S	silty clay
12	2.27 AT	1.36 R	21.28 AT	59.12 AT	5.83	6.62 R	2.29 T	0.24 AT	0.85 T	52.93 T	clay loam
13	0.80 R	0.20 R	16.32 S	30.83 S	5.59	4.34 R	0.26 S	0.18 S	1.05 T	47.09 T	clay
14	1.06 S	0.45 R	15.24 S	32.52 S	5.02	2.72 R	0.48 AT	0.19 S	1.04 T	52.25 T	clay
15	1.06 S	0.48 R	15.29 S	32.59 S	5.04	2.73 R	0.48 AT	0.19 S	1.02 T	53.29 T	clay

Remarks: R = Low; S = Medium; AT = Somewhat high; T = High

(Machfiroh *et al*. 2014). This negative association emerges because the soil contains more acidic cations than basic cations. Base saturation (KB) is also positively correlated with pH. The acidic pH at the research site is deemed unfavorable; acidic soil has high Fe and Al solubility and binds P into Al−P and Fe−P compounds that are unavailable to plants. Positively charged active Al and Fe compounds in the soil cause P to be adsorbed in the allophane mineral structure or bound to the OH^- or H^+ functional groups, influencing the amount of phosphate available at the low research location (Setiawati *et al*. 2020). Potassium at the research site is classified as medium−high; the potassium value is influenced by the severity of leaching, which is increased by the amount of rainfall that occurs. Potassium is also affected by soil texture, the coarser the texture, the lower the potassium value, and vice versa. This may be seen in the analytical results, which demonstrate that clay-textured soil contains more potassium. Coarse soil texture (sand) can also accelerate the leaching of N elements (Afandi *et al*. 2015). At the research site, the N element is rated as medium−high. The fact that N components are movable contributes to their limited availability.

The volumetric weight (BV) indicator indicates soil density; soil with high density (high BV) due to the soil's composition of fine particles with irregular structures will be difficult to transport water and for plant roots to penetrate because the number of soil pores is limited. BV at the research site ranges from low to high. BV has a negative link with porosity, hence soil with a high BV has a low porosity rating. The low porosity value is due to the small number of soil pores (Supriyadi *et al*. 2016). Soil texture study reveals the relative proportion or amount of coarseness by comparing the number of sand, silt, and clay grains (soil components). According to Hazriyal *et al*. (2015), good soil for root growth and respiration is clay loam textured soil with 50% sand, 10−20% silt, and 30−40% clay composition. Clay loam textured soil has excellent water retention, aeration, and drainage. Clay loam-textured soil can be found at LMU 4, 8, and 12.

Soil Quality Index Analysis

The SQI was calculated by analyzing physical, chemical, and biological factors and testing their correlation with statistical analysis PCA using SPSS software. PCA provides data known as PCs. The PCs have eigenvalues near 1 or −1. The physical, chemical, and biological indicators utilized are interrelated. The link between these markers is known as correlation analysis (Pearson correlation). Table 4 shows the correlation analysis results for each SQI. Pearson significant correlation (p <0.05) and extremely significant correlation (p <0.01) indicate a positive and negative relationship between the parameters examined. Wilson *et al*. (2015) explained that the higher the organic C value, the more decomposition occurs, forming organic acids and binding Al, Fe, and Ca to create complex compounds, resulting in P becoming available in the soil. The relationship between CEC, available-P, and total N exists because the higher the CEC, the more active the soil colloid is and can absorb NH_4^+, which produces ammonium and promotes nitrification in the soil. The nitrification process releases H^+ and lowers the pH, increasing the solubility of Fe, Mn, and Al. P is then fixed and available in the soil (Wilson *et al*. 2015).

Negative correlation denotes an inverse link between the compared parameters; if one parameter increases, the other parameter drops, and vice versa; if one parameter lowers, the comparable parameter increases. According to Soepandi (1983) in Dewi *et al*. (2020), the negative correlation between BV with organic C and BV with porosity occurs because organic matter acts as a binding material in the formation of soil aggregates, resulting in more space between aggregates (macropores) and pore space within the aggregate (micropores). As the soil becomes more porous, the soil bulk density decreases. This is consistent with the opinion of Supriyadi *et al*. (2016), that the denser the soil, the higher the BV, meaning that the soil will be more difficult to transmit water or penetrate by plant roots because the number of soil pores is small and the soil composition is made up of

Table 4 Principal component analysis of SQI

	C-Org	C-Mic	KTK	KB	pH	P-Ter	K-Ter	N-Tot	BV
C-Mic	0.751 **								
CEC	0.170	0.308 *							
KB	0.015	0.251	0.174						
pH	0.788 **	0.479 **	0.021	0.025					
P-Ter	0.755 **	0.429 **	0.295 *	−0.118	0.712 **				
K-Ter	0.612 **	0.792 **	−0.118	0.262	0.434 **	0.208			
N-Tot	0.591 **	0.393 **	0.109	−0.397 **	0.535 **	0.370 *	0.359 *		
BV	−0.417 **	−0.143	0.197	0.223	−0.358 *	−0.488 **	−0.153	−0.154	
Porosity	0.331 *	0.081	−0.199	−0.172	0.250	0.400 **	0.100	0.067	−0.935 **

Remarks: C-Org = C organic; C-mic = C microbial biomass; CEC = cation exchange capacity; KB = base saturation; P-Ter = P available; K-Ter = K available; N-Tot = N total; BV = volume weight; * = Significant correlation <0.05; ** = Significant correlation <0.0

fine particles. The findings of the PCA are shown in Table 5.

The Minimum Data Set (MDS) is the smallest data set that can capture all soil quality indicator values. All indicators will be chosen to represent each MDS. The PC was used to choose an MDS from the indicators that best reflect soil function. The PC employed as the MDS has an eigenvalue near to 1 or −1, or a *p*-value less than 0.05 or 5% (Supriyadi *et al*. 2016). The weight index (Wi) was then determined by selecting the indicator with the highest value. The Wi value was calculated using the results of the PCA test, which was the proportion divided by the number of data points present in the selected PC divided by the cumulative. Following that, the chosen indicators were scored as the MDS at each sample point. Figure 1 depicts the histogram of the SQI, from which Figure 2 shows the SQI Map in Bandar District.

Table 5 Principal component analysis results

Eigenvalue	4,1536	2,0419	1,2951	1,2178
Proportion	0.415	0.204	0.13	0.122
Cumulative	0.415	0.62	0.749	0.871
Variable	PC1	PC2	PC3	PC4
C-organic	0.465*	−0.103	0.03	−0.057
C-biomass	0.366*	−0.362	−0.081	0.115
CEC	0.043	−0.33	−0.239	−0.69
KB	−0.023	−0.415	−0.56	0.238
pH	0.406*	−0.037	0.093	−0.066
P-available	0.389 *	0.072	−0.081	−0.415
K-available	0.318	−0.28	−0.011	0.511*
N-total	0.304	0.008	0.612*	0.018
BV	−0.284	−0.49	0.305	−0.065
Porosity	0.239	0.502*	−0.372	0.09

Remark: *= Selected indicator

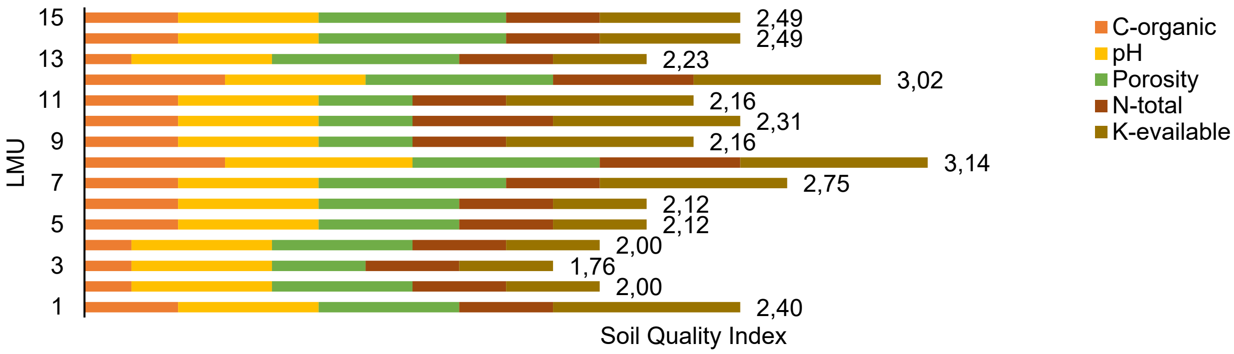

Figure 1 Soil quality index in Bandar District.

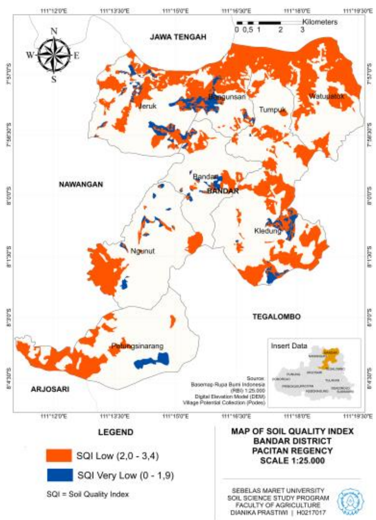

Figure 2 Soil quality index map in Bandar District.

The SQI was calculated by multiplying the index weight value (Wi) by the MDS indicator scoring for each LMU. The Wi value was obtained by dividing the proportion by the cumulative, and the indicator scoring is based on Wander *et al*. (2002), Karlen *et al*. (1994), and Balittan (2005). The SQI value was classified using Cantu *et al*. (2007), but with some modifications. Each LMU has a SQI class that spans from low to very low. This occurs because the research site has Inceptisols and Entisols soil types, which are undeveloped soils, so that the decomposition of organic matter is slow, resulting in low nutrient availability in the soil (Helmi *et al*. 2016).

Land Suitability Evaluation

Land suitability classes were determined using the FAO (1976) technique, which was divided into three categories: order, class, sub-class, and unit. Sub-classes imply limiting factors. The matching method of land suitability assessment (Table 6) employs Leibig's minimum law to identify the limiting factors that influence land suitability classes and subclasses. Table 7 displays the actual and possible land suitability classes for cocoa plants in Bandar District, while Figure 3 depicts the actual land suitability map and Figure 4 illustrates the potential land suitability map.

Table 6 Criteria for cocoa plant growth requirements (Ritung *et al.* 2011)

Land characteristics	Land suitability class			
	S1	S2	S3	N
Temperature (tc)				
Average temperature (°C)	25–28	20–25 or 28–32	32–35	< 20 or >35
Water availability (wa)				
Rainfall (mm)	1,500–2,500	2,500–3,000	1,250–1,500 3,000–4,000	< 1,250 or > 4,000
Length of dry period (months)	1–2	2–3	3–4	> 4
Humidity (%)	40–65	65–75 or 35–40	75–85 or 30–35	> 85 or <30
Oxygen availability (oa)				
Drainage	good, moderate	somewhat hampered	hampered, rather fast	very hampered, fast
Rooting media (rc)				
Texture	smooth, somewhat smooth	currently	a bit rough, very smooth	rough
Crude material (%)	< 15	15–35	35–55	> 55
Soil depth (cm)	> 100	75–100	50–75	< 50
Peat				
Thickness (cm)	< 100	100–200	200–300	> 300
Maturity	Saprik	Sapric, hemic	Hemic	Fibric
Nutrient retention (nr)				
Soil CEC (cmol)	> 16	5–16	< 5	-
Base saturation (%)	> 35	20–35	< 20	
pH $_{H2O}$	6.0–7.0	5.5–6.0 7.0–7.6	< 5.5 > 7.6	
C-organic (%)	> 1.2	0.8–1.2	< 0.8	
Available nutrients (na)				
N total (%)	Currently	Low	Very low	-
P2O5 (mg /100 g)	Currently	Low	Very low	-
K_2O (mg/100 g)	Tall	Currently	Low- very low	-
Toxicity (xc)				
Salinity (dS/m)	< 1.1	1.1–1.8	1.8–2.2	> 2.2
Sodicity (xn)				
Alkalinity/ESP (%)	-	-	-	-
Sulfide hazard (xs)				
Sulfidic depth (cm)	> 125	100–125	60–100	< 60
Danger of erosion (eh)				
Slope (%)	< 8	8–15	15–30	> 30
Danger of erosion	very light	Light–moderate	heavy	very heavy
Danger of flooding/inundation (fh)				
- Height (cm)	-	-	25	> 25
- Duration (day)	-	-	<7	≥ 7
Land preparation (lp)				
Surface rocks (%)	< 5	5–15	15–40	> 40
Rock outcrop (%)	< 5	5–15	15–25	> 25

Table 7 Actual and potential land suitability classes for cocoa plants

LMU	Actual land suitability class	Limiting factors	Improvement efforts	Potential land suitability class	Limiting factors
1	S3-wa,nr,na	Humidity pH P Available	- Liming Fertilization	S3-wa	Humidity
2	S3-wa,rc,nr,na	Humidity Coarse material pH, C-Organic P available, K available	- - Liming, addition of organic matter Fertilization	S3-wa,rc	Moisture, coarse material
3	S3-wa,rc,nr,na	Humidity Coarse material pH, C-Organic P available, K available	- - Liming, addition of organic matter Fertilization	S3-wa-rc	Moisture, coarse material
4	S3-wa,nr,na	Humidity pH P available, K available	- Liming Fertilization	S3-wa	Humidity
5	S3-wa,nr,na	Humidity pH P available, K available	- Liming Fertilization	S3-wa	Humidity
6	S3-wa,na	Humidity P available, K available	- Fertilization	S3-wa	Humidity
7	S3-wa,na	Humidity P available	- Fertilization	S3-wa	Humidity
8	S3-wa,na	Humidity P available	- Fertilization	S3-wa	Humidity
9	S3-wa,nr,na	Humidity pH P available	- Liming Fertilization	S3-wa	Humidity
10	S3-wa,nr,na	Humidity pH P available	- Liming Fertilization	S3-wa	Humidity
11	S3-wa,nr,na	Humidity pH P available	- Liming Fertilization	S3-wa	Humidity
12	S3-wa,rc,na	Humidity Coarse material P available	- - Fertilization	S3-wa,rc	Moisture, coarse material
13	S3-wa,nr,na	Humidity C-Organic P available, K available	- Addition of organic materials Fertilization	S3-wa	Humidity
14	S3-wa,nr,na	Humidity pH P available, K available	- Liming Fertilization	S3-wa	Humidity
15	S3-wa,nr,na	Humidity pH P available, K available	- Liming Fertilization	S3-wa	Humidity

Remark: S3 = Marginal fit

Relationship between SQI and Land Suitability Evaluation

Soil quality is influenced by land use and farming practices. As a result, limiting one of the land functions will have an impact on soil quality (Wicaksono *et al.* 2020). Soil quality was determined using dynamic SQI derived from soil parameters that might reflect the soil's functional capacity, calculated by assigning values and weights to these indicators. Meanwhile, this study's approach to land evaluation is parametric. The parametric approach is deemed appropriate because the data used is objective, and the land property criteria can be quantified and chosen. The assessment used gives a maximum value (100) if the land properties are optimal; otherwise, if the land use under consideration does not meet the criteria, a minimum value (0) is given (Dwiarsa *et al*. 2021).

According to an analysis of the SQI in Bandar District, 15 LMUs have low-very low SQI, whereas the land suitability class is S3 (marginally suitable). The investigation of the link between the SQI and land suitability (Table 8) reveals that the connecting indication is present in all LMUs. The available P in all 15 LMUs is low. The low P content in all LMUs, as determined by both the soil quality and land suitability assessments, indicates that the soil at the study site releases P very slowly. Low P can be improved by adding P fertilizer and organic matter. This is expected to increase pH and available P while decreasing available Al and Fe (Azurianti *et al*. 2022). Figure 5 displays a map showing the association between the SQI and land suitability. The results of a statistical analysis performed with SPSS software to examine the association between SQI and land suitability (Table 9). The analysis reveals a positive and highly correlated relationship (r = 0.688, p = 0.000). The correlation results show that land suitability improves as SQI increases. Conversely, the lower the SQI, the less suitable the land is.

CONCLUSION

The research findings in Bandar District, Pacitan Regency, East Java, were divided into 15 LMUs. Soil quality analysis at the research location revealed a SQI ranging from 1.76 (very low) to 3.14 (low). Organic C, microbial biomass C, pH, available P, porosity, total N, and available K were all indicators that influenced the SQI at the research site. The lowest SQI was discovered in soil with low organic C, microbial biomass C, available P, and moderate available K and total N. The land suitability for cocoa plants in Bandar District was classified as S3 (marginally suitable). Moisture, coarse matter, pH, organic C, available P, and available K were identified as limiting criteria for land suitability at the research site using correlation tests. The SQI and land suitability at the research site showed a good association (r = 0.688, p = 0.000). LMU with a low SQI shown increasingly poor appropriateness. The indicator that connects the two is available P. Efforts to improve soil quality can be based on the limiting indicator, which is liming, adding organic matter, and fertilizing to meet the needs of cocoa plants.

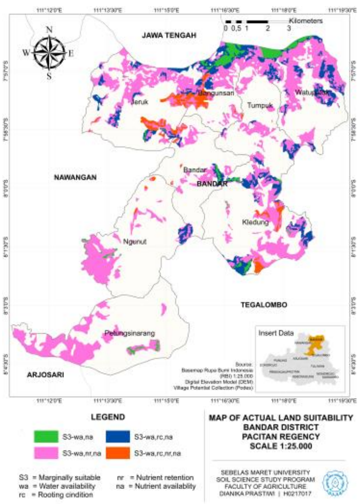

Figure 3 Actual land suitability map in Bandar District.

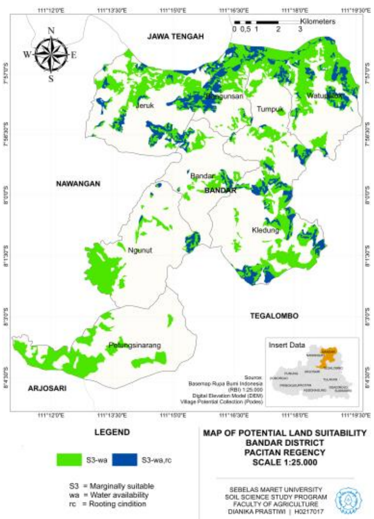

Figure 4 Potential land suitability map in Bandar District.

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Table 8 Relationship between SQI and land suitability in Bandar District

LMU	Soil quality index (SQI)			Land suitability		
	Limiting factors in the MDS of soil quality	Scoring	SQI	Limiting factors	Scoring	Land suitability class
1	C-organic; C-Microbial biomass; available P; total N	2;1;1;2	2.4	Moisture, pH, P available	4	S3
2	C-organic; C-Microbial biomass; available P; total N; available K	1;1;1;2;2	2	Moisture, coarse matter, pH, C-Organic, available P, available K	1	S3
3	C-organic; C-Microbial biomass; P available; Porosity; N total; K available	1;1;1;2;2;2	1.76	Moisture, coarse matter, pH, C-Organic, available P, available K	1	S3
4	C-organic; C-Microbial biomass; available P; total N; available K	1;1;1;2;2	2	Moisture, pH, available P, available K	3	S3
5	C-organic; C-Microbial biomass; available P; total N; available K	2;1;1;2;2	2.12	Moisture, pH, available P, available K	3	S3
6	C-organic; C-Microbial biomass; available P; total N; available K	2;1;1;2;2	2.12	Moisture, available P, available K	4	S3
7	C-organic; C-Microbial biomass; available P; total N	2;1;2;2	2.75	Humidity, P available	5	S3
8	C-Microbial biomass; available P	1.2	3.14	Humidity, P available	5	S3
9	C-organic; C-Microbial biomass; P available; Porosity; N total	2;1;1;2;2	2.16	Moisture, pH, P available	4	S3
10	C-organic; C-Microbial biomass; P available; Porosity	2;1;1;2	2.31	Moisture, pH, P available	4	S3
11	C-organic; C-Microbial biomass; P available; Porosity; N total	2;1;1;2;2	2.16	Moisture, pH, P available	4	S3
12	C-Microbial biomass; available P	1.2	3.02	Moisture, coarse material, available P	4	S3
13	C-organic; C-Microbial biomass; available P; total N; available K	1;1;1;2;2	2.23	Moisture, C-organic, available P, available K	3	S3
14	C-organic; C-Microbial biomass; available P; total N	2;1;1;2	2.49	Moisture, pH, available P, available K	3	S3
15	C-organic; C-Microbial biomass; available P; total N	2;1;1;2	2.49	Moisture, pH, available P, available K	3	S3

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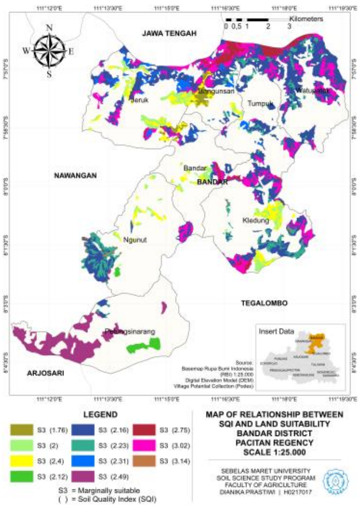

Figure 5 Relationship between SQI and land suitability.

Table 9 Correlation analysis of soil quality index with land suitability

		SQI
Land suitability	Pearson correlation	0.688 **
	Sig. (2-tailed)	0.000

Remarks: Results of correlation analysis with SPSS Software; SQI = soil quality index; **. Correlation is significant at the 0.01 level (2-tailed).

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