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Comparison of land suitability class for endemic *Coffea liberica Pinogu* HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia

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ABSTRACT

Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange, but its productivity remains low due to cultivation on low potential land. This study aimed to determine the land suitability of endemic liberica coffee using two different methods and formulate recommendations for land management in Pinogu Plateau. Thirteen land units were surveyed, and soil samples were collected and analyzed in the laboratory to identify the land characteristics. Land suitability classes (LSCs) were compared by limiting factor and parametric methods. Analysis using the limiting factor method showed that the actual LSCs for liberica coffee consisted of moderately suitable (S2) and marginally suitable (S3) classes. Efforts for improvement could increase the potential of LSC to become very suitable (S1) and S2 classes. Meanwhile, the assessment with the parametric method indicated that the LSC consisted of S1, S2, and S3 classes. These results revealed that the parametric method provides more realistic land characteristics than the limiting factor method. Land management II or the land that had a little limiting factor turned out to be more dominant with the recommendation of adding P and organic fertilizer.

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1. INTRODUCTION

Coffee has long been recognized as a refreshing drink. Its global distribution is composed of arabica coffee at 80%, robusta coffee at 20%, and liberica coffee at only <1% (Nillian et al., 2020). References and publications on liberica coffee are scarce because of its limited planting area. By 2050, the land suitable for robusta coffee cultivation will reach 83%, and that for arabica coffee will only be 17% (Magrach & Ghazoul, 2015). Claude et al. (2019) reported that based on pedoclimatic zoning, liberica coffee shows higher potential for cultivation than robusta and arabica because agro-climatic zoning increases its production potential in the coming years.

Coffee is a strategic commodity in Indonesia because its export value contributes to the country's foreign exchange. National coffee production and export in 2020 separately reached 753,941 and 375,555.9 tons (value of 809,158,900 US$) with increases of 0.19% and 2.62%, respectively, from the previous year (BPS, 2014). Gorontalo Province contributed only 139 tons or 0.02% of the total national coffee production (Kementan, 2021).

Pinogu is one of the sub-districts in Bone Bolango Regency, Gorontalo Province. This area is relatively flat and wide (496 km^2) with an altitude of > 300 m above sea level and is surrounded by hills and mountains, hence the name Pinogu Plateau. This sub-district has long been known as a coffee producer, even during the Dutch colonial era (Humola et al., 2021; Sancayaningsih et al., 2016). Almost every family in Pinogu Plateau owns a coffee plantation as their main crop because of its highest productivity level among other commodities (Ahmad & Paserangi, 2018). Pinogu coffee is organic (Fatmalasari et al., 2016) because local farmers do not use pesticides, herbicides, or other chemical fertilizers during cultivation (Zainuddin, 2020). This coffee is processed from robusta and liberica varieties (Susilo et al., 2021; Zainuddin, 2020).

Liberica coffee (*Coffea liberica*) has been planted since 1875 (Sancayaningsih et al., 2016) and is now classified as endemic in the northern part of Celebes because it only exists and grows in Pinogu District. This variety has the advantages of good taste (Gusfarina, 2014) and distinctive jackfruit flavor (Saidi & Suryani, 2021), which make Pinogu coffee a superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have encountered several obstacles, one of which is low productivity. Martono (2018) reported that although Pinogu coffee has reached global recognition, its productivity is still low at only 0.75 ton ha^{-1} $year^{-1}$. By comparison, the productivity of liberica coffee can reach 1.69–1.98 ton ha^{-1} (Balittri, 2015). Coffee plantation area accounts for the largest proportion in this district at 282.63 ha (66.21%) and new production of 36.34 tons (Humola et al., 2021). Such conditions affect the availability of coffee raw materials to meet market demand. The coffee productivity is low possibly because it is being cultivated on land with low potential.

Information about the land potential in Pinogu Plateau is available only for the highly developed robusta coffee but not for liberica coffee. Land suitability in Bone Bolango Regency is classified as marginally suitable (S3) for robusta coffee (Indrianti, 2020; Taslim, 2016) and other plantation commodities such as coconut, cocoa, cloves, candlenut, and vanilla (Taslim, 2016). Liberica coffee is endemic, highly resistant to pests and plant diseases (Harni et al., 2016), resistant to leaf rust, and slightly resistant to coffee berry borer pests (Gusfarina, 2014). Ignorance of land potential among coffee planters greatly affect the productivity of liberica coffee; land potential varies for every plant according to growth conditions based on land characteristics (Sukarman et al., 2018).

Land management requires land suitability assessment to ensure that land can be used productively and sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is important in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use (AbdelRahman et al., 2016), and efficient agriculture land use (Zakarya et al., 2021). Information on land use potential is presented as the output of land evaluation, including the consequences, beneficial, and severity of each degree class (Shalaby et al., 2017). This scheme is also suitable for land use planning for liberica coffee. Different land evaluation methods have varying data requirements and estimate qualities; to date, no rule has been imposed to define when and what evaluation method to use and when is complex analysis necessary (Mathewos et al., 2018; Mugiyo et al., 2021).

Limiting factor method is mainly used in assessing land suitability for coffee. The parametric method identifies the combination of soil characteristics affecting agricultural production by using mathematical equations (Elaalem, 2013) to minimize the interaction between land characteristics. The former uses the lowest constraint for classification, and the latter employs the correlation between all variables (Rabia & Terribile, 2013). (Bagherzadeh & Gholizadeh, 2016) stated that in the parametric approach, different land suitability classes (LSCs) are defined as completely separate groups with different but consistent ranges. Differences in land suitability values due to the use of varying methods have an effect on land management. Therefore, this study aimed to determine the land suitability of endemic liberica coffee by using two different methods and formulate recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

2. MATERIAL AND METHODS

2.1. Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Its geographical location is at 0°24'5.4”–0°38'29.04” north to 123°18'38.52”–123°33'15.48” east covering an area of 2,804.28 ha with elevation of 300–338 m above sea level (Fig. 1). The annual rainfall is 2,541.90 mm, and the monthly rainfall ranges from 19.00 mm to 408.18 mm. The study area is included in the agro-climatic zone of C1 because the number of dry months (monthly rainfall less than 100 mm) is only 1, and the number of wet months (monthly rainfall more than 200 mm) is 6. The monthly air temperature fluctuates between 24.34°C and 25.79°C, and the relative humidity is between 78.60% and 84.40%. The monthly sunshine duration is between 44.52% and 70.50%, and the monthly wind speed is between 2 and 2.60 knots. The study area is located upstream of Bone watershed flowing to Tomini Bay.

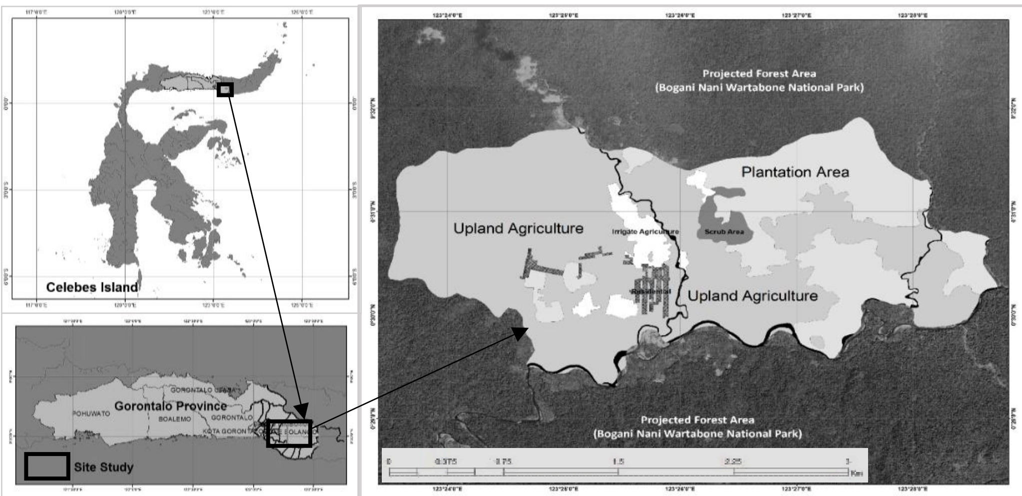

Figure 1. Research location map

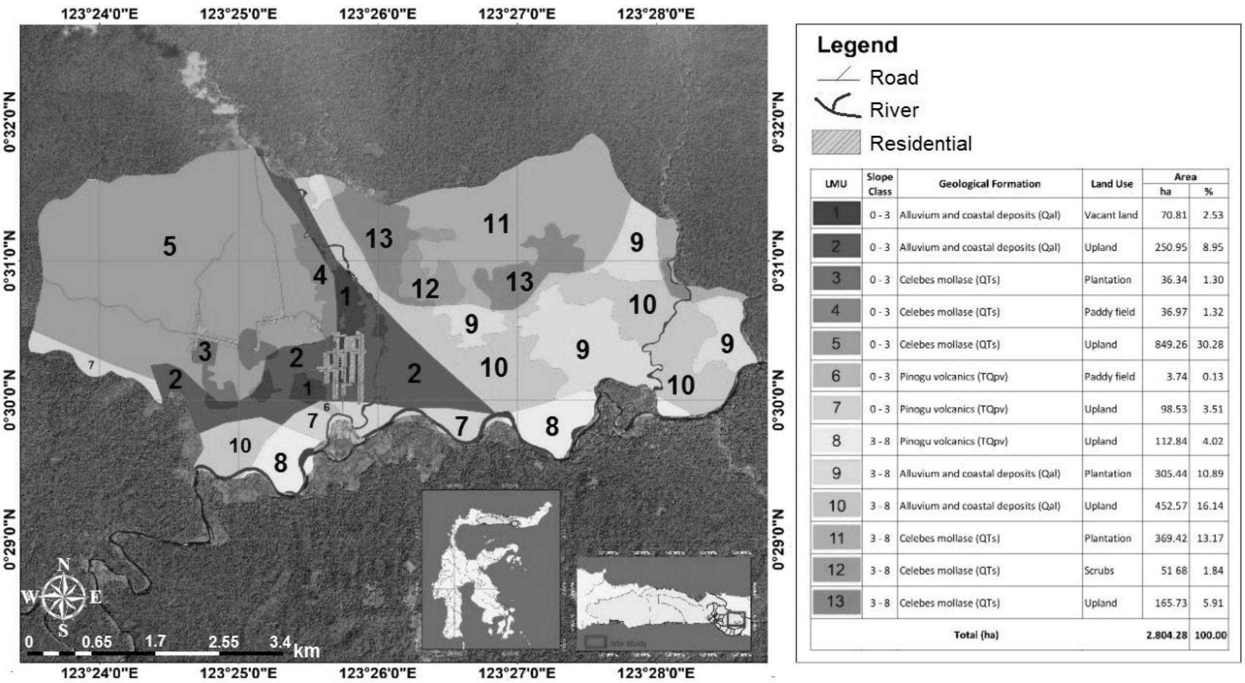

Figure 2. Land mapping unit

2.2. Land Mapping Unit

Prior to soil surveying and land observations, a map of the land unit was drawn at a scale of 1: 12,000 (Fig. 2). This map contains 13 land units generated from basic map overlays, namely, landform maps, slope maps, geological maps, and maps of existing land use, which were adjusted to the map scale. This land unit map served as a reference in soil survey and land observations, especially in determining soil observation points.

2.3. Soil Survey and Land Observation

The following soil survey tools were used: soil knife, pH meter, soil belt, hoe, spade, clinometer, and permanent whiteboard marker. The materials included soil profile card, plastic bag, fastening rubber, label paper, climate data from the local BMKG station for 5 years (2015–2021), and soil samples for laboratory analysis. A soil survey method on a scale of 1: 12,000 was adopted by observing the soil properties on 13 land units (Fig.2). Field observations were carried out to determine land characteristics, such as elevation and slope. Approximately 1 kg of soil samples were taken for laboratory analysis.

2.4. Soil Laboratory Analysis

The soil samples were air-dried for 3 days and then filtered through a 2 mesh sieve. Soil properties were analyzed following the method of Eviati and Sulaeman (2009). Soil reaction parameters (pH H_2O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content was measured using the Walkley and Black method. Available P content was computed using the Olsen method, cation exchange capacity (CEC) was evaluated with 1N NH_4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, and base saturation was calculated. All soil data and selected land characteristic data were inputted in a spreadsheet.

Table 1. Selected land suitability criteria for *Coffea liberica*

Land use requirements/ land characteristics	Symbol	Unit	Land suitability class			
			S1	S2	S3	N
Elevation	el	m asl	300–500	600–800; 0–300	800–1.000	>1,000
Slopes	sl	%	0–8	8–25	25–45	>45
Nutrient retention:						
Soil pH (*H_2O Extraction*)			5.5–6.0	6.1–7.0	7.1–8.0	>8.0
C-organic (*Walkley & Black*)		%	2–5	1–2; 5–10	0.5–1.0; 10–15	<0.5; >15
Cation exchange capacity (*NH_4.OAc pH 7 Extraction*)	nr	cmol kg^{-1}	>15	10–15	5–10	<5
Base saturation (*NH_4.OAc pH 7 Extraction*)		%	>35	20–35	<20	-
Nutrient availability:						
P availability (*Olsen*)	na	ppm	>16	10–15	<10	-

Source: (Kementan, 2014), modified.

Remarks: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable, m asl = meters above sea level, ppm = part per million

2.5. Land Suitability Assessment

Land suitability assessment was carried out using the selected land characteristics for both methods. For the limiting factor method, the land evaluation framework was adopted (FAO, 1976), and the land characteristics and qualities were compared according to the criteria (Table 1) selected from the Kementan (2014) to choose the actual land suitability class and limiting factors for land use. Optimization was further performed on the limiting factor of the actual land suitability class to obtain a potential land suitability class.

For the parametric method, the productivity (Y) of coffee was estimated using the following equations (Simbolon, 2018):

Y = −2.672 + 0.026 Elevation [1]
Y = 17.190 − 0.090 Slope [2]
Y = 3.055 + 0.005 pH H_2O [3]
Y = 4.050 − 0.019 C-organic [4]
Y = -28.796 + 0.621 P Olsen [5]
Y = 32.450 − 0.109 Cation exchange capacity [6]
Y = 0.457 − 0.002 Base saturation [7]

where Y = estimated production (ton ha^{-1}). The optimal productivity of liberica coffee was 0.75 ton ha^{-1} (Martono, 2018). The accuracy of the estimated liberica coffee productivity was analyzed using the root mean square error (RMSE) with the following equation:

$$RMSE = \sqrt{\frac{\sum_{t-1}^{n}(At-Ft)^2}{n}} \quad [8]$$

where RMSE = root mean square error, At = actual productivity (ton ha^{-1}), Ft = estimated productivity (ton ha^{-1}), and n = number of data. The smaller or closer to 0 the RMSE is, the more accurate the prediction results will be. A land index (LI) of root mean square (Khiddir, 1986) was also used in the land suitability assessment for liberica coffee and calculated as follows:

$$LI = LC_{min}\sqrt{\frac{A}{100}\,x\,\frac{B}{100}\,x\,\frac{C}{100}\,x\,...\,x\,\frac{N}{100}} \quad [9]$$

where LI= land index; LC= land characteristic; LC_{min}= minimum LC rating; A, B, C, ..., N = other LC in beside the minimum LC.

LI was calculated from all LC values affecting the liberica coffee productivity and scored using the following LI criteria (Sys et al., 1991): S1 class (highly suitable) with a value of 75–100, S2 class (moderately suitable) with a value of 50–75, S3 class (marginally suitable) with a value of 25–50, and N class (not suitable) with a value 0–25.

Recommendations of land management for liberica coffee were formulated on the basis of the final suitability class. Recommendation I was the land with suitability of S1 class, II was the land with suitability of S2 class, and III was the land with suitability of S3 class. Not recommended was the land with suitability of N class. All data and information obtained were described and presented in tabular form, and their spatial distribution was presented in map form.

3. RESULTS

3.1. Land Suitability Class Based on Limiting Factor Method

The results of matching the land suitability criteria with the land characteristics in the actual land suitability class for liberica coffee in Pinogu Plateau are shown in Table 2 and Fig. 3. The actual land suitability class was moderately suitable (S2), which dominated a total area of 2,149.64 ha or 76.66%. By comparison, the marginally suitable class (S3) accounted for 654.64 ha or only 23.34%. Highly suitable class (S1) and not suitable (N) were not obtained from this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in Pinogu Plateau were nutrient retention (C-organic, base saturation, and soil pH) and nutrient availability (P availability). In addition, an elevation limiting factor was identified in LMUs 1 and 7.

The potential land suitability class was dominated by S1 covering an area of 1,980.30 ha or 70.62%, and the remaining part was classified as S2 covering an area of 823.98 ha or 29.38%. After the improvement of the actual land suitability class against the limiting factor, all LMUs can be upgraded to potential land suitability class, except for LMUs 1 and 7 that cannot be repaired because of the elevation limiting factor (Table 3, Fig. 3). The limiting factors for nutrient retention, namely, pH, C-organic, and low base saturation, were improved with the addition of organic matter. Meanwhile, the limiting factor for available nutrient, that is, low P availability, was enhanced with the addition of P fertilizer.

Table 2. Actual land suitability class for *Coffea liberica* in Pinogu Plateau

LMU	Elevation		Slope		pH		C-Organic		CEC		BS		Ava-P		Actual LSC	Area	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC		ha	%
1	293	S2el	3	S1	5.82	S1	1.59	S2nr	19.24	S1	32.75	S2nr	13.87	S2na	S2el,nr,na	70.81	2.53
2	307	S1	3	S1	5.88	S1	1.30	S2nr	23.77	S1	33.75	S2nr	15.85	S2na	S2nr,na	250.95	8.95
3	313	S1	3	S1	6.22	S2nr	0.78	S3nr	27.60	S1	28.00	S2nr	9.77	S3na	S3nr,na	36.34	1.30
4	302	S1	3	S1	5.64	S1	1.21	S2nr	22.77	S1	24.67	S2nr	12.22	S2na	S2nr,na	36.97	1.32
5	311	S1	3	S1	5.78	S1	1.46	S2nr	26.39	S1	29.25	S2nr	17.04	S1	S2nr	849.26	30.28
6	305	S1	3	S1	6.12	S2nr	1.02	S2nr	33.50	S1	29.68	S2nr	18.52	S1	S2nr	3.74	0.13
7	290	S2el	3	S1	6.28	S2nr	1.43	S2nr	27.92	S1	39.75	S1	14.53	S2na	S2el,nr,na	98.53	3.51
8	288	S1	3	S1	5.89	S1	1.92	S2nr	23.22	S1	36.67	S1	20.35	S1	S2nr	112.84	4.02
9	338	S1	3	S1	6.25	S2nr	1.79	S2nr	27.10	S1	37.00	S1	14.98	S2na	S2nr,na	305.44	10.89
10	300	S1	8	S1	5.92	S1	1.38	S2nr	23.67	S1	42.33	S1	9.98	S3na	S3na	452.57	16.14
11	334	S1	3	S1	5.96	S1	1.15	S2nr	27.69	S1	33.00	S2nr	17.12	S1	S2nr	369.42	13.17
12	306	S1	8	S1	5.95	S1	1.07	S2nr	25.03	S1	39.50	S1	16.41	S1	S2nr	51.68	1.84
13	310	S1	3	S1	6.00	S1	1.35	S2nr	32.67	S1	23.67	S2nr	7.78	S3na	S3na	165.73	5.91
Area (ha)																2,804.28	100

Remarks: LMU= land mapping unit, LC= land characteristic, LSC= land suitability class, CEC= cation exchange capacity, BS= base saturation, Ava-P= Phosphor availability, m sl= meters sea level, ppm = part per million, S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, el = elevation, nr = nutrient retention, na = nutrient availability

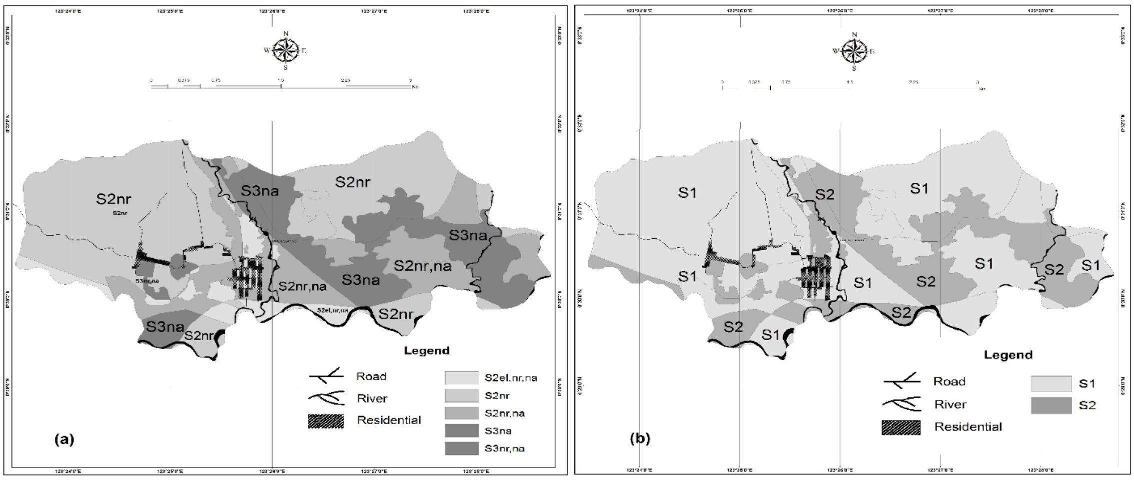

Figure 3. Actual (a) and potential (b) of land suitability class of *Coffea liberica* in Pinogu Plateau (Remarks: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, el = elevation, nr = nutrient retention, na = nutrient availability)

Table 3. Potential land suitability classes for *Coffea liberica* in Pinogu Plateau

LMU	Actual LSC	Limiting Factors	Efforts	Potential LSC	Area	
					ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C-organic, base saturation), nutrient availability (available of P)	Cannot be fixed (elevation)	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic matter - Addition of P fertilizer	S2	36.34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic matter	S1	1,386.94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
		Total (Ha)			2.804,28	100

Remarks: LMU = land mapping unit, LSC = land suitability class, S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, el = elevation, nr = nutrient retention, na = nutrient available, C = carbon, P = phosphor

3.2. Land Suitability Class Based on Parametric Method

Table 4 shows the highest liberica coffee productivity for slope characteristics with an average of 1.69 ton ha^{-1} and the lowest for P availability with an average of 0.20 ton ha^{-1}. The remaining land characteristics had an average productivity 0.30. RMSE values on the alleged productivity of liberica coffee were all close to 0; LMU 8 had the highest value (0.53), which was higher than those for LMUs 3, 10,12, and 13 (0.51). The remaining LMUs had a RMSE of 0.52 (Table 4). The productivity of liberica coffee affects the land characteristic index, which ultimately determines the LI and land suitability class for liberica coffee.

The relative land characteristic index values followed the pattern of liberica coffee productivity in Pinogu Plateau. The highest and optimal land characteristic index was acquired for slope characteristic with an average of 100 (Table 5), and the lowest was obtained for available P with an average of P availability index of 26.39. The remaining land characteristics were relatively diverse, but the average land characteristic index was 30 in the remaining LMUs in Pinogu Plateau. The land characteristic index value affects the LI. Hence, LMUs 3 and 13 obtained the highest Lis at 76 and 80, respectively. Meanwhile, LMU 8 had the lowest LI of 50. The remaining LMUs achieved a LI ranging from 50 to 71. The variation in LI greatly affects the land suitability class for liberica coffee.

On the basis of Lis, the land suitability class for liberica coffee was dominated by S2 covering 88.77% of total area (Table 5). Meanwhile, S1 and S3 classes accounted for 7.21% and 4.02%, respectively. Not suitable class (N) was not detected.

3.3. Comparison of Land Suitability Classes and Recommendations on Land Management

Comparison in Table 6 and Fig. 4 shows that the two methods exhibit similarity in the land suitability class S2:S2 comprising 22.18% of total area (LMUs 1, 7, and 10). However, the most dominant class difference was S1:S2 accounting for 66.59% of total area (LMUs 2, 4, 5, 6, 9, 11, and 12), followed by class S2:S1 at 7.21% (LMUs 3 and 13) and the lowest was class S1:S3 at 4.02% (LMU 8).

On the basis of the land suitability class from the limiting factor method, the land that was included in recommendation I (S1) accounted for 70.62% of the total area, and that in recommendation II (S2) comprised 29.38%. No land recommendations III (S3) and IV (N) were noted. For the parametric method, the land included in recommendation I (S1) accounted for 7.21% of the total area, that in recommendation II (S2) comprised 88.77%, and that in recommendation III (S3) constituted 4.20%. Land recommendation IV (N) was not detected.

Table 4. Estimated value of *Coffea liberica* productivity in Pinogu Plateau

LMU	Elevation Value (m sl)	Elevation Y (ton ha⁻¹)	Slope Value (%)	Slope Y (ton ha⁻¹)	pH H2O Value	pH H2O Y (ton ha⁻¹)	C-Organic Value (%)	C-Organic Y (ton ha⁻¹)	CEC Value (cmol)	CEC Y (ton ha⁻¹)	BS Value (%)	BS Y (ton ha⁻¹)	Ava-P Value (ppm)	Ava-P Y (ton ha⁻¹)	Ȳ (ton ha⁻¹)	Stdev	RMSE
1	293	0.49	3	1.69	5.82	0.31	1.59	0.40	19.24	0.30	32.75	0.39	13.87	0.20	0.60	0.49	0.52
2	307	0.53	3	1.69	5.88	0.31	1.30	0.40	23.77	0.30	33.75	0.39	15.85	0.19	0.60	0.49	0.52
3	313	0.55	3	1.69	6.22	0.31	0.78	0.40	27.60	0.29	28.00	0.40	9.77	0.23	0.61	0.49	0.51
4	302	0.52	3	1.69	5.64	0.31	1.21	0.40	22.77	0.30	24.67	0.41	12.22	0.21	0.60	0.49	0.52
5	311	0.54	3	1.69	5.78	0.31	1.46	0.40	26.39	0.30	29.25	0.40	17.04	0.18	0.60	0.49	0.52
6	305	0.53	3	1.69	6.12	0.31	1.02	0.40	29.68	0.29	29.68	0.40	18.52	0.17	0.60	0.49	0.52
7	290	0.49	3	1.69	6.28	0.31	1.43	0.40	27.92	0.29	39.75	0.38	14.53	0.20	0.60	0.49	0.52
8	288	0.48	3	1.69	5.89	0.31	1.92	0.40	23.22	0.30	36.67	0.38	20.35	0.16	0.59	0.49	0.53
9	338	0.61	3	1.69	6.25	0.31	1.79	0.40	27.10	0.29	37.00	0.38	14.98	0.19	0.61	0.49	0.52
10	300	0.51	8	1.65	5.92	0.31	1.38	0.40	23.67	0.30	42.33	0.37	9.98	0.23	0.60	0.48	0.51
11	334	0.60	3	1.69	5.96	0.31	1.15	0.40	27.69	0.29	33.00	0.39	17.12	0.18	0.61	0.49	0.52
12	306	0.53	8	1.65	5.95	0.31	1.07	0.40	25.03	0.30	39.50	0.38	16.41	0.19	0.59	0.48	0.51
13	310	0.54	3	1.69	6.00	0.31	1.35	0.40	32.67	0.29	23.67	0.41	7.78	0.24	0.61	0.49	0.51

Remarks: LMU= land mapping unit, C-Org= C-organic, Exc= exchangeable, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, Y = productivity, m asl= meters above sea level, ppm= part per million, Stdev= standard deviation, RMSE= root mean square error.

Table 5. Value of land characteristic rating, land index, and land suitability class for *Coffea liberica*

LMU	Elevation Y (ton ha⁻¹)	Elevation LC	Slope Y (ton ha⁻¹)	Slope LC	pH H2O Y (ton ha⁻¹)	pH H2O LC	C-Organic Y (ton ha⁻¹)	C-Organic LC	CEC Y (ton ha⁻¹)	CEC LC	BS Y (ton ha⁻¹)	BS LC	Ava-P Y (ton ha⁻¹)	Ava-P LC	LI	LCS	Area ha	Area %
1	0.49	65.95	1.69	100	0.31	41.12	0.40	53.60	0.30	40.47	0.39	52.20	0.20	26.91	64	S2	70.81	2.53
2	0.53	70.80	1.69	100	0.31	41.13	0.40	53.67	0.30	39.81	0.39	51.93	0.19	25.27	62	S2	250.95	8.95
3	0.55	72.88	1.69	100	0.31	41.15	0.40	53.80	0.29	39.26	0.40	53.47	0.23	30.31	76	S1	36.34	1.30
4	0.52	69.07	1.69	100	0.31	41.11	0.40	53.69	0.30	39.96	0.41	54.36	0.21	28.28	70	S2	36.97	1.32
5	0.54	72.19	1.69	100	0.31	41.12	0.40	53.63	0.30	39.43	0.40	53.13	0.18	24.29	61	S2	849.26	30.28
6	0.53	70.11	1.69	100	0.31	41.14	0.40	53.74	0.29	38.95	0.40	53.02	0.17	23.06	56	S2	3.74	0.13
7	0.49	64.91	1.69	100	0.31	41.15	0.40	53.64	0.29	39.21	0.38	50.33	0.20	26.37	61	S2	98.53	3.51
8	0.48	64.21	1.69	100	0.31	41.13	0.40	53.51	0.30	39.89	0.38	51.16	0.16	21.54	50	S3	112.84	4.02
9	0.61	81.55	1.69	100	0.31	41.15	0.40	53.55	0.29	39.33	0.38	51.07	0.19	25.99	67	S2	305.44	10.89
10	0.51	68.37	1.65	100	0.31	41.13	0.40	53.65	0.30	39.83	0.37	49.64	0.23	30.13	71	S2	452.57	16.1
11	0.60	80.16	1.69	100	0.31	41.13	0.40	53.71	0.29	39.24	0.39	52.13	0.18	24.22	63	S2	369.42	13.17
12	0.53	70.45	1.65	100	0.31	41.13	0.40	53.73	0.30	39.63	0.38	50.40	0.19	24.81	60	S2	51.68	1.84
13	0.54	71.84	1.69	100	0.31	41.13	0.40	53.66	0.29	38.52	0.41	54.62	0.24	31.95	80	S1	165.73	5.91
								Total (ha)									2.804,28	100

Remarks: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, CEC = cation exchange capacity, BS = base saturation, Ava-P = P availability, LI = land index, LSC = land suitability classes.

4. DISCUSSION

The land suitability for liberica coffee vary between the two methods in terms of class and areas. The dominant class was highly suitable (S1) based on the limiting factor method but moderately suitable (S2) according to the parametric method. Although the land suitability class from the former technique appears to be of a high class and wide distribution, it is only based on the land characteristics and has not been linked with liberica coffee productivity. The limiting factor method has weaknesses, including the complicated interactions between land characteristics (Elsheikh et al., 2013; Hartati et al., 2018).

By contrast, the land suitability class from the parametric method is based on the performance of land characteristics and directly related to the productivity of liberica coffee in the research area. Hence, the interactions are easy to explain. According to Sitorus (2018), the parametric method has greater precision and reliability than other land evaluation methods. Its advantage is that land evaluation is easy to carry out and only consists of a few categories (Rodcha et al., 2019). Marbun et al. (2019) also stated that the superiority of this technique is calculating LSCs based on soil properties and considering all factors and mapping them in one land suitability map. The parametric method with the square root of LI uses a minimum rating to assess LSCs (Juita et al., 2020). Mathewos et al. (2018) reported that the square root LI is higher than the Storie index. For an improved land evaluation approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee, the number of limiting factors was higher in the limiting factor method than in the parametric method. The only minimum rating value in the parametric method was the low P availability. A low land suitability index should be improved to ensure that the plant grows optimally (Isramiranti et al., 2020). A land with S3 suitability class can be enhanced through various land improvement efforts to become class S2 or even S1 (Refitri et al., 2016). Low nutrient availability can be ameliorated through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be accomplished by adding organic matter and fertilizing according to the recommended fertilizer dose. The addition of organic matter can increase soil pH and C-organic content (Afandi et al., 2017; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Table 6. Comparison of land suitability classes with limiting factors and parametric methods for *Coffea liberica* in Pinogu Plateau

LMU	Land Suitability Class		Land Suitability Class		Area	
	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%
1, 7, 10	S2	II	S2	II	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	I	S2	II	1,867.46	66.59
3, 13	S2	II	S1	I	202.07	7.21
8	S1	I	S3	III	112.84	4.02
Total (ha)					2,804.28	100.00

Remark: LMU = land mapping unit; S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable

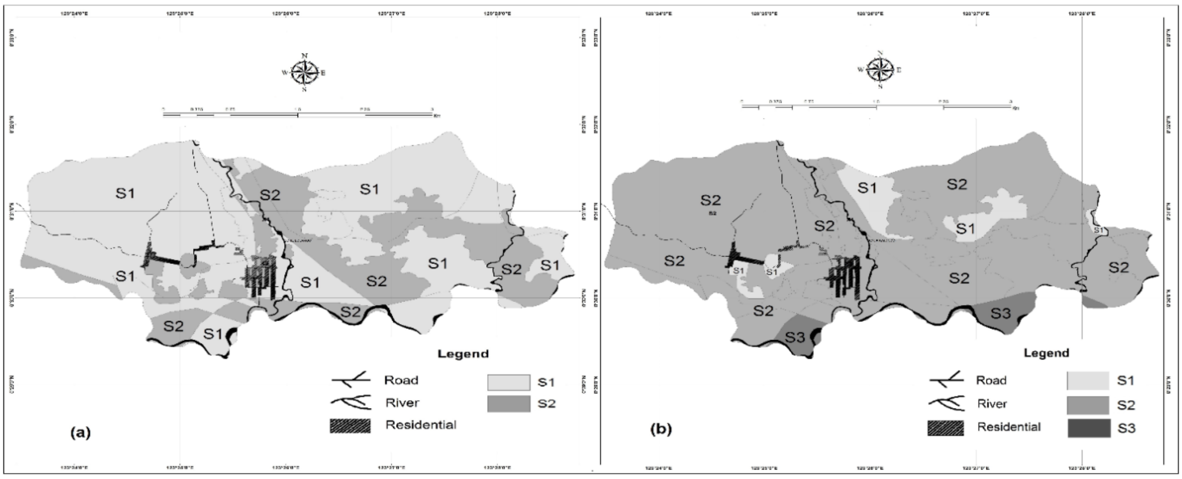

Figure 4. Comparison of land suitability classes for *Coffea liberica* in Pinogu Plateau obtained using limiting factor (a) and parametric methods (b) (Remarks: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable)

Land suitability class assessment using the limiting factor method often contrasts between LSCs and their real productivity. At LMUs 4 and 6, the existing land uses, which are irrigated rice fields and swamps that are often inundated, were classified as highly suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role; hence, the other factors can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment do not have further specifications (Abbasi et al., 2019). With the parametric method, LMUs 4 and 6 were included in the moderately suitable class (S2), which is in accordance with the conditions of land use. In principle, the parametric method assigns values at different limiting levels to land properties on a normal scale from a maximum of 100 to a minimum of 0 (Juita et al., 2020). In this case, the effect of the most limiting factor is reduced because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013).

The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric method followed the class pattern S2 > S1 > S3. In addition to calculating LSCs based on soil properties, this technique calculates all factors and places them in one land suitability map (Marbun et al., 2019). The land index obtained by the parametric method was close to the actual field conditions; the average liberica coffee productivity in the Pinogu Plateau ranges from 0.51 ton ha^{-1} to 0.61 ton ha^{-1}, and that of Pinogu coffee currently reaches 0.75 ton ha^{-1} (Martono, 2018). Ghazanchaii and Fariabi (2014) stated a significant relationship between land index and production, that is, the yield based on the range of LSCs increases with the land index. Diagnostic criteria were assessed numerically and mathematically in the parametric method to obtain LSCs (Marbun et al., 2019) and describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019).

With the limiting factor method, the land for liberica coffee was dominated by recommendation I, followed by recommendation II because the land with S1 class was wider than that with S2 class. With the parametric method, the land was dominated by recommendation II, followed by I and III because the land with S2 class was wider than those with S1 and S3 classes. For optimal liberica coffee land use, the cultivation system must be improved, such as through fertilization (Nugroho, 2015). In addition, the liberica coffee plantations in the Bogani-Nani Wartabone National Park and upstream Bone watershed must implement conservation agriculture. Coffee-based agroforestry can be applied because it affects growth and production, land and water conservation, and adds nutrients (Supriadi & Pranowo, 2016). The distribution of LSCs and the land recommendations for liberica coffee in Plato Pinogu are important for its development. According to Saidi and Suryani (2021), land suitability maps provide information on the suitability of various agricultural commodities and the distribution of limiting factors in an area.

5. CONCLUSION

The actual land suitability for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable (S3) classes with elevation, nutrient retention, and available nutrient constraints. Efforts to improve the S3 class by organic matter addition and fertilization could upgrade it to highly suitable (S1) and moderately suitable (S2) classes. The parametric method consists of S1, S2, and S3 classes because of low P nutrients. The land for liberica coffee consists of recommendations I and II according to the limiting factor method but is composed of recommendations I, II, and III according to the parametric method. Land suitability assessment using the parametric method provides more realistic land characteristics in relation to liberica coffee productivity than the limiting factor method.

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Declaration of Competing Interest

The authors declare no competing financial or personal interests that may appear and influence the work reported in this paper.

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