# **SUBMISSION**



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Thank you for submitting the manuscript, "A COMPARISON OF LAND SUITABILITY VALUES FOR ENDEMIC LIBERICA COFFEE WITH DIFFERENT METHODS, AND THEIR IMPACT ON LAND MANAGEMENT IN THE PINOGU PLATEAU, BONE BOLANGO REGENCY" to SAINS TANAH - Journal of Soil Science and Agroclimatology. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

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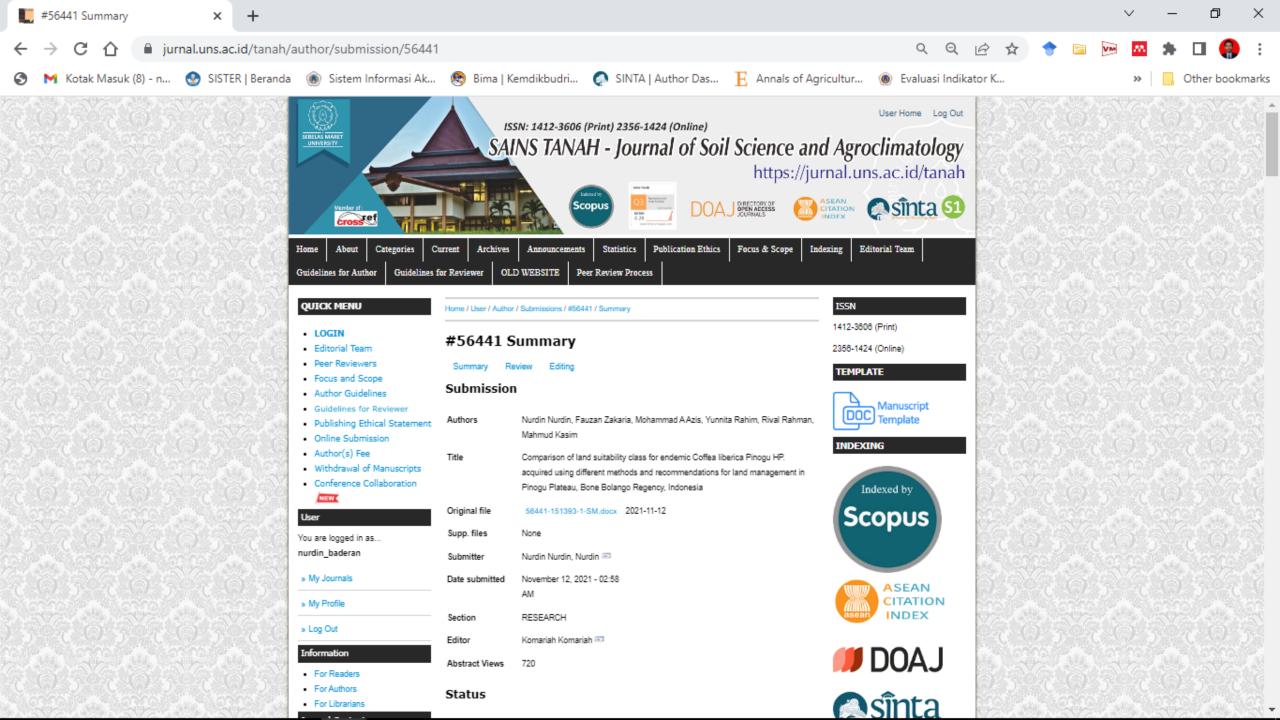
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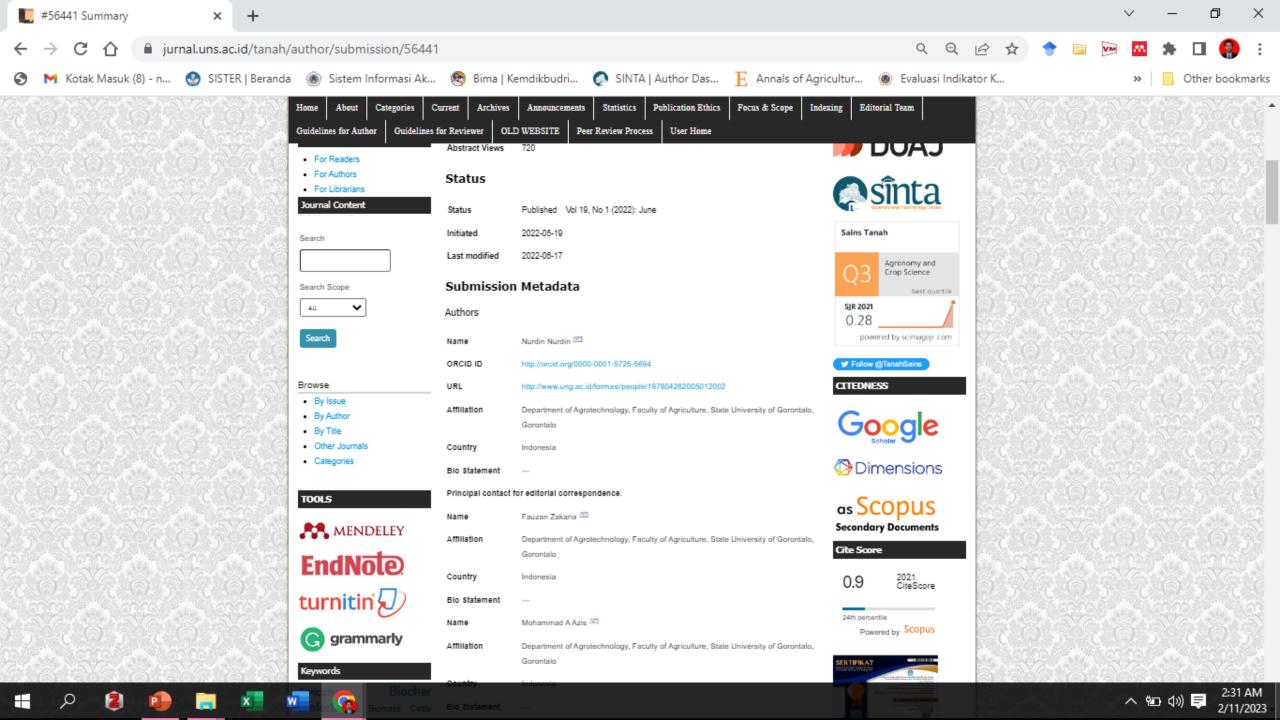
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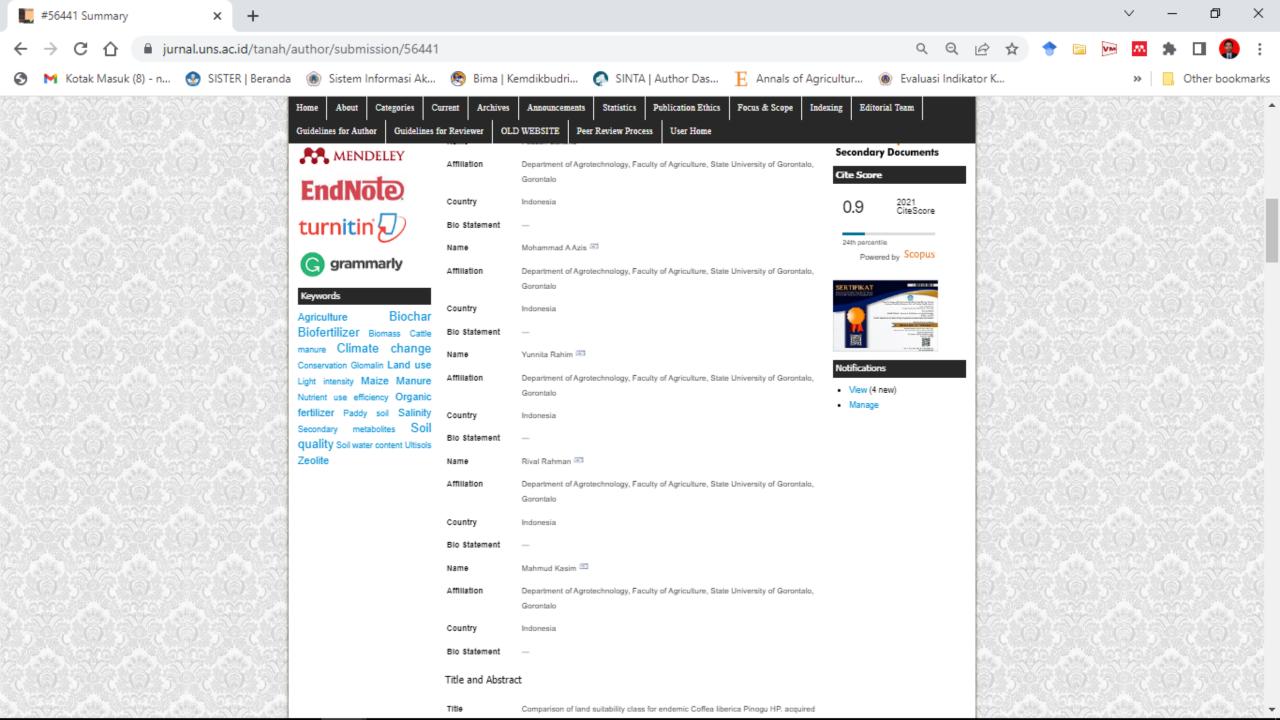
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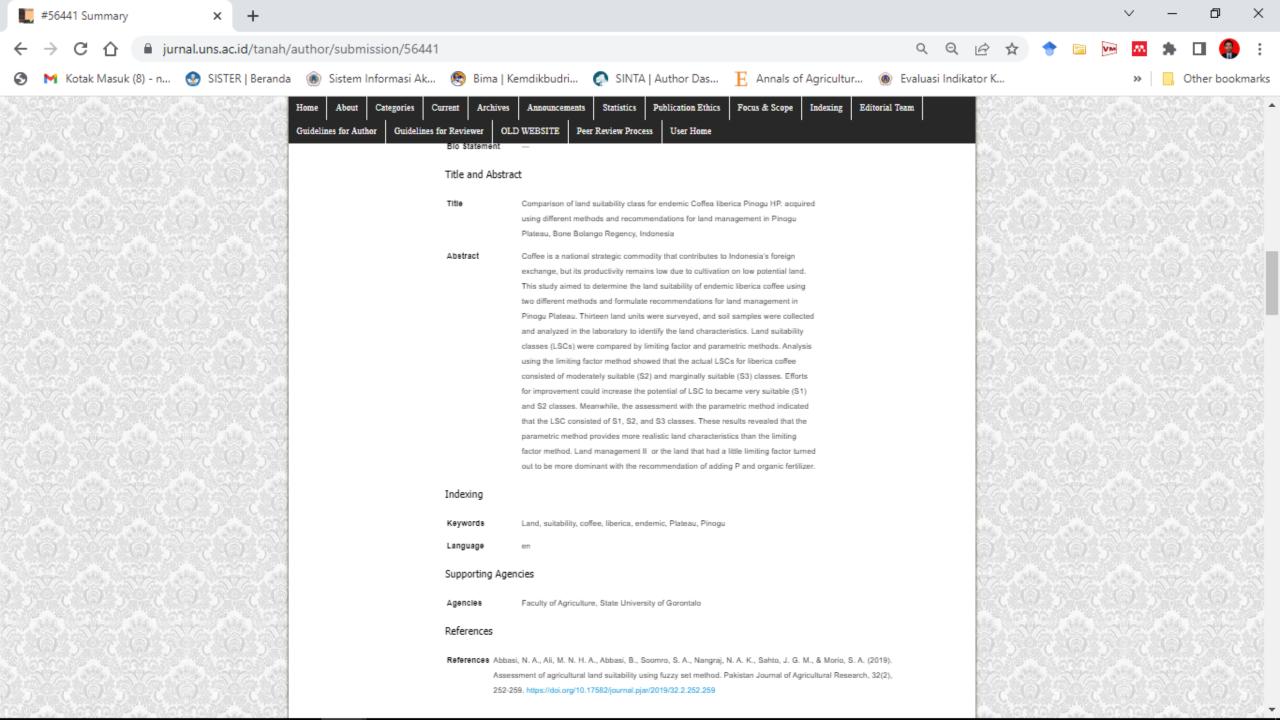
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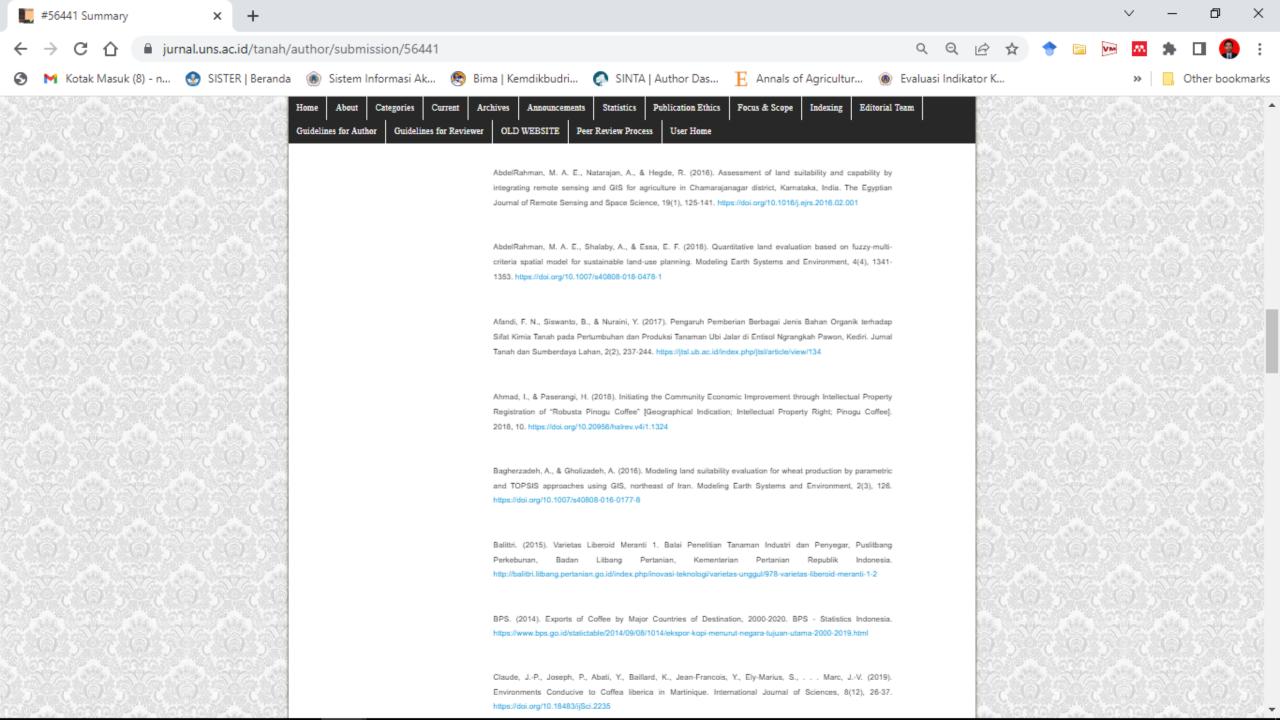
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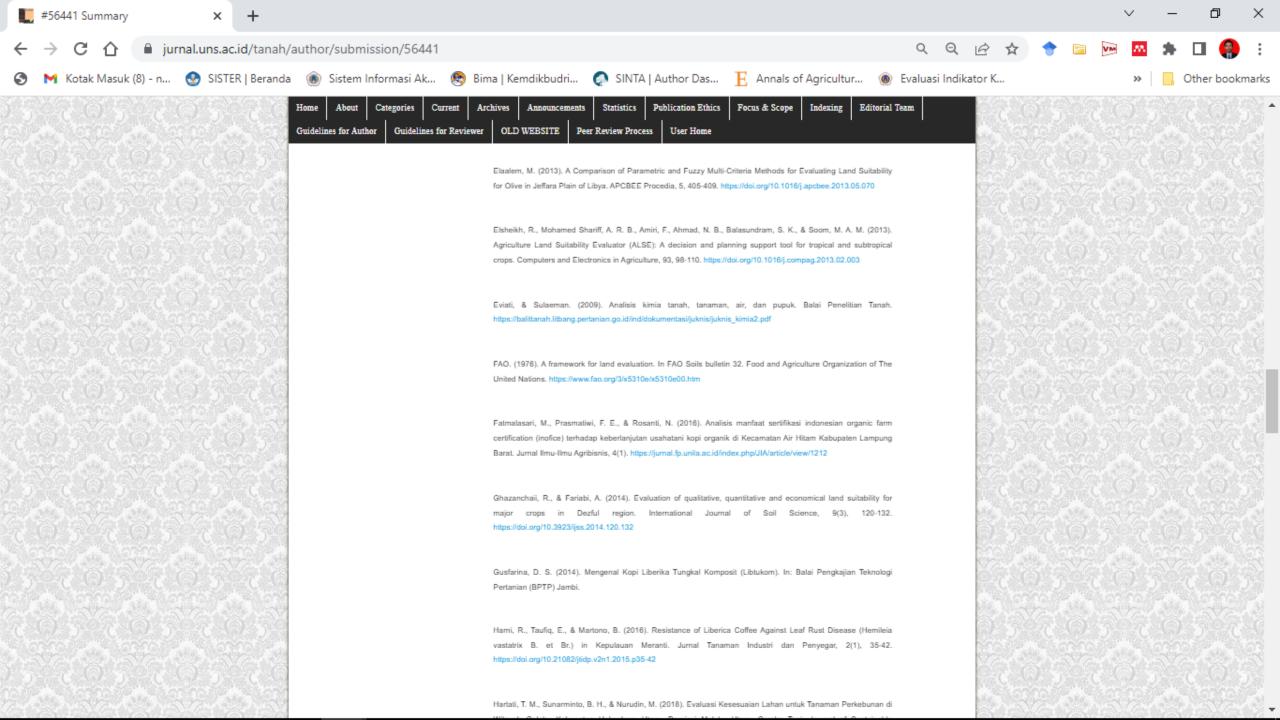


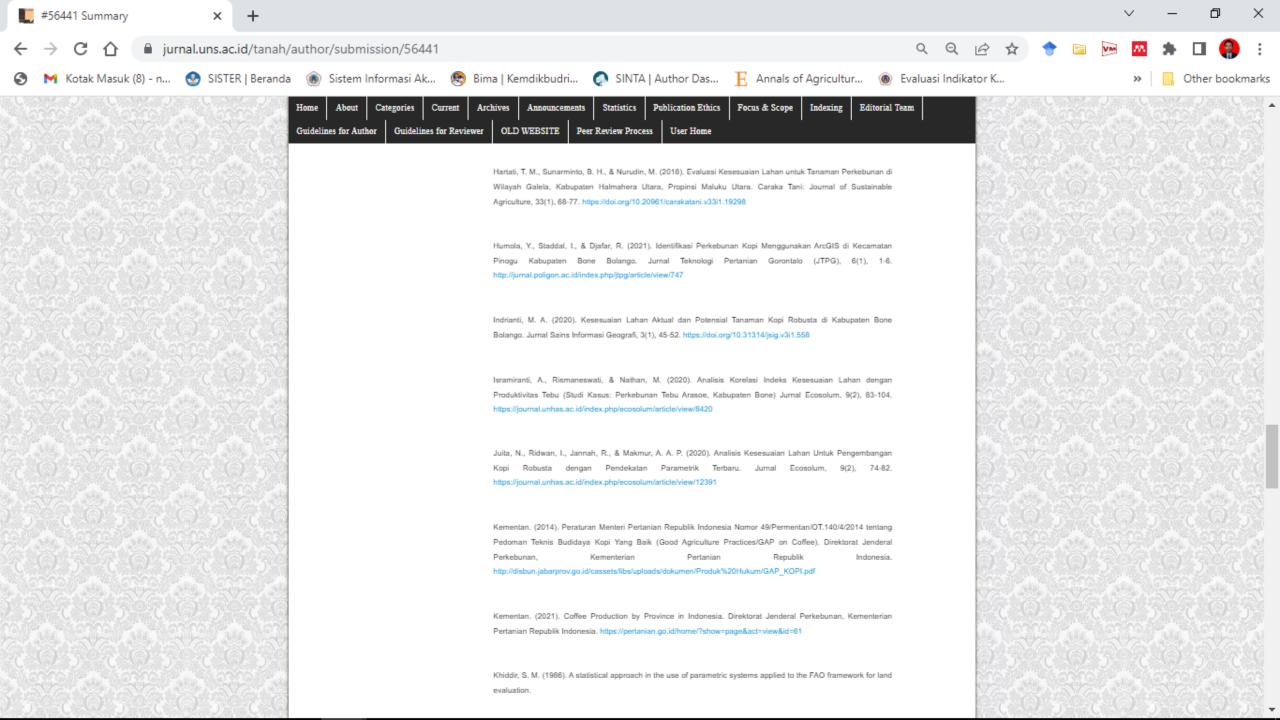


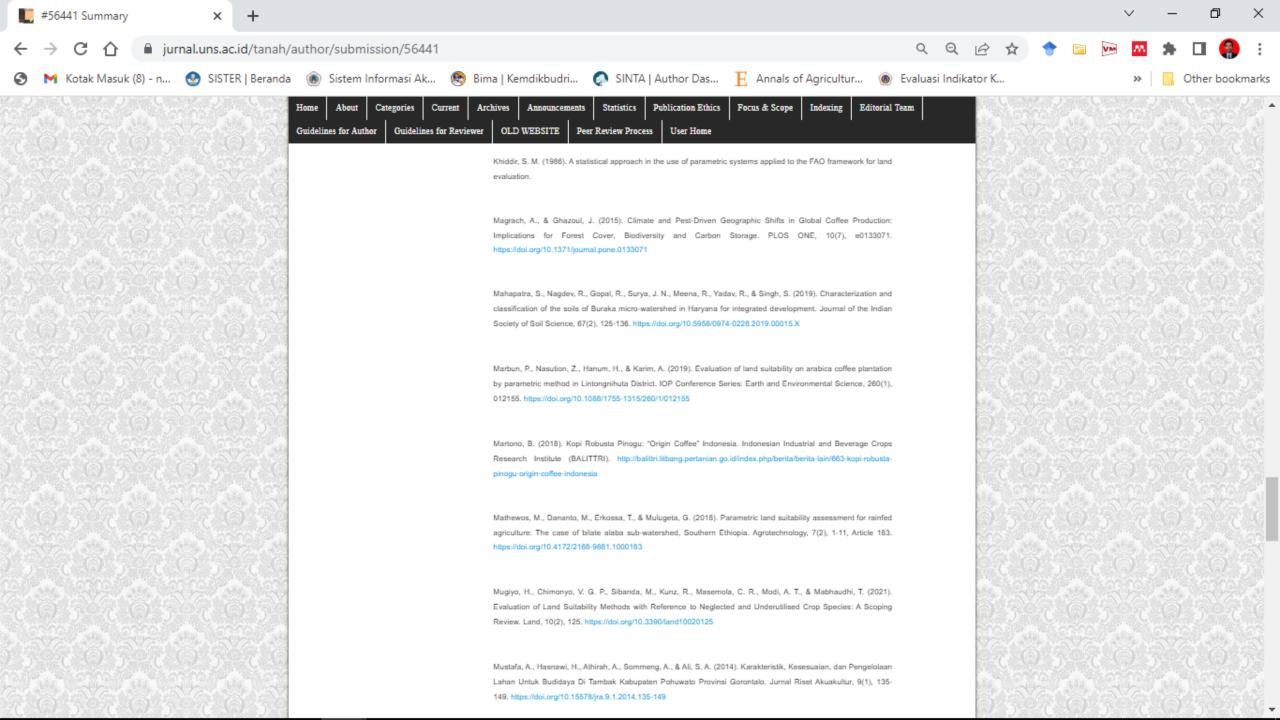


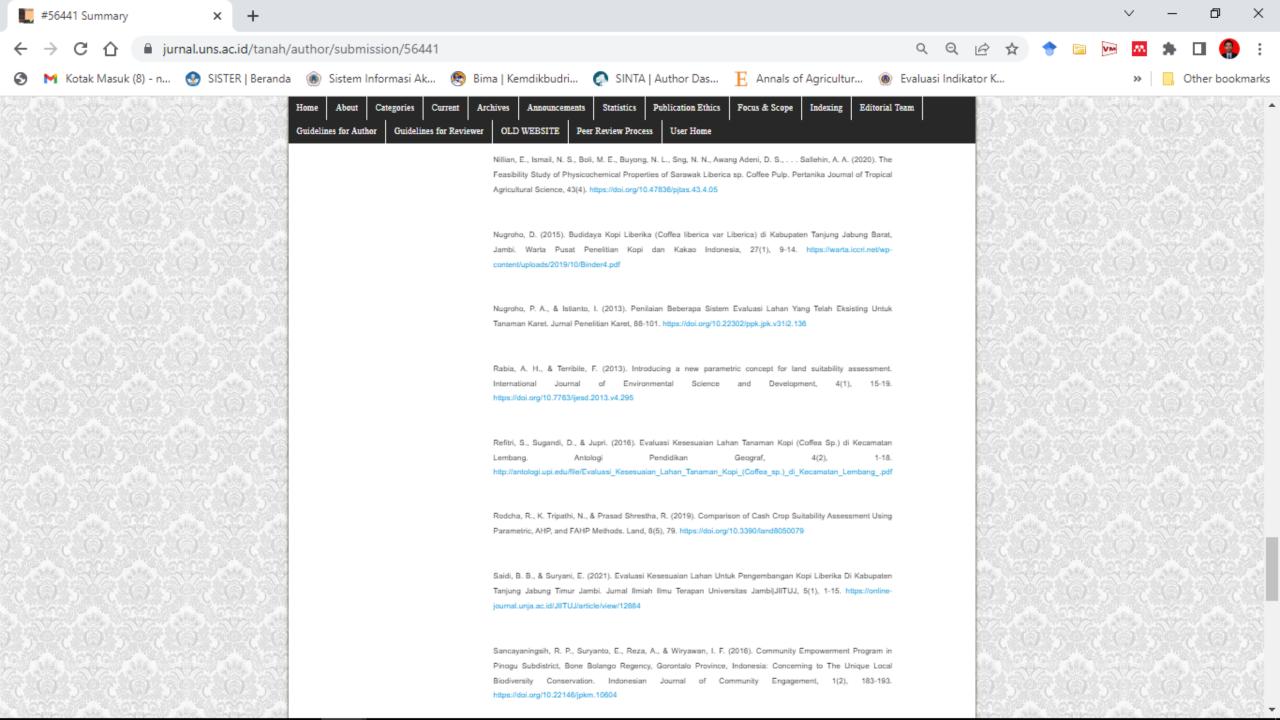


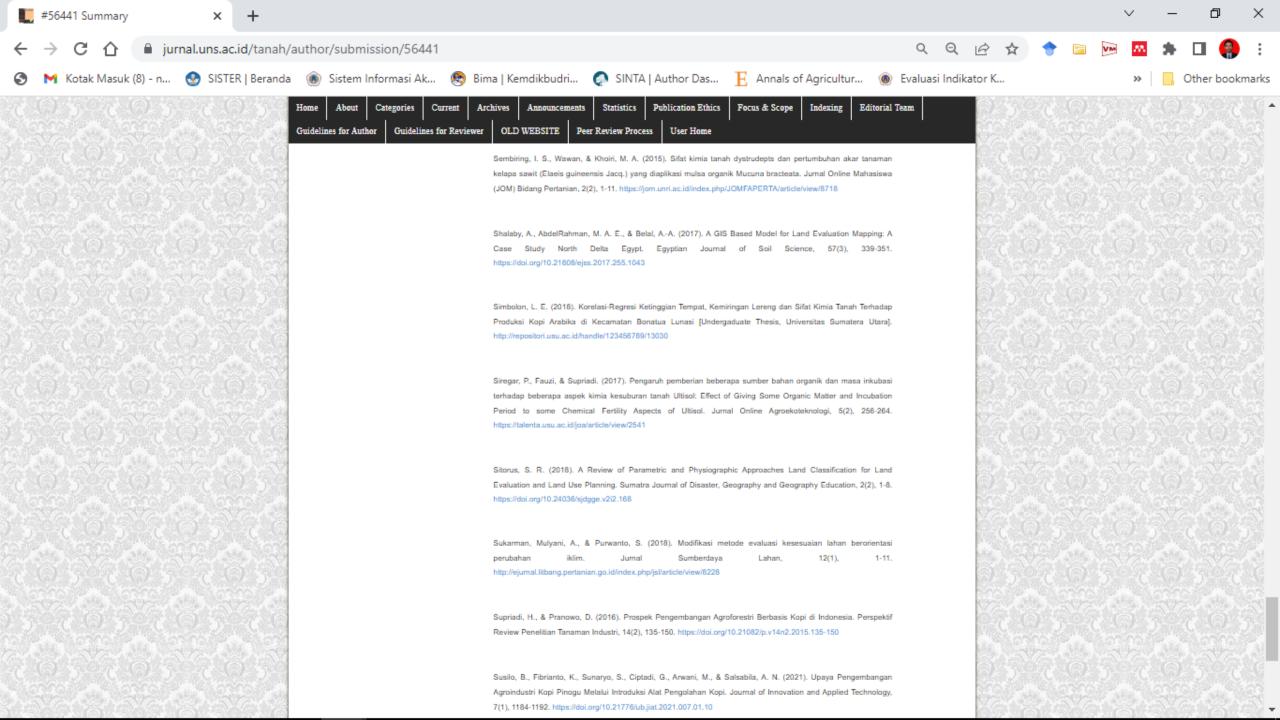


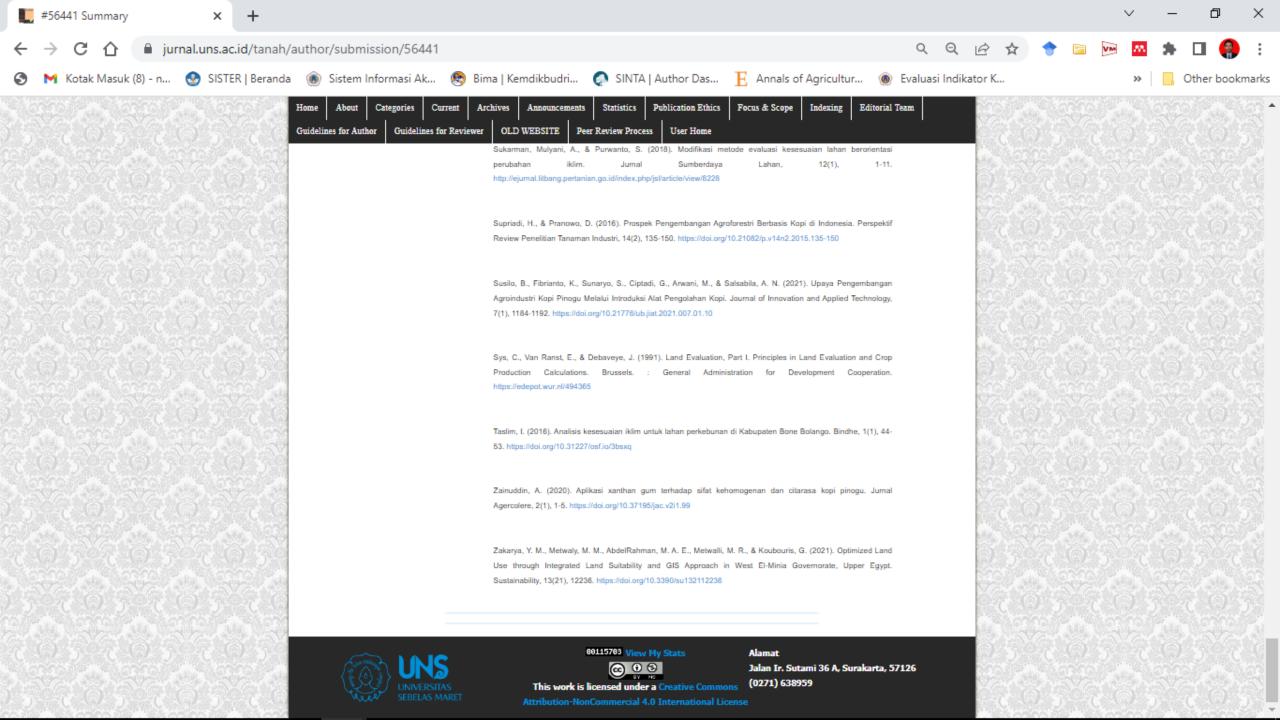












# **COVER PAGE**

# I. Manuscript Title

# A COMPARISON OF LAND SUITABILITY VALUES FOR ENDEMIC LIBERICA COFFEE WITH DIFFERENT METHODS, AND THEIR IMPACT ON LAND MANAGEMENT IN THE PINOGU PLATEAU, BONE BOLANGO REGENCY

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### VIII. The main findings and why they are important and useful.

1. Land suitability class for liberica coffee in Pinogu Plateau is the result of research that was first produced in this region and in the province of Gorontalo, both with the limiting factor method and the parametric method. Thus, the results are very important in planning and sustainable land use for liberica coffee as well as for land management in this region given its position as the upstream of the Bone watershed.

- 2. It turns out that the land suitability class using the parametric method is more sensitive and approaches the profitability conditions of Liberica coffee which are more real in the field, so that it has an impact on land management inputs that are less than the limiting factor method. Consequently, by using the land suitability class as a result of the parametric method, Liberica coffee farmers will get the efficiency of their plantation business.
- 3. The use of the coffee profitability estimating equation is proven to be able to produce profitability values that are close to the existing conditions of profitability for liberica coffee, so that the limitations of profitability data on land units can be overcome.

# IX. Why the readers of the journal would be interested in the work.

- 1. Liberica coffee is a refreshing commodity that is strategic and closely related to the daily life of coffee lovers, so its availability is needed both nationally and globally. Thus, efforts to develop coffee by intensification and extensification on existing and potential land in a sustainable manner will always be carried out.
- 2. Readers will obtain information on the potential of land resources through land suitability for liberica coffee, so that the information will become a reference for the parties to increase the production and profitability of liberica coffee in a sustainable manner.
- 3. Readers will get a choice of adequate information about the results of the land suitability assessment for liberica coffee using the limiting factor method and the parametric method, so that later decision making will be wiser and wiser, especially with regard to Pinogu Plateau's position as the headwaters of the Bone watershed.

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# X. Suggested Reviewers : (at least 2 reviewers)

# A COMPARISON OF LAND SUITABILITY VALUES FOR ENDEMIC LIBERICA COFFEE WITH DIFFERENT METHODS, AND THEIR IMPACT ON LAND MANAGEMENT IN THE PINOGU PLATEAU, BONE BOLANGO REGENCY

# ABSTRACT

7 Coffee is a national strategic commodity that contributes to the country's foreign exchange but these 8 profitability is still low due to cultivation on low potential land. Study aimed to determine the land 9 suitability value of endemic liberica coffee with two different methods and their impact on land 10 management in Pinogu Plateau. The 13 land units were surveyed and analyzed the soil samples in the 11 laboratory to obtain data of the land characteristic selected. Comparison of different land suitability 12 values using the limiting factor method and the parametric method. The results showed that the land 13 suitability class for liberica coffee using the limiting factor method actually consisted of a moderately 14 suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention and available 15 nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, so that it has the potential to become a very suitable class (S1) and S2 class. Meanwhile, the land suitability class 16 17 using the parametric method consisted of S1, S2 and S3 classes due to low P nutrients. The input for 18 land management with the parametric method was P fertilization only compared to the limiting factor 19 method that more input of land managements.

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21 Keywords: Land, suitability, coffee, liberica, endemic, Pinogu.

# 23 INTRODUCTION

Coffee is still a strategic commodity for Indonesia because it can contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 tons, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 tons or increased by 2.62% from the previous year with a value of 809,158,900 US\$ (BPS, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 tons or 0.02% of the total national coffee production (Ditjendbun, 2021).

31 Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively 32 flat and wide (496 km2) at an altitude of > 300 m above sea level, and is surrounded by hills and 33 mountains so that it can be called the Pinogu plateau. This district has long been known as a coffee 34 producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021). 35 According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee plantation and makes it their main commodity because the productivity level of this coffee is the 36 37 highest compared to other commodities. Pinogu coffee has a distinctive taste, including: a more 38 fragrant aroma, tastes like jackfruit with a moderate acidity level, so it is not too bitter and is safe in 39 the stomach (Liputan6.com, 2017). The advantages of pinogu coffee include the fact that local farmers 40 do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin, 2020), 41 so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes from 42 robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021).

Liberica coffee (Coffea Liberica) has been planted since 1875 (Sancayaningsih et al., 2016) and is endemic because this species only exists and grows in an area (KBBI, 2021) in this case in Pinogu District only for Gorontalo Province. Liberika coffee has the advantage of good taste (Gusfarina, 2014), relatively low caffeine content (1.1-1.3%), so it is safe for consumers who are sensitive to caffeine (Puslitkoka, 2014). This condition makes pinogu coffee an icon and superior commodity of Bone

6 Bolango Regency (Zainuddin, 2020).

7 Efforts to maintain the sustainability of liberika coffee products have so far encountered several 8 obstacles, one of which is the low profitability of the coffee. Martono (2018) reports that although 9 Pinogu Coffee has become global, its profitability is still low at only 0.75 tons ha<sup>-1</sup> year<sup>-1</sup>. In fact, the profitability of liberica coffee can reach 1.69 - 1.98 tons ha<sup>-1</sup> (Balittri, 2015). The report of BPS 10 11 Kabupaten Bone Bolango (2021) shows that Pinogu District has a coffee plantation area of 282.63 ha 12 or the largest in this district (66.21%) with new production of 32.43 tons. Such conditions will affect 13 the availability of coffee raw materials to meet market demand later. The low profitability of coffee is 14 thought to be because coffee cultivation is carried out on land that is not in accordance with the 15 potential of the land. Land potential is generally determined based on the characteristics and quality 16 of the land inherent in the land (Nurdin, 2021).

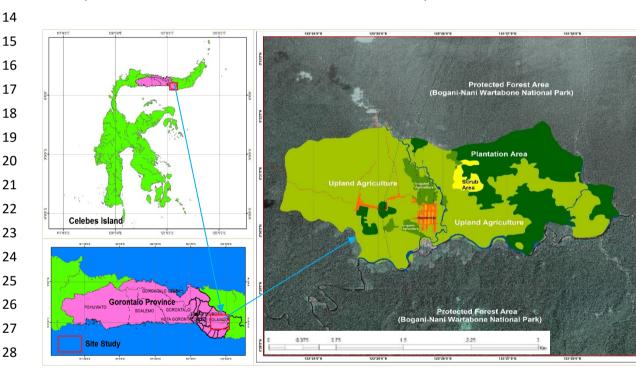
17 Until now, there is no available information about the potential of land for the development of Liberika 18 Coffee in the Pinogu Plateau area, except for the potential of land for Robusta coffee because it is more 19 developed as a research report by Taslim (2018); Indrianti (2020) and Humola et al., (2021). Even 20 though this liberica coffee is not only endemic, it is also more resistant to pests and plant diseases 21 (Harni et al., 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests (Gusfarina, 22 2014; Balittri, 2015). Ignorance of coffee planters regarding land potential will greatly affect the 23 profitability of the land in supporting the growth and production of liberica coffee itself. Diversity of 24 land characteristics and quality will be responded differently by each plant because each land-based 25 commodity requires certain requirements to be able to grow and produce optimally (Rayes, 2007; 26 Ritung et al., 2011).

27 Sustainable land management requires land evaluation methods that contain plant growth 28 requirements for optimal production (Suryani, 2012) through land suitability assessment so that a land 29 can be used productively and sustainably (Mustafa et al., 2014), including land suitability assessment 30 for Liberika Coffee. However, often the results of land suitability assessments do not match the facts 31 of actual production achievements in the field (Nurdin, 2021). Previous research on land suitability 32 assessment for coffee mostly used the limiting factor method. The limiting factor method is used to 33 determine the class based on the lowest constraint, while the parametric method is determined based 34 on the interaction between all variables (Baja, 2012). In the parametric method, there is a combination 35 of soil characteristics that affect agricultural production using mathematical equations (Elaalem, 2013) 36 so that interactions between land characteristics can be minimized. Furthermore, Bagherzadeh & 37 Gholizadeh (2016) stated that in the parametric approach, different land suitability classes are defined 38 as completely separate groups and separated from each other with different and consistent ranges. 39 Differences in land suitability values due to the use of different methods on a land will have an impact 40 on differences in land management. Therefore, the aim of the study was to determine the land 41 suitability value of endemic liberica coffee with two different methods and their impact on land 42 management in Pinogu Plateau, Bone Bolango Regency.

# 1 MATERIAL AND METHODS

### 2 Site Study

3 This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Geographically, the research location is located at 0°24'5.4" - 0°38'29.04" North Latitude to 4 5 123°18'38.52" – 123°33'15.48" South Latitude covering an area of 2,804.28 ha with an elevation of 300 – 338 m above sea level (Fig. 1). Annual rainfall is 2,541.90 mm with an average monthly rainfall 6 7 ranging from 19.00 mm to 408.18 mm (BPP Pinogu District, 2021), so based on the agro-climatic zone 8 (Oldeman and Darmiyati, 1977), the research area is included in the agro-climatic zone. C1 because 9 the dry month (<100 mm) is only 1 month and 6 months is wet (>200 mm). The monthly air 10 temperature in the study area fluctuates between 24.34°C to 25.79°C while the relative humidity is between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52% to 70.50%. while 11 12 the monthly wind speed is between 2 knots to 2.60 knots (BMKG Moutong, 2021). The research area 13 is the upstream of the Bone watershed which flows to Tomini Bay.



29

Figure 1. Research Location Map

### 30 Soil Survey and Land Observation

31 A set of soil survey tools, including: soil knife, pH meter, meter, hoe, spade, machete, clinometer and 32 F marker. Meanwhile, the materials used consist of: soil maps, geological maps, slope maps, landform 33 maps, land use maps, maps 1: 12,000 scale land unit, soil profile card, plastic bag, rubber band, label paper, climate data from the local BMKG station for 5 years (2015-2021) and soil samples for laboratory 34 35 analysis. This field research uses a soil survey method on a scale of 1: 12,000 by observing the 36 characteristics of the land in 13 land units. Furthermore, field observations were carried out to 37 determine the characteristics of the land in the form of elevation and slope. After that, 1 kg of soil 38 samples were taken for analysis in the laboratory.

39

# 1 Soil Laboratory Analysis

- 2 Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil
- 3 properties based on research parameters refers to the soil analysis procedure according to Eviyati &
- 4 Sulaeman (2009). Soil reaction parameters (pH H<sub>2</sub>O) were determined with a pH meter extracted in a
- 5 solution of 1:2.5 soil and water. Organic carbon content using the Walkley and Black method. The P
- 6 content was available using the Olsen method, while the cation exchange capacity (CEC) was extracted
- 7 with 1N NH<sub>4</sub>OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, while base saturation was
- 8 determined by calculation. All soil data and selected land characteristic data are input in dbf or xls
- 9 format.

# 10 Land Suitability Assesment

- 11 The deskwork in the suitability assessment is carried out based on the parameters of the selected land
- 12 characteristics which are the same between the limiting factor method and the parametric method.
- 13 Assessment of land suitability classes using the limiting factor method follows the land evaluation
- 14 framework according to FAO (1976) from the order and class categories (suitable, not suitable) to units.
- 15 Furthermore, the data on land characteristics and quality were compared with the selected Liberika
- 16 Coffee land suitability criteria (Table 1) according to the Ditjendbun (2014), in order to obtain the
- 17 actual land suitability class along with the limiting factors for land use. The limiting factor is then
- 18 improved, so that the potential land suitability class is obtained.

19	<b>Table 1</b> . Selected Land Suitability Criteria for Liberica Coffee	
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Land use requirements /land		Land suitab	ility class	
characteristics	S1	S2	S3	N
Elevation-el (m sl)	300 – 500	600 - 800; 0 - 300	800 - 1.000	>1,000
Slopes-sl (%)	0-8	8 – 25	25 – 45	>45
Nutrient retention (nr):				
Soil pH	5.5 - 6.0	6.1 - 7.0	7.1 - 8.0	>8.0
C-organic (%)	2 – 5	1 – 2; 5 – 10	0.5 - 1.0; 10 - 15	<0.5; >15
Cation exchange capacity (cmol)	>15	10 – 15	5 - 10	<5
Base saturation (%)	>35	20-35	<20	
Nutrient availability (na):				
Availability of P (ppm)	>16	10 – 15	<10	
Remark: (Ditiendbun, 2014), modifed				

20 Remark: (Ditjendbun, 2014), modifed.

21 Meanwhile, in assessing land suitability using the parametric method, it is estimated that the 22 profitability of coffee uses several equations (Simbolon, 2018) based on the parameters of the selected 23 soil and land properties, namely: Y = -2.672+0.026X (elevation), Y = 17,190-0.090X (slope), Y = -2.672+0.026X24 3.055+0.005X (soil pH), Y = 4.050-0.019X (C-organic), Y = -28.796+0.621X (P availability), Y = 32.450-25 0.109X (CEC), and Y = 0.457-0.002X (base saturation). In this case, Y = estimated production 26 (tonnes/ha), X = soil and land properties parameters, CEC = cation exchange capacity, and KB = base 27 saturation. The assumption of optimal profitability of liberica coffee used is 0.75 tons ha<sup>-1</sup> (Martono, 28 2018). In order to assess the accuracy of the estimated profitability of the liberica coffee, it was 29 analyzed using the Root Mean Square Error (RMSE) with the following equation:

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

31

1 where: RMSE = root mean square error, At = actual profitability (ton  $ha^{-1}$ ), Ft = estimated profitability

2 (ton ha<sup>-1</sup>), and n = number of data. The smaller or closer to 0 the value of the RMSE, the more accurate

3 the prediction results will be. Furthermore, land suitability assessment for liberica coffee uses a land

4 index of root mean square (Khiddir, 1986), namely:

$$LI = LC_{min} \sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}}$$

where: LI = land index; LC<sub>min</sub> = minimum LC rating; A, B, C, ..., N = other LC in beside the minimum LC.
Determination of land suitability classification based on LI is calculated from all LC which is influenced
by the profitability of liberica coffee and has a certain land suitability class. LI score criteria using LI
value criteria (Sys et al., 1991), namely: S1 class (very 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
class N (not suitable) with value 0 – 25. All data and information obtained are described and presented
in tabular form, while their spacial distribution is presented in map form.

# 14 **RESULTS**

# 15 Land Suitability Based on Limiting Factor Method

The result of matching the land suitability criteria with the land characteristics resulted in the actual land suitability class for liberica coffee in Pinogu Plateau (Table 2, Figure 2). It seems that the actual land suitability class was moderately suitable (S2) which was more dominant in an area of 2,149.64 ha or 76.66% compared to the marginally suitable class (S3) which was only 654.64 ha or only 23.34%. While the very suitable class (S1) and not suitable (N) has not found in the results of this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in the Pinogu Plateau include: nutrient retention (C-organic, base saturation and soil pH) and nutrients availability (P

availability). In addition, there was an elevation limiting factor at LMU 1 and LMU 7.

24	Table 2. The Actu	ial Land Su	itability Cla	ass for Liberic	a Coffee in	Pinogu Pla	iteau
	Elevation	Slope	pН	C-Organic	CEC	BS	Ava-P

	Eleva	tion	Slo	ре	pl	Н	C-Or	ganic	CE	С	B	S	Ava	i-P		Area	а
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual 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
							A	Area (ha)								2,804.28	100

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS =
 base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

27 After making efforts to improve the actual land suitability class against the limiting factor, all LMUs can

28 be upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be repaired

29 because of the elevation limiting factor (Table 3, Figure 2). The limiting factors for nutrient retention,

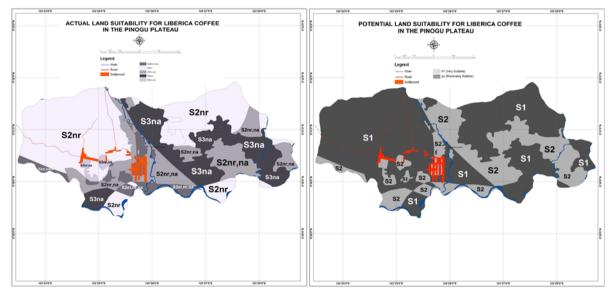
30 both pH, C-organic, and low base saturation were corrected with the addition of organic matter, while

- 1 the limiting factor for available nutrients in the form of low P availability was corrected with the
- 2 addition of P fertilizer. The most dominant potential land suitability class was very suitable (S1)
- 3 covering an area of 1,980.30 ha or 70.62% and the rest including S2 class covering an area of 823.98
- 4 ha or 29.38% only.

Actual	Actual	Lingiting Frankson	<b>F</b> ( <b>Cb</b> -	Potential	Area		
LMU	LSC	Limiting Factors	Efforts	LSC	ha	%	
1, 7	S2el,nr,na	Elevation, nutrient retention (C- organic, base saturation), nutrient availability (available of P)	Can not 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)	<ul> <li>Addition of organic</li> <li>material</li> <li>Addition of P fertilizer</li> </ul>	S1	593,36	8.95	
3	S3nr,na	Nutrient retention (C-organic),	- Addition of organic material	S2	36,34	1.30	
		nutrient availability (available of P)	- Addition of P fertilizer		ha 169,34 593,36		
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic material	S1	1.386,94	30.28	
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.1	
		Luas (Ha)			2.804,28	10	

5 **Table 3**. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

6 Remark: LMU = land mapping unit, LSC = land suitability class.



7 8

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Figure 2. Actual and Potential of Land Suitability Class for Liberica Coffee in Pinogu Plateau

# 10 Land Suitability Based on Parametric Method

11 The results of the profitability analysis (productivity) of liberica coffee based on each land 12 characteristic showed that the highest profitability was obtained on the slope characteristics which averaged 1.69 tons ha<sup>-1</sup>, while the lowest profitability was obtained on the available P characteristics 13 14 which only ranged from 0.16 - 0.24 ton ha<sup>-1</sup> with an average of 0.20 ton ha<sup>-1</sup> (Table 4). The remaining 15 land characteristics has an average profitability 0.30. The results of the RMSE analysis on the alleged 16 profitability of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13 are smaller (0.51) 17 compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE value of 0.52 (Table 18 4). The profitability of liberica coffee will affect the land characteristic index which will ultimately 19 determine the land index and land suitability class for liberica coffee.

- 1 It seems that the relative land characteristic index values follow the pattern of profitability for liberica
- 2 coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the optimal value
- 3 was the slope characteristic which averaged a value of 100 (Table 5), while the lowest land
- 4 characteristic index value was obtained for the available P which an average of P availability index of
- 5 26.39 only. The remaining land characteristics are relatively diverse but the average value of the land
- 6 characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index
- 7 value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index,
- 8 respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value which was 50 only. The
- 9 remaining LMUs get land index values ranged from 50 71.

Characteristic							LMU						
/Provitability	1	2	3	4	5	6	7	8	9	10	11	12	13
Elev. (m sl)	293	307	313	302	311	305	290	288	338	300	334	306	310
Y (ton ha-1)	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
Slo. (%)	3	3	3	3	3	3	3	3	3	8	3	8	3
Y (ton ha-1)	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
pН	5.82	5.88	6.22	5.64	5.78	6.12	6.28	5.89	6.25	5.92	5.96	5.95	6.00
Y (ton ha-1)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
C-Org (%)	1.59	1.30	0.78	1.21	1.46	1.02	1.43	1.92	1.79	1.38	1.15	1.07	1.35
Y (ton ha <sup>-1</sup> )	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
CEC (cmol)	19.24	23.77	27.60	22.77	26.39	29.68	27.92	23.22	27.10	23.67	27.69	25.03	32.6
Y (ton ha <sup>-1</sup> )	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
BS (%)	32.75	33.75	28.00	24.67	29.25	29.68	39.75	36.67	37.00	42.33	33.00	39.50	23.6
Y (ton ha <sup>-1</sup> )	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
Av-P (ppm)	13.87	15.85	9.77	12.22	17.04	18.52	14.53	20.35	14.98	9.98	17.12	16.41	7.78
Y (ton ha <sup>-1</sup> )	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
Ϋ́ (ton ha⁻¹)	0.60	0.60	0.61	0.60	0.60	0.60	0.60	0.59	0.61	0.60	0.61	0.59	0.61
Stdev	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.49	0.48	0.49
RMSE	0.52	0.52	0.51	0.52	0.52	0.52	0.52	0.53	0.52	0.51	0.52	0.51	0.52

10 **Table 4**. Estimated Value of Liberica Coffee Provitability in Pinogu Plateau

11 Remark: LMU = land mapping unit, Elev. = elevation, Slo. = slopes, C-Org = C-organic, Exc. = exchangeable, CEC = cation

axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million, Stdev = standard
 deviation, RMSE = root mean square error.

14 Based on the value of the land index, the land suitability class for liberica coffee was more dominant

15 S2 with covering an area of 2,489.37 ha or 88.77% (Table 5). Meanwhile, the S1 class was 202.07 ha or

16 7.21% and the S3 class was 112.84 ha or 4.02% only without not suitable class (N).

17 Table 5. Value of Land Characteristics Index, Land Index and Land Suitability Class for Liberica Coffee

Profitability							LMU						
/LC Value	1	2	3	4	5	6	7	8	9	10	11	12	13
Y-El. (ton ha⁻¹)	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
LC-El.	65.95	70.80	72.88	69.07	72.19	70.11	64.91	64.21	81.55	68.37	80.16	70.45	71.84
Y-SI. (ton ha⁻¹)	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
LC-Slo.	100	100	100	100	100	100	100	100	100	100	100	100	100
Y-pH (ton ha⁻¹)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
LC-pH	41.12	41.13	41.15	41.11	41.12	41.14	41.15	41.13	41.15	41.13	41.13	41.13	41.13
Y-Corg. (ton ha⁻¹)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
LC-Corg.	53.60	53.67	53.80	53.69	53.63	53.74	53.64	53.51	53.55	53.65	53.71	53.73	53.66
Y-CEC (ton ha⁻¹)	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
LC-CEC	40.47	39.81	39.26	39.96	39.43	38.95	39.21	39.89	39.33	39.83	39.24	39.63	38.52

Y-BS (ton ha⁻¹)	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
LC-BS	52.20	51.93	53.47	54.36	53.13	53.02	50.33	51.16	51.07	49.64	52.13	50.40	54.62
Y-Ava.P (ton ha⁻¹)	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
LC-Ava.P	26.91	25.27	30.31	28.28	24.29	23.06	26.37	21.54	25.99	30.13	24.22	24.81	31.95
LI	64	62	76	70	61	56	61	50	67	71	63	60	80
							-						
LSC	S2	S2	S1	S2	S2	S2	S2	S3	S2	S2	S2	S2	S1
LSC Area (ha)	S2 70.81	S2 250.95	S1 36.34	S2 36.97	S2 849.26	S2 3.74	S2 98.53	S3 112.84	S2 305.44	S2 452.57	S2 369.42	S2 51.68	S1 165.73

1

Remark: LMU = land mapping unit, Y = profitability, LC = land characteristic rating, Exc. = exchangeable, Ava. = availability, El. 2 = elevation, SI. = slope, Corg. = C-organic, K = potassium, Ca = calcium, Mg = magnesium, Na = natrium, P = phosfor, CEC =

3 cation exchange capacity, BS = base saturatio, LI = land index, LSC = land suitability classes.

#### 4 **Comparison of Land Suitability Classes and Their Impact on Land Management**

5 Based on the results of the land suitability assessment using the limiting factor method and the

6 parametric method, there were similarities in land suitability class (S2 = S2) covering an area of 621.91

7 ha or 22.18% at LMU 1, 7 and LMU 10 with (Table 6, Figure 3). While the difference in results between

8 the two methods follows a pattern:  $S1 \neq S2$  covering 1,867.46 ha or 66.59% at LMU 2, 4, 5, 6, 9, 11,

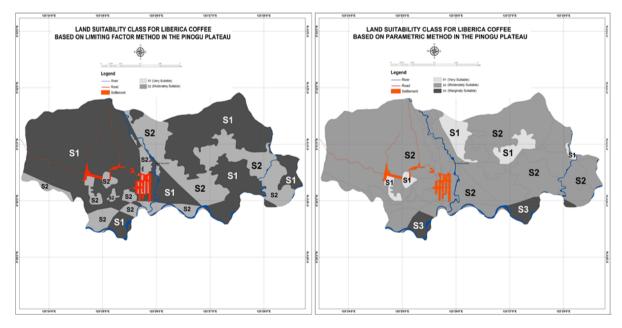
9 and LMU 12, S2 ≠ S1 pattern covering an area of 202.07 ha or 7.21% at LMU 3 and LMU 13, while the

10  $S1 \neq S3$  pattern was only 112.84 ha or 4.02% at LMU 8.

#### Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for 11 Liberica Coffee in Pinogu Plateau 12

LIDCHCU COIN				
LMU	Land Suitab	Area		
LIVIO	Limiting Factor Method	Parametric Method	ha	%
1, 7, 10	S2	S2	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	S2	1,867.46	66.59
3, 13	S2	S1	202.07	7.21
8	S1	S3	112.84	4.02
	Area (ha)		2,804.28	100.00

13 Remark: LMU = land mapping unit.





15 Figure 3. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau 16

# 1 DISCUSSION

2 The level of land suitability for a particular use, both in actual and after repair or potential conditions, 3 was known as land suitability (Ritung et al., 2011), where the results become the basis for developing 4 a land use on a large scales (Hardjowigeno & Widiatmaka, 2007). In land suitability assessment for 5 liberica coffee using the limiting factor method on the actual land suitability class, it turned out that 6 the S2 class was more dominant with the limiting factors of elevation, nutrient retention (C-organic, 7 base saturation and soil pH) and available nutrients (availability of P). All of these limiting factors can 8 be improved, except for the elevation limiting factor which according to Hardjowigeno & Widiatmaka 9 (2007) cannot be improved. The ideal elevation for Liberica coffee is between 300 – 500 m above sea 10 level (Ditjendbun, 2014). Land suitability class S3 has limiting factors for nutrient retention (C-organic) and available nutrients (availability of P). The limiting factors for nutrient retention (C-organic, base 11 saturation and soil pH) can be improved by adding organic matter (Suheri et al., 2018) because it can 12 13 increase soil pH and C-organic (Afandi et al., 2015; Siregar et al., 2017), and base saturation (Sembiring 14 et al., 2015). While the availability of nutrients (available P) can be improved by applying fertilizers 15 (Suheri et al., 2018), especially P fertilizers. According to Singh et al., (2003) and Mahapatra et al., 16 (2019), land management can be done by adding organic matter and fertilization according to the 17 recommended dose of fertilizer. Land management factors play a very important role in maintaining soil organic matter content (Dariah et al., 2005). Meanwhile, according to (Suheri et al., 2018), 18 19 fertilization is intended to add nutrients to the soil for plants. 20 The improvement of the actual suitability class was able to increase the liberica coffee class in Pinogu

Plateau to a potential land suitability whose assessment results were dominant in the S1 class 21 22 compared to S2, without the S3 class and the N class with the class S1 > S2 pattern, so that the area 23 and distribution of these classes also increased. This is in line with the statement (Refitri et al., 2016) 24 that land that has a suitability class of S3 has the opportunity to be improved through various land 25 improvement efforts, so that it becomes class S2 to class S1. However, the land suitability class 26 assessment using the limiting factor method has not at all linked the class acquisition to the 27 profitability of liberica coffee itself, so that there is often a contrast between the land suitability class 28 and its real profitability. In fact, at LMU 4 and LMU 6, the existing land use conditions are irrigated rice 29 fields, rainfed rice fields and swamps that are often flooded, so the actual land suitability class S2 and 30 potential land suitability class S1 for liberica coffee still need to be checked again in the field.

31 In principle, the parametric method in evaluating land suitability is to assign values to different limiting 32 levels of land properties, on a normal scale given a maximum value of 100 to a minimum value of 0 33 (Juita et al., 2020). In land suitability assessment for liberica coffee in Pinogu Plateau with parametric 34 method dominated by S2 class followed by S1 class and S3 class without class N with class pattern S2 > 35 S1 > S3. It seems that the land index obtained by the parametric method is closer to the real conditions 36 in the field, where the average production of liberica coffee in the Pinogu Plateau ranges from 0.51 to 37 0.61 tons ha<sup>-1</sup>, while the profitability of Pinogu coffee currently reaches 0.75. ton ha-1 (Martono, 2018). 38 This parametric method with the square root of the land index uses a minimum rating to assess land 39 suitability classes (Juita et al., 2020), so that the minimum rating in this case the low availability of P 40 nutrients causes the low land suitability class. A low land suitability index should be improved so that the plant grows optimally (Isramiranti et al., 2020). Low nutrient availability can be corrected by 41 42 applying fertilizers (Suheri et al., 2018), especially P.

43

1 The difference in land suitability class between the two methods has an impact on land management

- 2 for liberica coffee in Pinogu Plateau. In the limiting factor method, differences in land suitability classes
- 3 were caused by prominent limiting factors (Table 3) including: elevation, nutrient retention (pH,
- 4 organic C, base saturation), and nutrient availability (available P). This condition resulted in more land
- 5 management inputs needed, including the addition of organic matter and P fertilization. Meanwhile,
- 6 the difference in land suitability classes in the parametric method was caused by the interaction of all
- soil and land properties parameters with the profitability of liberica coffee in Pinogu Plateau (Table 5),
- although the levels of The available P yields the lowest profitability and the slope with the highest
  profitability. Thus, the low availability of P nutrients can be corrected by only P fertilization, resulting
- 10 in fewer inputs for land management.
- 11 This research uses both land suitability assessment methods to be the same and consistent in terms 12 of the type and number of land characteristics used, so that differences in land suitability assessment 13 results are not caused by differences in land characteristics. but because of the final value produced
- by both methods. In addition, the use of land characteristics is also based on the availability of
- 15 mathematical equations to estimate the profitability of liberica coffee because only LMU 3, 9, 10 and
- 16 LMU 13 have liberica coffee plants and have produced 0.75 tons ha<sup>-1</sup> (Martono, 2018). Meanwhile,
- 17 other LMUs do not have liberica coffee plants, so the profitability must be estimated.
- Limitations in the type and number of land characteristics used in this study are a challenge for future research to be added or expanded to other land characteristics. This refers to the land suitability criteria for liberica coffee (Ditjendbun, 2014), where the characteristics of land that have not been used in this study are: annual rainfall, dry month length, effective depth, texture, rock on the surface, inundation, drainage class, nitrogen (N), salinity and aluminum saturation (Al). However, the results of this study have shown that the use of the parametric method is more sensitive to the increase or decrease in the profitability of liberica coffee and better describes the real conditions in the field.
- 25 Meanwhile, the use of the limiting factor method, although the land suitability class for liberica coffee
- 26 is higher, is in contrast to the facts on the ground, so it must be re-checked.
- Research on land suitability for liberica coffee in Pinogu Plateau is the first research conducted in this area and in the province of Gorontalo. Therefore, Liberika coffee, which is endemic to the Pinogu Plateau, Bone Bolango Regency, Gorontalo Province, needs to be maintained in the future. In addition to the Pinogu area, liberica coffee is also found in the Modayag District, East Bolaang Mongondow Regency, North Sulawesi Province, which is still an island of Sulawesi and was endemic in the province, so that future research is interesting and can be focused on comparing land suitability classes for
- 33 liberica coffee in the two regions and their agronomic performance and profitability.
- 34

# 35 CONCLUSION

The actual of land suitability class for liberica coffee using the limiting factor method consists of moderately suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention and nutrient availability constraints. Efforts to improve the class by adding organic matter and fertilization, so the potential class were very suitable class (S1) and S2 class. The parametric method consists of S1, S2 and S3 class. The input for land management using the parametric method was P fertilization only.

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# 5 STATEMENT OF COMPETING INTEREST

6 The authors state that no competing financial or personal interests might arise and affect the work7 reported in this paper.

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# [STJSSA] Editor Decision (RESUBMIT FOR REVIEW)

1 pesan

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Dear Nurdin:

We have reached a decision regarding your submission to SAINS TANAH -Journal of Soil Science and Agroclimatology, "A COMPARISON OF LAND SUITABILITY VALUES FOR ENDEMIC LIBERICA COFFEE WITH DIFFERENT METHODS, AND THEIR IMPACT ON LAND MANAGEMENT IN THE PINOGU PLATEAU, BONE BOLANGO REGENCY".

Our decision is: Resubmit for Review (due date is: 2021-12-08)

Please revise your article according to the comments. We believe you can revise it quickly before the due date.

We kindly ask you to resubmit the corrected article under the same identification number. To do so, login into the system, click on this article and fill in the "Upload Author Version" input field.

The revised version must include highlighted changes and modifications recommended in the first revision to ensure that all reviewer(s)' comments were considered.

Should you have any questions about the system or other functions please do not hesitate to contact us.

Best regards.

STJSSA Editorial Team Department of Soil Science, Faculty of Agriculture, Sebelas Maret University sainstanah@mail.uns.ac.id 24 November 2021 pukul 16.14

#### **COVER PAGE**

### I. Manuscript Title A COMPARISON OF LAND SUITABILITY VALUES FOR ENDEMIC LIBERICA COFFEE WITH DIFFERENT METHODS, AND THEIR IMPACT ON LAND MANAGEMENT IN THE PINOGU PLATEAU, BONE BOLANGO REGENCY

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#### VIII. The main findings and why they are important and useful.

1. Land suitability class for liberica coffee in Pinogu Plateau is the result of research that was first produced in this region and in the province of Gorontalo, both with the limiting factor method and the parametric method. Thus, the results are very important in planning and sustainable land use for liberica coffee as well as for land management in this region given its position as the upstream of the Bone watershed.

- 2. It turns out that the land suitability class using the parametric method is more sensitive and approaches the profitability conditions of Liberica coffee which are more real in the field, so that it has an impact on land management inputs that are less than the limiting factor method. Consequently, by using the land suitability class as a result of the parametric method, Liberica coffee farmers will get the efficiency of their plantation business.
- 3. The use of the coffee profitability estimating equation is proven to be able to produce profitability values that are close to the existing conditions of profitability for liberica coffee, so that the limitations of profitability data on land units can be overcome.

#### IX. Why the readers of the journal would be interested in the work.

- Liberica coffee is a refreshing commodity that is strategic and closely related to the daily life of coffee lovers, so its availability is needed both nationally and globally. Thus, efforts to develop coffee by intensification and extensification on existing and potential land in a sustainable manner will always be carried out.
- 2. Readers will obtain information on the potential of land resources through land suitability for liberica coffee, so that the information will become a reference for the parties to increase the production and profitability of liberica coffee in a sustainable manner.
- 3. Readers will get a choice of adequate information about the results of the land suitability assessment for liberica coffee using the limiting factor method and the parametric method, so that later decision making will be wiser and wiser, especially with regard to Pinogu Plateau's position as the headwaters of the Bone watershed.

			/		
No	Name	Affiliation	Review Interests	E-mail address And Phone contact number (if any)	ORCID ID/ Scopus ID/ Linkedin ID/ Google Scholar Profile Address
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# A COMPARISON OF LAND SUITABILITY VALUES FOR ENDEMIC LIBERICA COFFEE WITH DIFFERENT METHODS, AND THEIR IMPACT ON LAND MANAGEMENT IN THE PINOGU PLATEAU, BONE BOLANGO REGENCY

#### ABSTRACT

7 Coffee is a national strategic commodity that contributes to the country's foreign exchange but these 8 profitability is still low due to cultivation on low potential land. Study aimed to determine the land 9 suitability value of endemic liberica coffee with two different methods and their impact on land 10 management in Pinogu Plateau. The 13 land units were surveyed and analyzed the soil samples in the 11 laboratory to obtain data of the land characteristic selected. Comparison of different land suitability 12 values using the limiting factor method and the parametric method. The results showed that the land suitability class for liberica coffee using the limiting factor method actually consisted of a moderately 13 suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention and available 14 nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, so that it 15 16 has the potential to become a very suitable class (S1) and S2 class. Meanwhile, the land suitability class 17 using the parametric method consisted of S1, S2 and S3 classes due to low P nutrients. The input for land management with the parametric method was P fertilization only compared to the limiting factor 18 19 method that more input of land managements.

21 Keywords: Land, suitability, coffee, liberica, endemic, Pinogu.

#### 23 INTRODUCTION

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Coffee is still a strategic commodity for Indonesia because it can contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 tons, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 tons or increased by 2.62% from the previous year with a value of 809,158,900 US\$ (BPS, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 tons or 0.02% of the total national coffee production (Ditjendbun, 2021).

31 Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively flat and wide (496 km2) at an altitude of > 300 m above sea level, and is surrounded by hills and 32 33 mountains so that it can be called the Pinogu plateau. This district has long been known as a coffee 34 producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021). 35 According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee 36 plantation and makes it their main commodity because the productivity level of this coffee is the 37 highest compared to other commodities. Pinogu coffee has a distinctive taste, including: a more 38 fragrant aroma, tastes like jackfruit with a moderate acidity level, so it is not too bitter and is safe in 39 the stomach (Liputan6.com, 2017). The advantages of pinogu coffee include the fact that local farmers 40 do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin, 2020), 41 so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes from

42 robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021).

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Commented [B33]: What is the scientific name for this variety? Commented [B34]: What do you mean by impact? Please revise the title appropriately

**Commented [B35]:** Please close the abstract with implication of the study

**Commented [B36]:** The previous studies are insufficient, especially regarding:

-The land suitability of liberica coffee worldwide

- The commodities which are suitable (according to land suitability analysis method) in the study site and surroundings

Liberica coffee (Coffea Liberica) has been planted since 1875 (Sancayaningsih et al., 2016) and is
endemic because this species only exists and grows in an area (KBBI, 2021) in this case in Pinogu District
only for Gorontalo Province. Liberika coffee has the advantage of good taste (Gusfarina, 2014),
relatively low caffeine content (1.1-1.3%), so it is safe for consumers who are sensitive to caffeine
(Puslitkoka, 2014). This condition makes pinogu coffee an icon and superior commodity of Bone
Bolango Regency (Zainuddin, 2020).

7 Efforts to maintain the sustainability of liberika coffee products have so far encountered several 8 obstacles, one of which is the low profitability of the coffee. Martono (2018) reports that although 9 Pinogu Coffee has become global, its profitability is still low at only 0.75 tons ha<sup>-1</sup> year<sup>-1</sup>. In fact, the 10 profitability of liberica coffee can reach 1.69 - 1.98 tons ha-1 (Balittri, 2015). The report of BPS Kabupaten Bone Bolango (2021) shows that Pinogu District has a coffee plantation area of 282.63 ha 11 12 or the largest in this district (66.21%) with new production of 32.43 tons. Such conditions will affect 13 the availability of coffee raw materials to meet market demand later. The low profitability of coffee is 14 thought to be because coffee cultivation is carried out on land that is not in accordance with the 15 potential of the land. Land potential is generally determined based on the characteristics and quality 16 of the land inherent in the land (Nurdin, 2021).

17 Until now, there is no available information about the potential of land for the development of Liberika 18 Coffee in the Pinogu Plateau area, except for the potential of land for Robusta coffee because it is more 19 developed as a research report by Taslim (2018); Indrianti (2020) and Humola et al., (2021). Even 20 though this liberica coffee is not only endemic, it is also more resistant to pests and plant diseases 21 (Harni et al., 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests (Gusfarina, 22 2014; Balittri, 2015). Ignorance of coffee planters regarding land potential will greatly affect the 23 profitability of the land in supporting the growth and production of liberica coffee itself. Diversity of 24 land characteristics and quality will be responded differently by each plant because each land-based 25 commodity requires certain requirements to be able to grow and produce optimally (Rayes, 2007; 26 Ritung et al., 2011).

27 Sustainable land management requires land evaluation methods that contain plant growth 28 requirements for optimal production (Survani, 2012) through land suitability assessment so that a land 29 can be used productively and sustainably (Mustafa et al., 2014), including land suitability assessment 30 for Liberika Coffee. However, often the results of land suitability assessments do not match the facts 31 of actual production achievements in the field (Nurdin, 2021). Previous research on land suitability 32 assessment for coffee mostly used the limiting factor method. The limiting factor method is used to determine the class based on the lowest constraint, while the parametric method is determined based 33 34 on the interaction between all variables (Baja, 2012). In the parametric method, there is a combination 35 of soil characteristics that affect agricultural production using mathematical equations (Elaalem, 2013) 36 so that interactions between land characteristics can be minimized. Furthermore, Bagherzadeh & 37 Gholizadeh (2016) stated that in the parametric approach, different land suitability classes are defined 38 as completely separate groups and separated from each other with different and consistent ranges. 39 Differences in land suitability values due to the use of different methods on a land will have an impact 40 on differences in land management. Therefore, the aim of the study was to determine the land 41 suitability value of endemic liberica coffee with two different methods and their impact on land 42 management in Pinogu Plateau, Bone Bolango Regency.

#### 1 MATERIAL AND METHODS

#### 2 Site Study

3 This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. 4 Geographically, the research location is located at 0°24'5.4" - 0°38'29.04" North Latitude to 123°18'38.52" - 123°33'15.48" South Latitude covering an area of 2,804.28 ha with an elevation of 5 300 – 338 m above sea level (Fig. 1). Annual rainfall is 2,541.90 mm with an average monthly rainfall 6 7 ranging from 19.00 mm to 408.18 mm (BPP Pinogu District, 2021), so based on the agro-climatic zone 8 (Oldeman and Darmiyati, 1977), the research area is included in the agro-climatic zone. C1 because 9 the dry month (<100 mm) is only 1 month and 6 months is wet (>200 mm). The monthly air 10 temperature in the study area fluctuates between 24.34°C to 25.79°C while the relative humidity is 11 between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52% to 70.50%, while the monthly wind speed is between 2 knots to 2.60 knots (BMKG Moutong, 2021). The research area 12 13 is the upstream of the Bone watershed which flows to Tomini Bay.

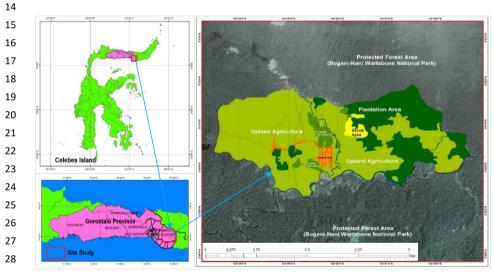


Figure 1. Research Location Map

#### 30 Soil Survey and Land Observation

31 A set of soil survey tools, including: soil knife, pH meter, meter, hoe, spade, machete, clinometer and 32 F marker. Meanwhile, the materials used consist of: soil maps, geological maps, slope maps, landform 33 maps, land use maps, maps 1: 12,000 scale land unit, soil profile card, plastic bag, rubber band, label 34 paper, climate data from the local BMKG station for 5 years (2015-2021) and soil samples for laboratory 35 analysis. This field research uses a soil survey method on a scale of 1: 12,000 by observing the characteristics of the land in 13 land units. Furthermore, field observations were carried out to 36 37 determine the characteristics of the land in the form of elevation and slope. After that, 1 kg of soil 38 samples were taken for analysis in the laboratory.

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#### 1 **Soil Laboratory Analysis**

2 Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil properties based on research parameters refers to the soil analysis procedure according to Eviyati & 3 4 Sulaeman (2009). Soil reaction parameters (pH H<sub>2</sub>O) were determined with a pH meter extracted in a 5 solution of 1:2.5 soil and water. Organic carbon content using the Walkley and Black method. The P 6 content was available using the Olsen method, while the cation exchange capacity (CEC) was extracted 7 with 1N NH<sub>4</sub>OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, while base saturation was 8 determined by calculation. All soil data and selected land characteristic data are input in dbf or xls 9 format.

#### 10 Land Suitability Assesment

11 The deskwork in the suitability assessment is carried out based on the parameters of the selected land

12 characteristics which are the same between the limiting factor method and the parametric method.

13 Assessment of land suitability classes using the limiting factor method follows the land evaluation

14 framework according to FAO (1976) from the order and class categories (suitable, not suitable) to units.

Furthermore, the data on land characteristics and quality were compared with the selected Liberika 15

16 Coffee land suitability criteria (Table 1) according to the Ditjendbun (2014), in order to obtain the

17 actual land suitability class along with the limiting factors for land use. The limiting factor is then

18 improved, so that the potential land suitability class is obtained. Table 1. Selected Land Suitability Criteria for Liberica Coffee 19

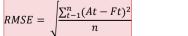
Land use requirements /land	Land suitability class							
characteristics	S1	S2	S3	Ν				
Elevation-el (m sl)	300 - 500	600 - 800; 0 - 300	800 - 1.000	>1,000				
Slopes-sl (%)	0-8	8 – 25	25 – 45	>45				
Nutrient retention (nr):								
Soil pH	5.5 - 6.0	6.1 - 7.0	7.1 - 8.0	>8.0				
C-organic (%)	2 – 5	1 - 2; 5 - 10	0.5 - 1.0; 10 - 15	<0.5; >15				
Cation exchange capacity (cmol)	>15	10 – 15	5 – 10	<5				
Base saturation (%)	>35	20-35	<20					
Nutrient availability (na):								
Availability of P (ppm)	>16	10 - 15	<10					
Availability of P (ppm)	>16	10 – 15	<10					

20 Remark: (Ditjendbun, 2014), modifed.

21 Meanwhile, in assessing land suitability using the parametric method, it is estimated that the 22 profitability of coffee uses several equations (Simbolon, 2018) based on the parameters of the selected soil and land properties, namely: Y = -2.672+0.026X (elevation), Y = 17,190-0.090X (slope), Y = 23 24 3.055+0.005X (soil pH), Y = 4.050-0.019X (C-organic), Y = -28.796+0.621X (P availability), Y = 32.450-25 0.109X (CEC), and Y = 0.457-0.002X (base saturation). In this case, Y = estimated production (tonnes/ha), X = soil and land properties parameters, CEC = cation exchange capacity, and KB = base 26 27 saturation. The assumption of optimal profitability of liberica coffee used is 0.75 tons ha<sup>-1</sup> (Martono,

28 2018). In order to assess the accuracy of the estimated profitability of the liberica coffee, it was

- analyzed using the Root Mean Square Error (RMSE) with the following equation: 29
- 30 31



Example: Y=ax+b ... . (1)

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1 where: RMSE = root mean square error, At = actual profitability (ton ha<sup>-1</sup>), Ft = estimated profitability

2 (ton ha<sup>-1</sup>), and n = number of data. The smaller or closer to 0 the value of the RMSE, the more accurate

3 the prediction results will be. Furthermore, land suitability assessment for liberica coffee uses a land

4 index of root mean square (Khiddir. 1986). namelv:

$$LI = LC_{min} \sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}}$$

6 where: LI = land index; LC<sub>min</sub> = minimum LC rating; A, B, C, ..., N = other LC in beside the minimum LC. 7 Determination of land suitability classification based on LI is calculated from all LC which is influenced 8 by the profitability of liberica coffee and has a certain land suitability class. LI score criteria using LI 9 value criteria (Sys et al., 1991), namely: S1 class (very suitable) with a value of 75 – 100, S2 class 10 (moderately suitable) with a value of 50 – 75, S3 class (marginally suitable) with a value of 25 – 50, and 11 class N (not suitable) with value 0 – 25. All data and information obtained are described and presented 12 in tabular form, while their spacial distribution is presented in map form.

#### 14 RESULTS

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#### 15 Land Suitability Based on Limiting Factor Method

16 The result of matching the land suitability criteria with the land characteristics resulted in the actual 17 land suitability class for liberica coffee in Pinogu Plateau (Table 2, Figure 2). It seems that the actual

17 failed suitability class for fiberica concern ringge rateau (fable 2, righte 2). It seems that the actual 18 land suitability class was moderately suitable (S2) which was more dominant in an area of 2,149.64 ha

19 or 76.66% compared to the maTable 3rginally suitable class (S3) which was only 654.64 ha or only

20 23.34%. While the very suitable class (S1) and not suitable (N) has not found in the results of this

21 assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in the

22 Pinogu Plateau include: nutrient retention (C-organic, base saturation and soil pH) and nutrients

availability (P availability). In addition, there was an elevation limiting factor at LMU 1 and LMU 7.

#### 24 **Table 2**. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

	Eleva	tion	Slo	pe	pl	H	C-Or	ganic	CE	С	B	S	Ava	a-P	-	Area	3
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual 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

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS =
 base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

27 After making efforts to improve the actual land suitability class against the limiting factor, all LMUs can

28 be upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be repaired

29 because of the elevation limiting factor (Table 3, Figure 2). The limiting factors for nutrient retention,

30 both pH, C-organic, and low base saturation were corrected with the addition of organic matter, while

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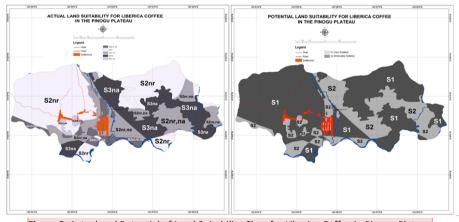
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- 1 the limiting factor for available nutrients in the form of low P availability was corrected with the
- 2 addition of P fertilizer. The most dominant potential land suitability class was very suitable (S1)
- 3 covering an area of 1,980.30 ha or 70.62% and the rest including S2 class covering an area of 823.98
- 4 ha or 29.38% only.

#### 5 Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual	Limiting Factors	Efforts	Potential	Area	a
LIVIO	LSC	Limiting Factors	Enorts	LSC	ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C- organic, base saturation), nutrient availability (available of P)	Can not be fixed (elevation)	S2	169,34	2.5
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	<ul> <li>Addition of organic material</li> <li>Addition of P fertilizer</li> </ul>	S1	593,36	8.9
3	S3nr,na	Nutrient retention (C-organic),	- Addition of organic material	S2	36,34	1.3
		nutrient availability (available of P)	- Addition of P fertilizer			
5, 6, 8, 11, 12 S2nr		Nutrient retention (C-organic, base saturation)	<ul> <li>Addition of organic material</li> </ul>	S1	1.386,94	30.2
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.1
		Luas (Ha)			2.804,28	10

6 Remark: LMU = land mapping unit, LSC = land suitability class.



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Figure 2. Actual and Potential of Land Suitability Class for Liberica Coffee in Pinogu Plateau

#### 7 8 9 10

Land Suitability Based on Parametric Method

The results of the profitability analysis (productivity) of liberica coffee based on each land 11 characteristic showed that the highest profitability was obtained on the slope characteristics which 12 averaged 1.69 tons ha<sup>-1</sup>, while the lowest profitability was obtained on the available P characteristics 13 which only ranged from 0.16 - 0.24 ton ha<sup>-1</sup> with an average of 0.20 ton ha<sup>-1</sup> (Table 4). The remaining 14 land characteristics has an average profitability 0.30. The results of the RMSE analysis on the alleged 15 16 profitability of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13 are smaller (0.51) 17 compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE value of 0.52 (Table 4). The profitability of liberica coffee will affect the land characteristic index which will ultimately 18

19 determine the land index and land suitability class for liberica coffee.

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1 It seems that the relative land characteristic index values follow the pattern of profitability for liberica

2 coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the optimal value

3 was the slope characteristic which averaged a value of 100 (Table 5), while the lowest land

4 characteristic index value was obtained for the available P which an average of P availability index of

5 26.39 only. The remaining land characteristics are relatively diverse but the average value of the land

6 characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index

7 value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index,

8 respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value which was 50 only. The

9 remaining LMUs get land index values ranged from 50 – 71.

#### 10 **Table 4.** Estimated Value of Liberica Coffee Provitability in Pinogu Plateau

						,	0						
Characteristic							LMU						
/Provitability	1	2	3	4	5	6	7	8	9	10	11	12	13
Elev. (m sl)	293	307	313	302	311	305	290	288	338	300	334	306	310
Y (ton ha⁻¹)	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
Slo. (%)	3	3	3	3	3	3	3	3	3	8	3	8	3
Y (ton ha⁻¹)	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
рН	5.82	5.88	6.22	5.64	5.78	6.12	6.28	5.89	6.25	5.92	5.96	5.95	6.00
Y (ton ha⁻¹)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
C-Org (%)	1.59	1.30	0.78	1.21	1.46	1.02	1.43	1.92	1.79	1.38	1.15	1.07	1.35
Y (ton ha⁻¹)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
CEC (cmol)	19.24	23.77	27.60	22.77	26.39	29.68	27.92	23.22	27.10	23.67	27.69	25.03	32.67
Y (ton ha⁻¹)	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
BS (%)	32.75	33.75	28.00	24.67	29.25	29.68	39.75	36.67	37.00	42.33	33.00	39.50	23.67
Y (ton ha⁻¹)	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
Av-P (ppm)	13.87	15.85	9.77	12.22	17.04	18.52	14.53	20.35	14.98	9.98	17.12	16.41	7.78
Y (ton ha⁻¹)	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
Ϋ́ (ton ha⁻¹)	0.60	0.60	0.61	0.60	0.60	0.60	0.60	0.59	0.61	0.60	0.61	0.59	0.61
Stdev	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.49	0.48	0.49
RMSE	0.52	0.52	0.51	0.52	0.52	0.52	0.52	0.53	0.52	0.51	0.52	0.51	0.51

11 Remark: LMU = land mapping unit, Elev. = elevation, Slo. = slopes, C-Org = C-organic, Exc. = exchangeable, CEC = cation

12 axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million, Stdev = standard

13 deviation, RMSE = root mean square error.

14 Based on the value of the land index, the land suitability class for liberica coffee was more dominant

15 S2 with covering an area of 2,489.37 ha or 88.77% (Table 5). Meanwhile, the S1 class was 202.07 ha or

16 7.21% and the S3 class was 112.84 ha or 4.02% only without not suitable class (N).

#### 17 Table 5. Value of Land Characteristics Index, Land Index and Land Suitability Class for Liberica Coffee

Profitability							LMU						
/LC Value	1	2	3	4	5	6	7	8	9	10	11	12	13
Y-El. (ton ha⁻¹)	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
LC-EI.	65.95	70.80	72.88	69.07	72.19	70.11	64.91	64.21	81.55	68.37	80.16	70.45	71.84
Y-SI. (ton ha⁻¹)	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
LC-Slo.	100	100	100	100	100	100	100	100	100	100	100	100	100
Y-pH (ton ha⁻¹)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
LC-pH	41.12	41.13	41.15	41.11	41.12	41.14	41.15	41.13	41.15	41.13	41.13	41.13	41.13
Y-Corg. (ton ha <sup>_1</sup> )	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
LC-Corg.	53.60	53.67	53.80	53.69	53.63	53.74	53.64	53.51	53.55	53.65	53.71	53.73	53.66
Y-CEC (ton ha <sup>-1</sup> )	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
LC-CEC	40.47	39.81	39.26	39.96	39.43	38.95	39.21	39.89	39.33	39.83	39.24	39.63	38.52

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Y-BS (ton ha⁻¹)	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
LC-BS	52.20	51.93	53.47	54.36	53.13	53.02	50.33	51.16	51.07	49.64	52.13	50.40	54.62
Y-Ava.P (ton ha <sup>-1</sup> )	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
LC-Ava.P	26.91	25.27	30.31	28.28	24.29	23.06	26.37	21.54	25.99	30.13	24.22	24.81	31.95
LI	64	62	76	70	61	56	61	50	67	71	63	60	80
LSC	S2	S2	S1	S2	S2	S2	S2	S3	S2	S2	S2	S2	S1
Area (ha)	70.81	250.95	36.34	36.97	849.26	3.74	98.53	112.84	305.44	452.57	369.42	51.68	165.73
Area (%)	2.53	8.95	1.30	1.32	30.28	0.13	3.51	4.02	10.89	16.14	13.17	1.84	5.91
Remark: LM	U = land r	napping	unit, Y =	profitab	ility, LC =	land ch	aracteris	stic rating	, Exc. = e	kchangea	ble, Ava.	= availa	oility, El.

 1
 Remark: LMU = land mapping unit, Y = profitability, LC = land characteristic rating, Exc. = exchangeable, Ava. = availability, El.

 2
 = elevation, Sl. = slope, Corg. = C-organic, K = potassium, Ca = calcium, Mg = magnesium, Na = natrium, P = phosfor, CEC =

3 cation exchange capacity, BS = base saturatio, LI = land index, LSC = land suitability classes.

#### 4 Comparison of Land Suitability Classes and Their Impact on Land Management

Based on the results of the land suitability assessment using the limiting factor method and the
parametric method, there were similarities in land suitability class (S2 = S2) covering an area of 621.91
ha or 22.18% at LMU 1, 7 and LMU 10 with (Table 6, Figure 3). While the difference in results between
the two methods follows a pattern: S1 ≠ S2 covering 1,867.46 ha or 66.59% at LMU 2, 4, 5, 6, 9, 11,
and LMU 12, S2 ≠ S1 pattern covering an area of 202.07 ha or 7.21% at LMU 3 and LMU 13, while the
S1 ≠ S3 pattern was only 112.84 ha or 4.02% at LMU 8.

#### 11 **Table 6.** Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for 12 Liberica Coffee in Pinogu Plateau

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

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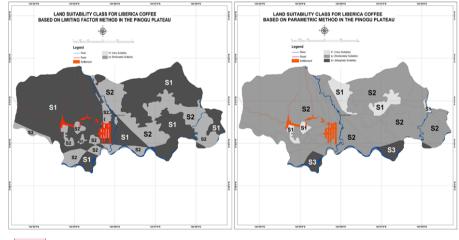
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#### 13 Remark: LMU = land mapping unit.



14 15 16

Figure 3. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu Plateau

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#### 1 DISCUSSION

2 The level of land suitability for a particular use, both in actual and after repair or potential conditions, 3 was known as land suitability (Ritung et al., 2011), where the results become the basis for developing a land use on a large scales (Hardjowigeno & Widiatmaka, 2007). In land suitability assessment for 4 5 liberica coffee using the limiting factor method on the actual land suitability class, it turned out that 6 the S2 class was more dominant with the limiting factors of elevation, nutrient retention (C-organic, 7 base saturation and soil pH) and available nutrients (availability of P). All of these limiting factors can be improved, except for the elevation limiting factor which according to Hardjowigeno & Widiatmaka 8 9 (2007) cannot be improved. The ideal elevation for Liberica coffee is between 300 - 500 m above sea 10 level (Ditjendbun, 2014). Land suitability class S3 has limiting factors for nutrient retention (C-organic) 11 and available nutrients (availability of P). The limiting factors for nutrient retention (C-organic, base 12 saturation and soil pH) can be improved by adding organic matter (Suheri et al., 2018) because it can 13 increase soil pH and C-organic (Afandi et al., 2015; Siregar et al., 2017), and base saturation (Sembiring et al., 2015). While the availability of nutrients (available P) can be improved by applying fertilizers 14 (Suheri et al., 2018), especially P fertilizers. According to Singh et al., (2003) and Mahapatra et al., 15 16 (2019), land management can be done by adding organic matter and fertilization according to the 17 recommended dose of fertilizer. Land management factors play a very important role in maintaining 18 soil organic matter content (Dariah et al., 2005). Meanwhile, according to (Suheri et al., 2018), 19 fertilization is intended to add nutrients to the soil for plants.

20 The improvement of the actual suitability class was able to increase the liberica coffee class in Pinogu 21 Plateau to a potential land suitability whose assessment results were dominant in the S1 class 22 compared to S2, without the S3 class and the N class with the class S1 > S2 pattern, so that the area 23 and distribution of these classes also increased. This is in line with the statement (Refitri et al., 2016) 24 that land that has a suitability class of S3 has the opportunity to be improved through various land 25 improvement efforts, so that it becomes class S2 to class S1. However, the land suitability class 26 assessment using the limiting factor method has not at all linked the class acquisition to the 27 profitability of liberica coffee itself, so that there is often a contrast between the land suitability class 28 and its real profitability. In fact, at LMU 4 and LMU 6, the existing land use conditions are irrigated rice 29 fields, rainfed rice fields and swamps that are often flooded, so the actual land suitability class S2 and 30 potential land suitability class S1 for liberica coffee still need to be checked again in the field.

31 In principle, the parametric method in evaluating land suitability is to assign values to different limiting levels of land properties, on a normal scale given a maximum value of 100 to a minimum value of 0 32 (Juita et al., 2020). In land suitability assessment for liberica coffee in Pinogu Plateau with parametric 33 34 method dominated by S2 class followed by S1 class and S3 class without class N with class pattern S2 > 35 S1 > S3. It seems that the land index obtained by the parametric method is closer to the real conditions 36 in the field, where the average production of liberica coffee in the Pinogu Plateau ranges from 0.51 to 37 0.61 tons ha<sup>-1</sup>, while the profitability of Pinogu coffee currently reaches 0.75. ton ha-1 (Martono, 2018). 38 This parametric method with the square root of the land index uses a minimum rating to assess land 39 suitability classes (Juita et al., 2020), so that the minimum rating in this case the low availability of P 40 nutrients causes the low land suitability class. A low land suitability index should be improved so that the plant grows optimally (Isramiranti et al., 2020). Low nutrient availability can be corrected by 41 42 applying fertilizers (Suheri et al., 2018), especially P.

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Discussion should be started with the answer to your objective, not citations.

- Please use the citations only to support your findings. Discuss your results COMPREHENSIVELY by comparing the general results between two methods. DO NOT discuss your results per parameter again because it is clearly explained in "Results" section. Linkage the parameter each
- other as a comprehensive discussion. What was lack in the first method, and can be identified in the second method?

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1 The difference in land suitability class between the two methods has an impact on land management 2 for liberica coffee in Pinogu Plateau. In the limiting factor method, differences in land suitability classes 3 were caused by prominent limiting factors (Table 3) including: elevation, nutrient retention (pH, organic C, base saturation), and nutrient availability (available P). This condition resulted in more land 4 5 management inputs needed, including the addition of organic matter and P fertilization. Meanwhile, 6 the difference in land suitability classes in the parametric method was caused by the interaction of all 7 soil and land properties parameters with the profitability of liberica coffee in Pinogu Plateau (Table 5), 8 although the levels of The available P yields the lowest profitability and the slope with the highest 9 profitability. Thus, the low availability of P nutrients can be corrected by only P fertilization, resulting 10 in fewer inputs for land management. 11 This research uses both land suitability assessment methods to be the same and consistent in terms

12 of the type and number of land characteristics used, so that differences in land suitability assessment

13 results are not caused by differences in land characteristics. but because of the final value produced

14 by both methods. In addition, the use of land characteristics is also based on the availability of

15 mathematical equations to estimate the profitability of liberica coffee because only LMU 3, 9, 10 and

16 LMU 13 have liberica coffee plants and have produced 0.75 tons ha<sup>-1</sup> (Martono, 2018). Meanwhile, 17 other LMUs do not have liberica coffee plants, so the profitability must be estimated.

18 Limitations in the type and number of land characteristics used in this study are a challenge for future research to be added or expanded to other land characteristics. This refers to the land suitability 19

20 criteria for liberica coffee (Ditjendbun, 2014), where the characteristics of land that have not been

21 used in this study are: annual rainfall, dry month length, effective depth, texture, rock on the surface,

22 inundation, drainage class, nitrogen (N), salinity and aluminum saturation (Al). However, the results of

23 this study have shown that the use of the parametric method is more sensitive to the increase or

24 decrease in the profitability of liberica coffee and better describes the real conditions in the field. 25 Meanwhile, the use of the limiting factor method, although the land suitability class for liberica coffee

26 is higher, is in contrast to the facts on the ground, so it must be re-checked.

27 Research on land suitability for liberica coffee in Pinogu Plateau is the first research conducted in this area and in the province of Gorontalo. Therefore, Liberika coffee, which is endemic to the Pinogu 28 29 Plateau, Bone Bolango Regency, Gorontalo Province, needs to be maintained in the future. In addition 30 to the Pinogu area, liberica coffee is also found in the Modayag District, East Bolaang Mongondow 31 Regency, North Sulawesi Province, which is still an island of Sulawesi and was endemic in the province, 32 so that future research is interesting and can be focused on comparing land suitability classes for

33 liberica coffee in the two regions and their agronomic performance and profitability.

#### 35 CONCLUSION

36 The actual of land suitability class for liberica coffee using the limiting factor method consists of 37 moderately suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention 38 and nutrient availability constraints. Efforts to improve the class by adding organic matter and 39 fertilization, so the potential class were very suitable class (S1) and S2 class. The parametric method 40 consists of S1, S2 and S3 class. The input for land management using the parametric method was P 41 fertilization only.

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#### 1 ACKNOWLEDGMENTS

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#### 5 STATEMENT OF COMPETING INTEREST

6 The authors state that no competing financial or personal interests might arise and affect the work7 reported in this paper.

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## **INSTRUKSI REVISI**



### [STJSSA] Editor Decision (REVISIONS REQUIRED)

1 pesan

Editorial Team of Sains Tanah <jurnal@mail.uns.ac.id> Balas Ke: STJSSA Editorial Team <sainstanah@mail.uns.ac.id> Kepada: Nurdin Nurdin Kyai Baderan <nurdin@ung.ac.id> Cc: Fauzan Zakaria <fauzanzakaria@ung.ac.id>, Muhammad Arief Azis <muh.arief@ung.ac.id>, Yunnita Rahim <yunnita\_rahim@ung.ac.id>, Rival Rahman <rival.rahman1307@gmail.com>, Mahmud Kasim <mahmudkasim207@gmail.com>

Dear Nurdin :

We have reached a decision regarding your submission to SAINS TANAH -Journal of Soil Science and Agroclimatology, "A COMPARISON OF LAND SUITABILITY VALUES FOR ENDEMIC LIBERICA COFFEE WITH DIFFERENT METHODS, AND THEIR IMPACT ON LAND MANAGEMENT IN THE PINOGU PLATEAU, BONE BOLANGO REGENCY".

Our decision is: Revisions Required (due date is: 06-02-2022)

Please revise your article according to the comments. We kindly ask you to resubmit corrected article under the same identification number. To do so, login into the system, click on this article and fill in "Upload Author Version" input field.

The revised version must include highlighted changes and modifications recommended in the first revision to ensure that all reviewer(s)' comments were considered.

Should you have any questions about the system or other functions please do not hesitate to contact us.

Best regards.

STJSSA Editorial Team Department of Soil Science, Faculty of Agriculture, Sebelas Maret University sainstanah@mail.uns.ac.id

Reviewer A: The manuscript is qualified for further process.

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23 Januari 2022 pukul 11.01

Reviewer B:

Paper ini baik dan sangat dinanti oleh para pembaca.

Namun, penyajian di naskah masih perlu ditingkatkan. Setiap menulis pastikan bahwa menulis untuk orang lain, bukan untuk diri sendiri. Beberapa catatan ada di naskah.

Saran bagi penulis:

1. Konsultasi dengan ahli bahasa inggris untuk memperbaiki bahasa inggris

2. abstrak diperbaiki dan sinkron dengan naskah

3. penulisan paraghraf yang panjang perlu dipersingkat yang dibedakan atas pikiran utamanya, biasakan menetapan pikiran utama sebelum menulis agar satu paragrah satu pesan

4. Tabel diperbaiki, dibuat beberapa tabel agar tabel mudah difahami oleh pembaca

5. Perlu ditambahkan penjelasan terhadap hasil. pembahasan masih dangkal. beri makna terhadap setiap data atau angka baik memaknai menggunakan pemikiran sendiri atau mengacu pemikiran orang.

6. Dalam tulisan ilmiah hanya menyajikan dan membahas fakta. jadi harus objektif dan hindari claim atau spekulasi

7. Liberika tidak hanya di Sulawesi tapi juga ada di Sumatera. Perbanyak baca dan cari pustaka yang relevan dengan tulisan ini. Bisa digunakan Google Scholar atau media database publikasi lainnya.

8. bab metode diperbaiki, ditambahkan keterangan/penjelasan tentang data input seperti peta satuan lahan atau peta tanah atau LMU serta penjelasan karaktersitik lahan

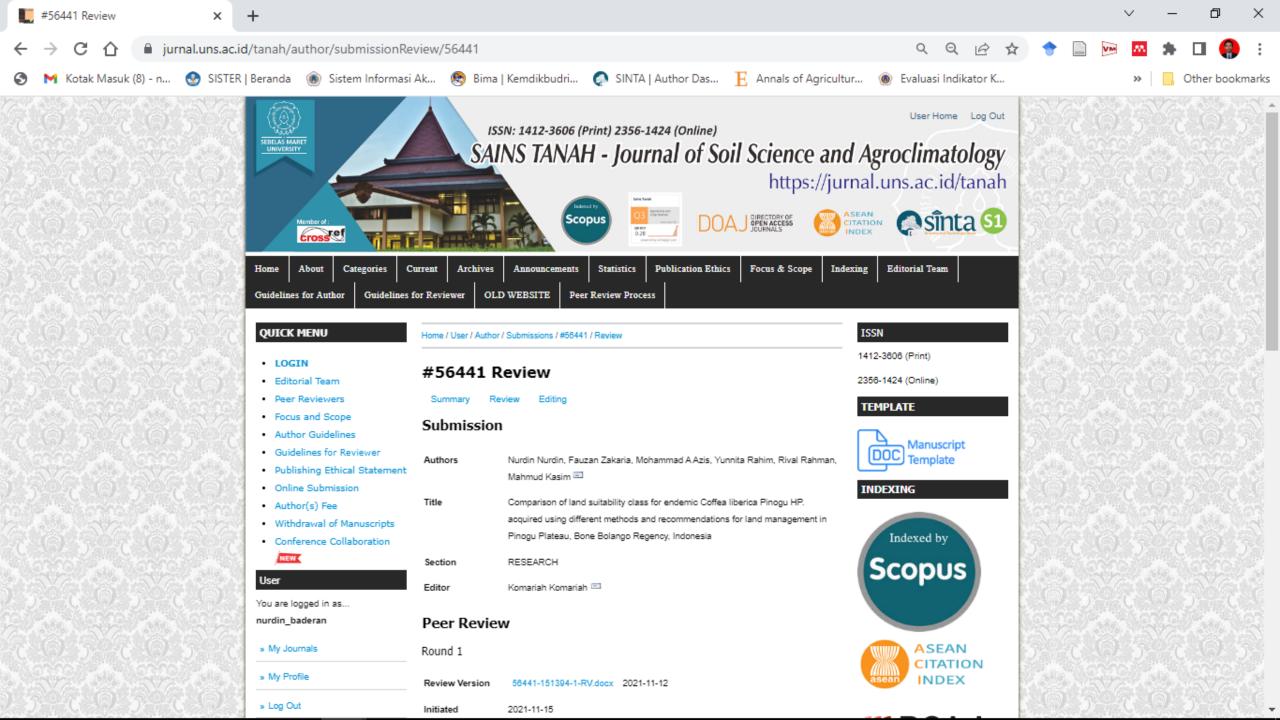
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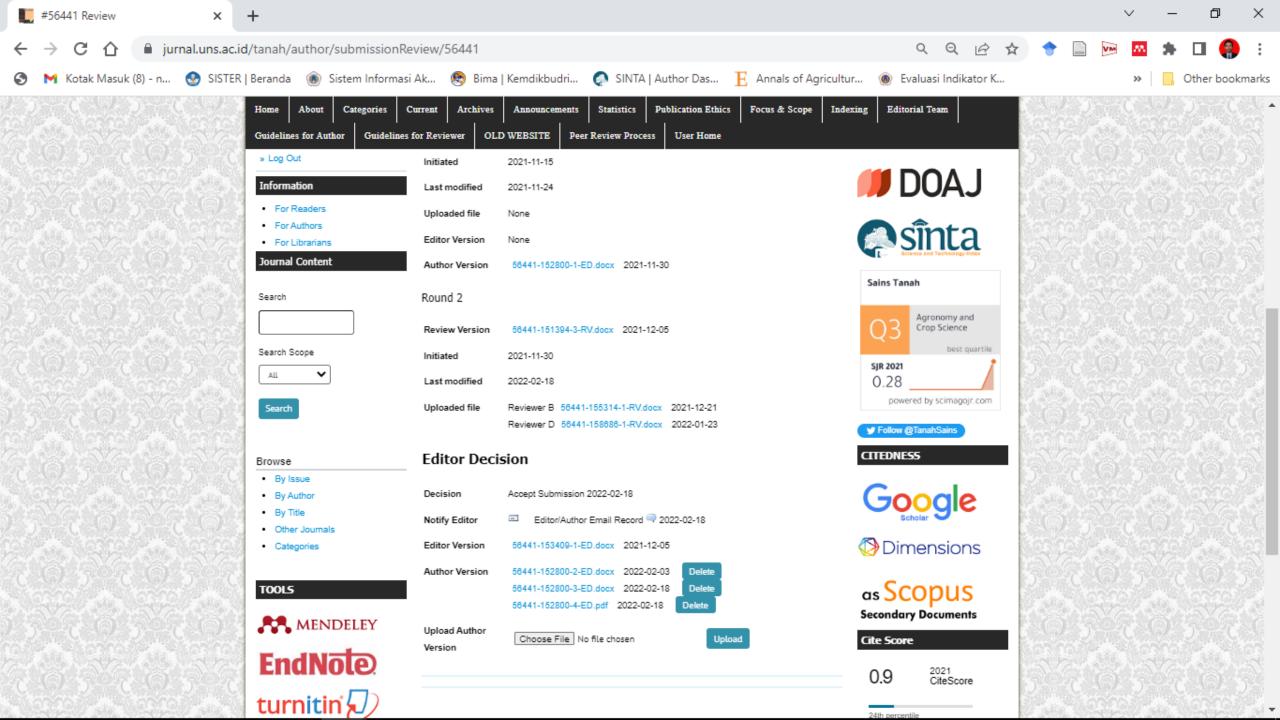
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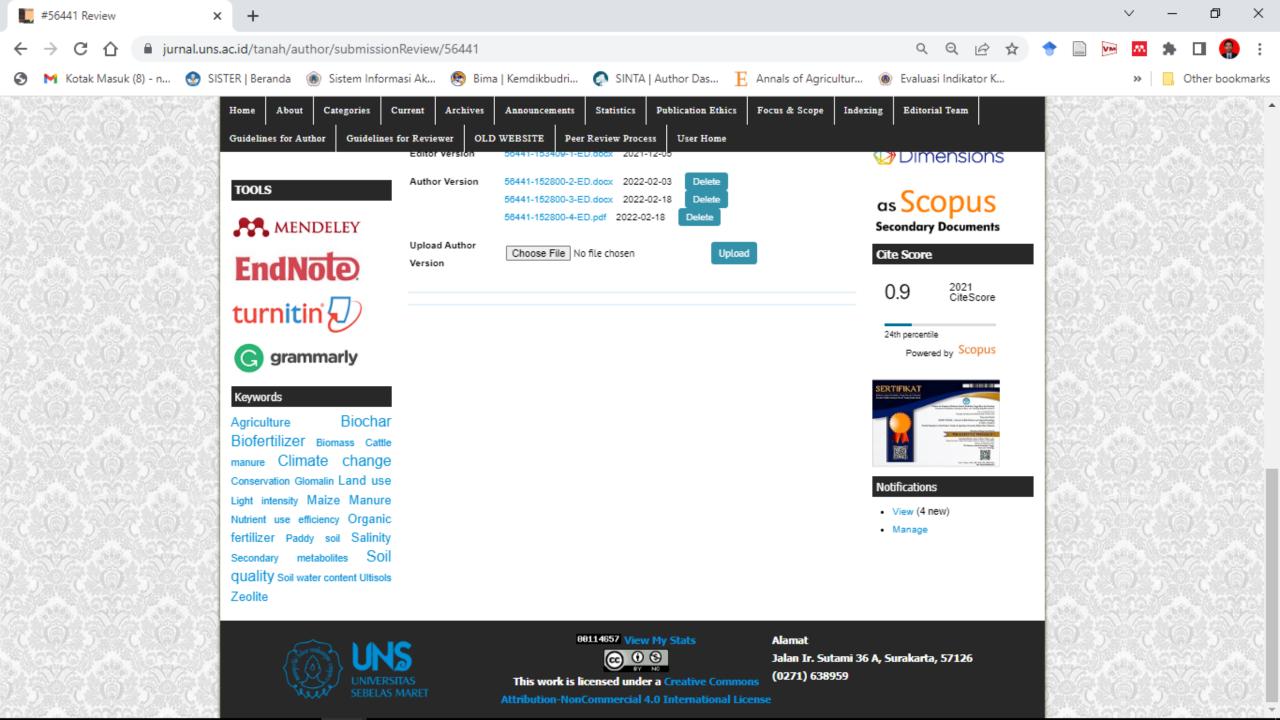
penelitian telah dilaksanakan lama yang menyita waktu, sangat sayang kalo penyajiannya tidak terstruktur dengan baik dan pembahasannya dangkal. pembaca ingin banyak menimba ilmu dari tulisan tersebut SAINS TANAH - Journal of Soil Science and Agroclimatology http://jurnal.uns.ac.id/tanah

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# 1THE COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC COFFEA2LIBERICA PINOGU HP. WITH DIFFERENT METHODS, AND THEIR3RECOMMENDATIONS OF LAND MANAGEMENT IN PINOGU PLATEAU, BONE4BOLANGO REGENCY

#### ABSTRACT

8 Coffee is a national strategic commodity that contributes to the country's foreign exchange but these 9 productivity is still low due to cultivation on low potential land. Study aimed to determine the land 10 suitability value of endemic liberica coffee with two different methods and their impact on land 11 management in Pinogu Plateau. The 13 land units were surveyed and analyzed the soil samples in the laboratory to obtain data of the land characteristic selected. Comparison of different land suitability 12 13 values using the limiting factor method and the parametric method. The results showed that the land 14 suitability class for liberica coffee using the limiting factor method actually consisted of a moderately 15 suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention and available 16 nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, so that it 17 has the potential to become a very suitable class (S1) and S2 class. Meanwhile, the land suitability class using the parametric method consisted of S1, S2 and S3 classes due to low P nutrients. Land 18 19 management recommendations for liberica coffee were priority I and II based on parametric methods. 20

21 **Keywords:** Land, suitability, coffee, liberica, endemic, Pinogu.

#### 23 INTRODUCTION

22

5 6

7

24 Coffee has long been a refreshing drink in the world. The distribution of world coffee includes Arabica 25 coffee with a distribution area of 80%, Robusta coffee by 20% and Liberica coffee with a distribution 26 area of only <1% (Nillian et al., 2020). It is relatively difficult to get research references on liberica 27 coffee in the world because of its limited area, so that publications are also relatively limited. It is 28 predicted that by 2050, the land suitable for robusta coffee cultivation is 83%, while arabica coffee is 29 only 17% in the world (Magrach & Ghazoul, 2015). However, according to Claude et al (2019), liberica 30 coffee based on pedoclimatic zoning is more potential to be cultivated than robusta and arabica coffee 31 because agro-climatic zoning shows an increase in the potential for this coffee production in the 32 coming years.

Coffee in Indonesia is still a strategic commodity because it is able to contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 tons, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 tons or an increase of 2.62% from the previous year with a value of 809,158,900 US\$ (Indonesian Central Bureau of Statistics, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 tons or 0.02% of the total national coffee production (Indonesian Directorate General of Plantations, 2021).

- Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively
   flat and wide (496 km<sup>2</sup>) at an altitude of > 300 m above sea level, and is surrounded by hills and
- 42 mountains so that it can be called the Pinogu Plateau. This district has long been known as a coffee

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Land suitability evaluation, liberica coffea, Pinogu Plateu, Sulawesi

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producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021).
 According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee
 plantation and makes it their main commodity because the productivity level of this coffee is the
 highest compared to other commodities. The advantages of pinogu coffee include the fact that local
 farmers do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin,
 2020), so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes
 from robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021).

8 Liberica coffee (Coffea liberica) has been planted since 1875 (Sancayaningsih et al., 2016) and is 9 endemic because this species exists and grows in the Pinogu District only. Liberica coffee has the 10 advantage of good taste (Gusfarina, D, 2014), and a distinctive taste of jackfruit (Saidi & Suryani, 2021). This condition makes pinogu coffee an icon of the superior commodity of Bone Bolango Regency 11 12 (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have so far 13 encountered several obstacles, one of which is the low productivity of the coffee. Martono (2018) 14 reports that although Pinogu Coffee has become global, its productivity is still low at only 0.75 t ha<sup>-1</sup> 15 year<sup>1</sup>. In fact, the productivity of liberica coffee can reach 1.69 – 1.98 ton ha<sup>-1</sup> (Indonesia Research 16 Institute for Industrial Plants and Refreshments, 2015). Pinogu sub-district has a coffee plantation area of 282.63 ha or the largest in this district (66.21%) with new production of 36.34 ton (Humola et al., 17 18 2021). Such conditions will affect the availability of coffee raw materials to meet market demand later. 19 The low productivity of coffee is thought to be because coffee cultivation is carried out on land that is 20 not in accordance with the potential of the land.

21 Until now there is no available information about the potential of land for the development of Liberika 22 Coffee in the Pinogu Plateau area, except for the potential of land for robusta coffee because it is more 23 developed. Land suitability for robusta coffee in Bone Bolango Regency is marginally suitable or S3 24 class (Taslim, 2018; Indrianti, 2020). Meanwhile, other plantation commodities such as coconut, cocoa, 25 cloves, candlenut and vanilla are included in the S2 class in Bone Bolango Regency (Taslim, 2018). 26 Liberica coffee is not only endemic, it is also more resistant to pests and plant diseases (Harni et al., 27 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests (Gusfarina, D, 2014). 28 Ignorance of coffee planters regarding land potential will greatly affect the productivity of liberica 29 coffee itself, because differences in land potential will be responded by variously by plants according 30 to growing conditions based on land characteristics (Sukarman et al., 2018).

31 Land management requires land suitability assessment so that a land can be used productively and 32 sustainably (Mustafa et al., 2014), including land suitability assessment for liberica coffee. Different 33 land evaluation methods have different data requirements and varying quality of estimates, but there 34 is no fixed rule that defines when and what method to use when there is a need for more complex 35 analyzes (Mathewos et al., 2018; Mugiyo et al., 2021). Previous research on land suitability assessment 36 for coffee mostly used the limiting factor method. The limiting factor method is used to determine the 37 class based on the lowest constraint, while the parametric method is determined based on the 38 correlation between all variables (Rabia & Terribile, 2013). In the parametric method, there is a 39 combination of soil characteristics that affect agricultural production using mathematical equations 40 (Elaalem, 2013) so that the interaction between land characteristics can be minimized. Furthermore, 41 Bagherzadeh & Gholizadeh (2016) stated that in the parametric approach, different land suitability 42 classes are defined as completely separate groups and separated from each other with different and

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consistent ranges. Differences in land suitability values due to the use of different methods on a land
 will have an impact on differences in land management. Therefore, the aim of the study was to
 determine the land suitability value of endemic liberica coffee with two different methods and to
 formulate recommendations for land management in Pinogu Plateau, Bone Bolango Regency,

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#### 6 MATERIAL AND METHODS

#### 7 Site Study

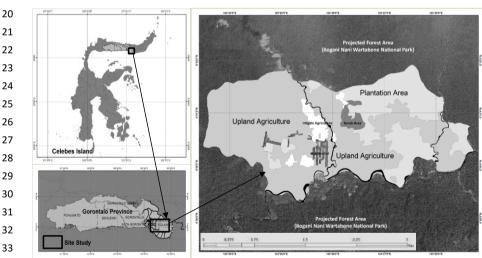
8 This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. 9 Geographically, the research location is located at 0°24'5.4" – 0°38'29.04" North Latitude to 10 123°18'38.52" – 123°33'15.48" South Latitude covering an area of 2,804.28 ha with an elevation of 11 300 – 338 m above sea level (Fig. 1). The aAnnual rainfall is 2,541.90 mm andwith thean average 12 monthly rainfall ranging from 19.00 mm to 408.18 mm, so the research-study area is included in the

agro-climatic zone\_of C1 because the <u>number of</u> dry month (<u>montly rainfall less than</u><100 mm) is only</li>
1 month and <u>the number of wet month (monthly rainfall more than 200 mm) is</u> 6 months is wet (>200
mm). The monthly air temperature in the study area-fluctuates between 24.34°C to 25.79°C while the
relative humidity is between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52%
to 70.50%<sub>z</sub> while the monthly wind speed is between 2 knots to 2.60 knots. The <u>research-study</u> area

18 is the upstream of the Bone watershed which flows to Tomini Bay.19

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34 Figure 1. Research Location Map

#### 35 Soil Survey and Land Observation

36 A set of soil survey tools, includ<u>eding</u>: soil knife, pH meter, meter, hoe, spade, machete, clinometer

37 and F marker, Meanwhile, the materials used-consist of: soil maps, geological maps, slope maps,

38 landform maps, land use maps, maps 1: 12,000 scale land unit, soil profile card, plastic bag, rubber

band, label paper, climate data from the local BMKG station for 5 years (2015-2021) and soil samples
 for laboratory analysis. This field research use<u>ds</u> a soil survey method on a scale of 1: 12,000 by
 observing the characteristics of the land in 13 land units. Furthermore, field observations were carried
 out to determine the characteristics of the land in the form of elevation and slope. After that, 1 kg of

5 soil samples were taken for analysis in the laboratory.

#### 6 Soil Laboratory Analysis

Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil
properties based on research parameters refers to the soil analysis procedure according to Eviyati &
Sulaeman (2009). Soil reaction parameters (pH H<sub>2</sub>O) were determined with a pH meter extracted in a
solution of 1:2.5 soil and water. Organic carbon content using the Walkley and Black method. The P
content was available using the Olsen method, while the cation exchange capacity (CEC) was extracted
with 1N NH<sub>4</sub>OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, while base saturation was
determined by calculation. All soil data and selected land characteristic data are input in spreasheet.

14 dbf or xls format.

#### 15 Land Suitability Assesment

The deskwork in the land suitability assessment is carried out based on the parameters of the selected 16 17 land characteristics which are the same between the limiting factor method and the parametric method. The aAssessment t- of land suitability classes used using the limiting factor method. 18 19 followin(gs the land evaluation framework according to (FAO2-(\_1976).- from the order and class 20 categories (suitable, not suitable) to units. Furthermore, the data on Lhand characteristics and quality 21 were compared with the selected Coffee liberica HP. land suitability criteria (Table 1) from according to 22 the Indonesian Directorate General of Plantations (2014), in order to obtain the actual land suitability 23 class along with the limiting factors for land use. The limiting factor is then improved, so that the 24 potential land suitability class is obtained.

25

#### 26 Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements /land		Land suitabi	lity class	
characteristics	<b>S1</b>	S2	S3	N
Elevation- <mark>el (m</mark> sl <mark>)</mark>	300 – 500	600 - 800; 0 - 300	800 - 1.000	>1,000
Slopes <mark>-sl (%)</mark>	0-8	8 – 25	25 – 45	>45
Nutrient retention (nr):				
Soil pH	5.5 - 6.0	6.1 - 7.0	7.1 - 8.0	>8.0
C-organic (%)	2 – 5	1 - 2; 5 - 10	0.5 - 1.0; 10 - 15	<0.5; >15
Cation exchange capacity (cmol/kg)	>15	10 - 15	5 - 10	<5
Base saturation (%)	>35	20-35	<20	
Nutrient availability (na):				
Availability of P (ppm)	>16	10 – 15	<10	

27 <u>SourceRemark:</u> (Indonesian Directorate General of Plantations, (2014), *modifed*.

- 28 Meanwhile, in assessing land suitability using the parametric method, it is estimated that the
- 29 productivity of coffee (Y) uses several equations (Simbolon, 2018) based on the parameters of the
- 30 selected soil and land properties, namely:
- 31 Y = -2.672+0.026X (elevation) .....(1)

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1	Y = 17,190-0.090X (slope)(2)
2	Y = 3.055+0.005X (soil pH)(3)
3	Y = 4.050-0.019X (C-organic)
4	Y = -28.796+0.621X (P availability)
5	Y = 32.450-0.109X (CEC)
6	Y = 0.457-0.002X (base saturation)
7	In this case, Y = estimated production (t ha <sup>-1</sup> ), X = soil and land properties parameters, and CEC = cation
8	exchange capacity. The assumption of optimal productivity of liberica coffee used is 0.75 t ha
9	(Martono, 2018). In order to assess the accuracy of the estimated productivity of the liberica coffee, it
10	was analyzed using the Root Mean Square Error (RMSE) with the following equation:
11	
	$\sum_{k=1}^{n} \frac{(At - Ft)^2}{(At - Ft)^2}$
12	$RMSE = \sqrt{\frac{\sum_{t=1}^{n} (At - Ft)^2}{n}} \dots $ (8)
13	where: RMSE = root mean square error, At = actual productivity (t ha <sup>-1</sup> ), Ft = estimated productivity (t
14	ha <sup>-1</sup> ), and n = number of data. The smaller or closer to 0 the value of the RMSE, the more accurate the
15	prediction results will be. Furthermore, land suitability assessment for liberica coffee uses a land index
16	of root mean square (Khiddir, 1986), namely:
17	
18	$LI = LC_{min} \sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}} $ (9)
19	where: LI = land index; $LC_{min}$ = minimum LC rating; A, B, C,, N = other LC in beside the minimum LC.
20	The depetermination of land suitability classification based on lan index (LI) is calculated from all LC
21	which is influenced by the productivity of liberica coffee and has a certain land suitability class. LI score
22	criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very suitable) with a value of 75 – 100,
23	S2 class (moderately suitable) with a value of 50 – 75, S3 class (marginally suitable) with a value of 25
24	- 50, and class N (not suitable) with value 0 - 25. All data and information obtained are described and
25	presented in tabular form, while their spacial distribution is presented in map form.
26	
27	RESULTS
28	Land Suitability <u>Class</u> Based on Limiting Factor Method
29	The result of matching the land suitability criteria with the land characteristics resulted in the actual
30	land suitability class for liberica coffee in Pinogu Plateau was shown to Table 2 and Figure 2. It seems
31	that the actual land suitability class was moderately suitable (S2) which was more dominant in an area
32	of 2,149.64 ha or 76.66% compared to the marginally suitable class (S3) which was only 654.64 ha or
33	only 23.34%. Meanwhile the very suitable class (S1) and not suitable (N) has not found in the results
34	of this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use
35	in the Pinogu Plateau were nutrient retention (C-organic, base saturation and soil pH) and nutrients
36	availability (P availability). In addition, there was an elevation limiting factor at LMU 1 and LMU 7.
37	
38	Table 2. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau
	Elevation Slope pH C-Organic CEC BS Ava-P Actual Area
	LMU LSC LSC LSC LSC LSC LSC LSC LSC LSC ha

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	sl)		(%)				(%)		(cmol)		(%)		(ppm)				
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

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

3 After making efforts to improve the actual land suitability class against the limiting factor, all LMUs can 4 be upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be repaired 5 because of the elevation limiting factor (Table 3, Figure 2). The limiting factors for nutrient retention, 6 both pH, C-organic, and low base saturation were improved with the addition of organic matter, while 7 the limiting factor for available nutrients of low P availability was improved with the addition of P 8 fertilizer. As a result, the most dominant potential land suitability class was S1 covering-an area of 9 1,980.30 ha or 70.62% of total area and the rest isncluding S2 class covering an area of 823.98 ha or 10 29.38% of total areaonly.

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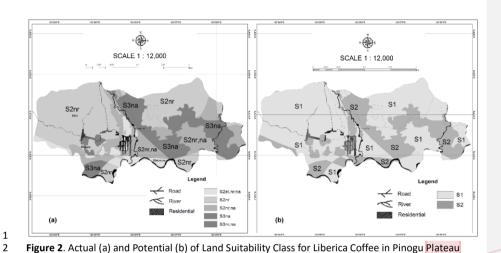
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#### 12 **Table 3**. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual	Limiting Factors	Efforts	Potential	Area		
LIVIO	LSC		Enorts	LSC	ha	%	
1, 7	S2el,nr,na	Elevation, nutrient retention (C- organic, base saturation), nutrient availability (available of P)	Can not be fixed (elevation)	S2	169,34	2.5	
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	- Addition of organic material - Addition of P fertilizer	S1	593,36	8.9	
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic material	S2	36,34	1.3	
			- Addition of P fertilizer				
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	<ul> <li>Addition of organic material</li> </ul>	S1	1.386,94	30.2	
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.1	
		Luas (Ha)			2.804,28	10	

13 Remark: LMU = land mapping unit, LSC = land suitability class.

14



#### Land Suitability class Based on Parametric Method

The results of the productivity analysis (productivity) of liberica coffee based on each land 6 characteristic showed that the highest productivity was obtained on the slope characteristics which averaged 1.69 t ha<sup>-1</sup>, while the lowest productivity was obtained on the available P characteristics 8 which only ranged from 0.16 – 0.24 t ha<sup>-1</sup> with an average of 0.20 t ha<sup>-1</sup> (Table 4). The remaining land characteristics has an average productivity 0.30. The results of the RMSE analysis on the alleged productivity of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13 are smaller (0.51) compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE value of 0.52 (Table 4). The productivity of liberica coffee will affect the land characteristic index which will ultimately 13 determine the land index and land suitability class for liberica coffee.

14 It seems that the relative land characteristic index values follow the pattern of productivity for liberica 15 coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the optimal value was the slope characteristic which the averaged a-value of 100 (Table 5), while the lowest land 16 17 characteristic index value was obtained for the available P which an average of P availability index of 18 26.39-only. The remaining land characteristics are relatively diverse but the average value of the land 19 characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index 20 value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index, 21 respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value which was 50 only. The remaining LMUs get land index values ranged from 50 – 71. So...what? 22

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Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau Characteristic LMU /Productivity 6 8 10 11 12 Elev. (m sl) 293 307 313 302 311 305 290 288 338 300 334 306 0.49 0.49 Y (t ha-1) 0.53 0.55 0.52 0.54 0.53 0.48 0.61 0.51 0.60 0.53 Slo. (%) 3 3 3 8 8 2 3 2 3 3 3 3 Y (t ha-1) 1.69 1.69 1.69 1.69 1.69 1.69 1.69 1.69 1.69 1.65 1.69 1.65

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Characteristic							LMU						
/Productivity	1	2	3	4	5	6	7	8	9	10	11	12	13
Y (t ha-1)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
C-Org (%)	1.59	1.30	0.78	1.21	1.46	1.02	1.43	1.92	1.79	1.38	1.15	1.07	1.35
Y (t ha-1)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
CEC (cmol)	19.24	23.77	27.60	22.77	26.39	29.68	27.92	23.22	27.10	23.67	27.69	25.03	32.67
Y (t ha-1)	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
BS (%)	32.75	33.75	28.00	24.67	29.25	29.68	39.75	36.67	37.00	42.33	33.00	39.50	23.67
Y (t ha-1)	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
Av-P (ppm)	13.87	15.85	9.77	12.22	17.04	18.52	14.53	20.35	14.98	9.98	17.12	16.41	7.78
Y (t ha <sup>-1</sup> )	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
Ϋ́ (t ha⁻¹)	0.60	0.60	0.61	0.60	0.60	0.60	0.60	0.59	0.61	0.60	0.61	0.59	0.61
Stdev	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.49	0.48	0.49
RMSE	0.52	0.52	0.51	0.52	0.52	0.52	0.52	0.53	0.52	0.51	0.52	0.51	0.51

Remark: LMU = land mapping unit, Elev. = elevation, Slo. = slopes, C-Org = C-organic, Exc. = exchangeable, CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million, Stdev = standard

deviation, RMSE = root mean square error.

#### Based on the land index values, the land suitability class for liberica coffee was more dominant S2 with

covering an area of 88.77% of... (Table 5). Meanwhile, the S1 class was 7.21% and the S3 class was

4.02% only without not suitable class (N).

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#### Table 5. Value of Land Characteristics Index, Land Index and Land Suitability Class for Liberica Coffee

Productivity							LMU						
/LC Value	1	2	3	4	5	6	7	8	9	10	11	12	13
Y-El. (t ha <sup>-1</sup> )	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
LC-EI.	65.95	70.80	72.88	69.07	72.19	70.11	64.91	64.21	81.55	68.37	80.16	70.45	71.84
Y-SI. (t ha <sup>-1</sup> )	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
LC-Slo.	100	100	100	100	100	100	100	100	100	100	100	100	100
Y-pH (t ha⁻¹)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
LC-pH	41.12	41.13	41.15	41.11	41.12	41.14	41.15	41.13	41.15	41.13	41.13	41.13	41.13
Y-Corg. (t	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
ha⁻¹)													
LC-Corg.	53.60	53.67	53.80	53.69	53.63	53.74	53.64	53.51	53.55	53.65	53.71	53.73	53.66
Y-CEC (t ha	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
<sup>1</sup> )													
LC-CEC	40.47	39.81	39.26	39.96	39.43	38.95	39.21	39.89	39.33	39.83	39.24	39.63	38.52
Y-BS (t ha⁻¹)	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
LC-BS	52.20	51.93	53.47	54.36	53.13	53.02	50.33	51.16	51.07	49.64	52.13	50.40	54.62
Y-Ava.P (t	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
ha⁻¹)													
LC-Ava.P	26.91	25.27	30.31	28.28	24.29	23.06	26.37	21.54	25.99	30.13	24.22	24.81	31.95
LI	64	62	76	70	61	56	61	50	67	71	63	60	80
LSC	S2	S2	S1	S2	S2	S2	S2	S3	S2	S2	S2	S2	S1
Area (ha)	70.81	250.95	36.34	36.97	849.26	3.74	98.53	112.84	305.44	452.57	369.42	51.68	165.73
Area (%)	2.53	8.95	1.30	1.32	30.28	0.13	3.51	4.02	10.89	16.14	13.17	1.84	5.91
Remark: LMU	emark: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, Exc. = exchangeable, Ava. = availability, El.												

#### 9 10

= elevation, Sl. = slope, Corg. = C-organic, K = potassium, Ca = calcium, Mg = magnesium, Na = natrium, P = phosfor, CEC =

11 cation exchange capacity, BS = base saturatio, LI = land index, LSC = land suitability classes.

#### 12

#### 13 Comparison of Land Suitability Classes and their Recommendations on Land Management

- 14 Based on the results of the land suitability assessment between the limiting factor and the parametric
- 15 method were shown in Table 6 and Figure 3. The comparison between the two methods shows the
- similarity of the land suitability class with the class pattern: S2 = S2 of 22.18% (LMU 1, 7 and LMU 10).
- But the most dominant class differences follow the pattern: S1 ≠ S2 of 66.59% (LMU 2, 4, 5, 6, 9, 11,
- and LMU 12), followed by class pattern: S2 ≠ S1 of 7.21% (LMU 3, and LMU 13), while the lowest was

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1 the class pattern: S1 ≠ S3 of 4.02% only (LMU 8). Thus, based on land suitability class using the limiting

2 factor method, the recommended land with priority I or equivalent to S1 was 70.62%, while land with

3 priority II or equivalent to S2 was 29.38% without land priority III or equivalent to S3 (0%). This was

4 different from the land suitability class using the parametric method, where the recommended land

5 with priority I or equivalent to S1 was 7.21% only, while land with priority II or equivalent to S2 was

6 88.77%, and land with priority III or equivalent to S3 was 4 ,20% only

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8	Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for
9	Liberica Coffee in Pinogu Plateau

	Land Suitabi	lity Class		Area		
LMU	Limiting Factor Parametric Method Method		Recomendation	ha	%	
1, 7, 10	S2	S2	Priority I	621.91	22.18	
2, 4, 5, 6, 9, 11, 12	S1	S2	Priority II	1,867.46	66.59	
3, 13	S2	S1	Priority I	202.07	7.21	
8	S1	S3	Priority III	112.84	4.02	
	2,804.28	100.00				
emark: LMU = land mappi	ng unit.					

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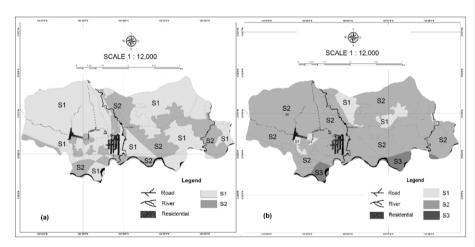
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Figure 3. Comparison of Land Suitability Classes with Limiting Factors (a) and Parametric Methods (b) for Liberica Coffee in Pinogu Plateau

#### 15 16 DISCUSSION

17 The suitability of land for liberica coffee with the limiting factor method and the parametric method

18 turned out to be different, both in terms of class and area. This study shown that the land suitability

19 class using the limiting factor method in Plato Pinogu was more dominant of very suitable, while the

land suitability class using the parametric method was more dominant of moderately suitable.
 Although the land suitability class using this limiting factor method appears to be of a higher class and

wider distribution, it was only based on the characteristics of the land and has not been linked at all

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1 with the productivity of liberica coffee. The limiting factor method has weaknesses, including 2 interactions between land characteristics that are difficult to explain (Elsheikh et al., 2013; Hartati, et 3 al., 2018). In contrast to the land suitability class with the parametric method, besides being based on 4 the performance of land characteristics, it has also been directly related to the productivity of liberica 5 coffee in the research area, so that the interactions in it are easy to explain. According to Sitorus (2018), 6 the precision and reliability of parametric methods more greater than other land evaluation methods. 7 The advantage of the parametric method is that land evaluation is easy to carry out and only consists 8 of a few categories (Rodcha et al., 2019). Furthermore, Marbun et al. (2019) stated that the superiority 9 of this parametric method is not only calculating land suitability classes based on soil properties but 10 also taking into account all factors and mapping them in one land suitability map. This parametric 11 method with the square root of the land index uses a minimum rating to assess land suitability classes 12 (Juita et al., 2020). In fact, Mathewos et al. (2018) stated that the square root land index value was 13 higher than the Storie index. To improve the land evaluation approach, qualitative and quantitative 14 approaches must be integrated (Mugiyo et al., 2021).

15 In the land suitability assessment for liberica coffee using the limiting factor method, it turns out that 16 there were more limiting factors, while the parametric method most less. The minimum rating value 17 in the parametric method was only the low availability of P nutrients. A low land suitability index 18 should be improved so that the plant grows optimally (Isramiranti et al., 2020). Land that has an S3 19 suitability class has the opportunity to be improved through various land improvement efforts, so that 20 it becomes a class S2 to class S1 (Refitri et al., 2016). Low nutrient availability was improved through 21 fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing 22 nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), 23 land management can be done by adding organic matter and fertilizing according to the recommended 24 dose of fertilizer. The addition of organic matter can increase soil pH and organic C (Afandi et al., 2015; 25 Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

26 Land suitability class assessment using the limiting factor method often contrasts between land 27 suitability classes and their real productivity. In fact, at LMU 4 and LMU 6, the existing land use 28 conditions are irrigated rice fields, rainfed rice fields and swamps that are often flooded, so the actual 29 land suitability class S2 and potential land suitability class S1 for liberica coffee still need to be checked 30 again in the field. While the parameteric method in principle gives values at different limiting levels to 31 land properties on a normal scale with a maximum value of 100 to a minimum value of 0 (Juita et al., 32 2020). The results of the land suitability assessment for liberica coffee in Plato Pinogu with the 33 parametric method following the class pattern S2 > S1 > S3. The advantage of this parametric method 34 is not only calculating land suitability classes based on soil properties but also taking into account all 35 factors and mapping them in one land suitability map (Marbun et al., 2019). It seems that the land 36 index obtained by the parametric method is closer to the real conditions in the field, where the average 37 liberica coffee production in the Pinogu Plateau ranges from 0.51 to 0.61 t ha-1, while the productivity 38 of Pinogu coffee currently reaches 0.75. t ha-1 (Martono, 2018). Ghazanchaii & Fariabi (2014) state 39 that there is a significant relationship between land index and production, where as the land index 40 increases, the yield based on the range of land suitability classes also increases quantitatively.

41 This research uses both land suitability assessment methods to be the same and consistent in terms 42 of the type and number of land characteristics used, so that the difference in the results of the land

43 suitability assessment is not caused by differences in the characteristics of the land but because of the

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1 final value produced by the two methods. In the limiting factor method, the most limiting factor has a 2 dominant role, so that other factors can be ignored (Nugroho & Istianto, 2013). The limiting factor 3 method makes it possible to determine the suitability class but without further specification (Abbasi et al., 2019). While in the parametric method, the use of land characteristics is based on the availability 4 5 of mathematical equations to estimate the productivity of liberica coffee because only LMU 3, 9, 10 6 and LMU 13 has liberica coffee plants and has been producing. Other LMUs do not have liberica coffee 7 plants, so their productivity must be estimated. In determining land suitability using the parametric 8 method, the most limiting factor will have less effect because it is covered by the cumulative value of 9 all factors (Nugroho & Istianto, 2013). Diagnostic criteria in the parametric method are assessed 10 numerically and mathematically to obtain land suitability classes (Marbun et al., 2019). The parametric 11 method is able to describe the degree of land suitability that does not depend on class boundaries 12 (Abbasi et al., 2019). Limitations in the type and number of land characteristics used in this study are 13 a challenge for future research to be added or expanded to other land characteristics. In fact, it can include environmental and socioeconomic variables (Mathewos et al., 2018). However, the use of the 14 parametric method is more significant for the increase or decrease in productivity (Ghazanchaii & 15 Fariabi, 2014) and is more realistic (Mathewos et al., 2018). Meanwhile, the use of the limiting factor 16 17 method, although the land suitability class for liberica coffee is higher, often contrasts with the facts 18 on the ground, so it must be re-checked.

19 Research on land suitability for liberica coffee in Plato Pinogu is the first research conducted in this area and in the province of Gorontalo. Therefore, Liberika coffee, which is endemic to the Pinogu 20 21 Plateau, Bone Bolango Regency, Gorontalo Province, needs to be maintained in the future. In addition 22 to the Pinogu area, Liberica coffee is also found in the East Bolaang Mongondow Regency, North Sulawesi Province (Lasabuda et al., 2015) and South Sulawesi (Kahpi, 2017) which are still on the island 23 24 of Sulawesi and are endemic in the province. Thus, future research can focus on the comparison of 25 land suitability classes for liberica coffee in each of these areas along with their agronomic 26 performance and productivity.

#### 28 CONCLUSION

The actual land suitability class for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, it has the potential became very suitable class (S1) and S2 class. The parametric method consists of S1, S2 and S3 classes because of low phosphorus nutrients. Land management recommendations for liberica coffee were priority I and II.

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# 1THE COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC COFFEA2LIBERICA PINOGU HP. WITH DIFFERENT METHODS, AND THEIR3RECOMMENDATIONS OF LAND MANAGEMENT IN PINOGU PLATEAU, BONE4BOLANGO REGENCY

#### ABSTRACT

8 Coffee is a national strategic commodity that contributes to the country's foreign exchange but these 9 productivity is still low due to cultivation on low potential land. Study aimed to determine the land 10 suitability value of endemic liberica coffee with two different methods and their impact on land 11 management in Pinogu Plateau. The 13 land units were surveyed and analyzed the soil samples in the laboratory to obtain data of the land characteristic selected. Comparison of different land 12 13 suitability values using the limiting factor method and the parametric method. The results showed 14 that the land suitability class for liberica coffee using the limiting factor method actually consisted of 15 a moderately suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention 16 and available nutrient constraints. Efforts to improve the class by adding organic matter and 17 fertilization, so that it has the potential to become a very suitable class (S1) and S2 class. Meanwhile, 18 the land suitability class using the parametric method consisted of S1, S2 and S3 classes due to low P 19 nutrients. Land management recommendations for liberica coffee were priority I and II based on 20 parametric methods.

22 Keywords: Land, suitability, coffee, liberica, endemic, Pinogu.

#### 24 INTRODUCTION

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25 Coffee has long been a refreshing drink in the world. The distribution of world coffee includes 26 Arabica coffee with a distribution area of 80%, Robusta coffee by 20% and Liberica coffee with a 27 distribution area of only <1% (Nillian et al., 2020). It is relatively difficult to get research references 28 on liberica coffee in the world because of its limited area, so that publications are also relatively 29 limited. It is predicted that by 2050, the land suitable for robusta coffee cultivation is 83%, while 30 arabica coffee is only 17% in the world (Magrach & Ghazoul, 2015). However, according to Claude et 31 al (2019), liberica coffee based on pedoclimatic zoning is more potential to be cultivated than 32 robusta and arabica coffee because agro-climatic zoning shows an increase in the potential for this 33 coffee production in the coming years.

Coffee in Indonesia is still a strategic commodity because it is able to contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 ts, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 ts or an increase of 2.62% from the previous year with a value of 809,158,900 US\$ (Indonesian Central Bureau of Statistics, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 ts or 0.02% of the total national coffee production (Indonesian Directorate General of Plantations, 2021).

Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively
flat and wide (496 km2) at an altitude of > 300 m above sea level, and is surrounded by hills and

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mountains so that it can be called the Pinogu Plateau. This district has long been known as a coffee 1 2 producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021). 3 According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee plantation and makes it their main commodity because the productivity level of this coffee is the 4 5 highest compared to other commodities. The advantages of pinogu coffee include the fact that local 6 farmers do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin, 7 2020), so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes from robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021). 8

9 Liberica coffee (Coffee liberica) has been planted since 1875 (Sancavaningsih et al., 2016) and is 10 endemic because this species exists and grows in the Pinogu District only. Liberica coffee has the advantage of good taste (Gusfarina, D, 2014), and a distinctive taste of jackfruit (Saidi & Suryani, 11 12 2021). This condition makes pinogu coffee an icon of the superior commodity of Bone Bolango 13 Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have so far encountered several obstacles, one of which is the low productivity of the coffee. Martono (2018) 14 15 reports that although Pinogu Coffee has become global, its productivity is still low at only 0.75 t ha<sup>-1</sup> 16 year<sup>-1</sup>. In fact, the productivity of liberica coffee can reach 1.69 - 1.98 t ha<sup>-1</sup> (Indonesia Research Institute for Industrial Plants and Refreshments, 2015). Pinogu sub-district has a coffee plantation 17 18 area of 282.63 ha or the largest in this district (66.21%) with new production of 36.34 t (Humola et 19 al., 2021). Such conditions will affect the availability of coffee raw materials to meet market demand 20 later. The low productivity of coffee is thought to be because coffee cultivation is carried out on land 21 that is not in accordance with the potential of the land.

22 Until now there is no available information about the potential of land for the development of 23 Liberika Coffee in the Pinogu Plateau area, except for the potential of land for robusta coffee because 24 it is more developed. Land suitability for robusta coffee in Bone Bolango Regency is marginally 25 suitable or S3 class (Taslim, 2018; Indrianti, 2020). Meanwhile, other plantation commodities such as coconut, cocoa, cloves, candlenut and vanilla are included in the S2 class in Bone Bolango Regency 26 27 (Taslim, 2018). Liberica coffee is not only endemic, it is also more resistant to pests and plant 28 diseases (Harni et al., 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests 29 (Gusfarina, D, 2014). Ignorance of coffee planters regarding land potential will greatly affect the 30 productivity of liberica coffee itself, because differences in land potential will be responded by 31 variously by plants according to growing conditions based on land characteristics (Sukarman et al., 32 2018).

33 Land management requires land suitability assessment so that a land can be used productively and 34 sustainably (Mustafa et al., 2014), including land suitability assessment for liberica coffee. Different 35 land evaluation methods have different data requirements and varying quality of estimates, but 36 there is no fixed rule that defines when and what method to use when there is a need for more 37 complex analyzes (Mathewos et al., 2018; Mugiyo et al., 2021). Previous research on land suitability 38 assessment for coffee mostly used the limiting factor method. The limiting factor method is used to 39 determine the class based on the lowest constraint, while the parametric method is determined 40 based on the correlation between all variables (Rabia & Terribile, 2013). In the parametric method, 41 there is a combination of soil characteristics that affect agricultural production using mathematical 42 equations (Elaalem, 2013) so that the interaction between land characteristics can be minimized. **Commented [D3]:** I recommend to read the following article to be added in this portion:

AbdelRahman, M.A.E., Natarajan, A. & Hegde R. 2016. Assessment of land suitability and capability by integrating remote sensing and GIS for agriculture in Chamarajanagar district, Karnataka, India, Egypt. J. Remote Sensing Space Sci. (2016), http://dx.doi.org/10.1016/j.ejrs.2016.02.001
A. Shalaby, M.A.E. AbdelRahman, A. A. Belal (2017). A GIS Based Model for Land Evaluation Mapping: A Case Study North Delta Egypt. Egypt. J. Soil Sci. Vol. 57 No. 3, pp.339 - 351 (2017).
Mohamed A. E. AbdelRahman, Adel Shalaby, E. F. Essa (2018). Quantitative land evaluation based on fuzzy-multi-criteria spatial model for sustainable land-use planning. Modeling Earth Systems and Environment, 4(1), 1-13. (2018). https://doi.org/10.1007/s40808-018-0478-1

 Mohamed A.E.AbdelRahman, A.Shalaby, E.S.Mohamed (2018).
 Comparison of two soil quality indices using two methods based on geographic information system. Egypt. J. Remote Sensing Space Sci., <u>https://doi.org/10.1016/j.ejrs.2018.03.001</u>
 - Zakarya, Y.M.; Metwally, M.M.; AbdelRahman, M.A.E.; Metwalli,

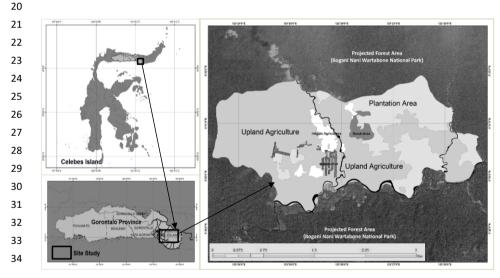
M.R.; Koubouris, G. Optimized Land Use through Integrated Land Suitability and GIS Approach in West El-Minia Governorate, Upper Egypt. Sustainability 2021, 13, 12236 https://doi.org/10.3390/su132112236 Furthermore, Bagherzadeh & Gholizadeh (2016) stated that in the parametric approach, different land suitability classes are defined as completely separate groups and separated from each other with different and consistent ranges. Differences in land suitability values due to the use of different methods on a land will have an impact on differences in land management. Therefore, the aim of the study was to determine the land suitability value of endemic liberica coffee with two different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

7

#### 8 MATERIAL AND METHODS

#### 9 Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. 10 Geographically, the research location is located at 0°24'5.4" - 0°38'29.04" North Latitude to 11 123°18'38.52" - 123°33'15.48" South Latitude covering an area of 2,804.28 ha with an elevation of 12 13 300 – 338 m above sea level (Fig. 1). Annual rainfall is 2,541.90 mm with an average monthly rainfall 14 ranging from 19.00 mm to 408.18 mm, so the research area is included in the agro-climatic zone C1 15 because the dry month (<100 mm) is only 1 month and 6 months is wet (>200 mm). The monthly air 16 temperature in the study area fluctuates between 24.34°C to 25.79°C while the relative humidity is between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52% to 70.50%. 17 18 while the monthly wind speed is between 2 knots to 2.60 knots. The research area is the upstream of the Bone watershed which flows to Tomini Bay. 19





#### 36 Soil Survey and Land Observation

37 A set of soil survey tools, including: soil knife, pH meter, meter, hoe, spade, machete, clinometer and

38 F marker. Meanwhile, the materials used consist of: soil maps, geological maps, slope maps,

1 landform maps, land use maps, maps 1 : 12,000 scale land unit, soil profile card, plastic bag, rubber

2 band, label paper, climate data from the local BMKG station for 5 years (2015-2021) and soil samples

3 for laboratory analysis. This field research uses a soil survey method on a scale of 1: 12,000 by

4 observing the characteristics of the land in 13 land units. Furthermore, field observations were 5 carried out to determine the characteristics of the land in the form of elevation and slope. After that,

6 1 kg of soil samples were taken for analysis in the laboratory.

#### 7 Soil Laboratory Analysis

Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil properties based on research parameters refers to the soil analysis procedure according to Eviyati & Sulaeman (2009). Soil reaction parameters (pH H<sub>2</sub>O) were determined with a pH meter extracted in a solution of 1:2.5 soil and water. Organic carbon content using the Walkley and Black method. The P content was available using the Olsen method, while the cation exchange capacity (CEC) was extracted with 1N NH<sub>4</sub>OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, while base saturation was determined by calculation. All soil data and selected land characteristic data are input

15 in dbf or xls format.

#### 16 Land Suitability Assesment

17 The deskwork in the suitability assessment is carried out based on the parameters of the selected 18 land characteristics which are the same between the limiting factor method and the parametric 19 method. Assessment of land suitability classes using the limiting factor method follows the land 20 evaluation framework according to FAO (1976) from the order and class categories (suitable, not 21 suitable) to units. Furthermore, the data on land characteristics and quality were compared with the 22 selected Coffea liberica HP. land suitability criteria (Table 1) according to the Indonesian Directorate 23 General of Plantations (2014), in order to obtain the actual land suitability class along with the limiting factors for land use. The limiting factor is then improved, so that the potential land suitability 24 25 class is obtained.

26

#### 27 Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements /land	Land suitability class							
characteristics	S1	S2	S3	Ν				
Elevation-el (m sl)	300 - 500	600 - 800; 0 - 300	800 - 1.000	>1,000				
Slopes-sl (%)	0-8	8 – 25	25 – 45	>45				
Nutrient retention (nr):								
Soil pH	5.5 - 6.0	6.1 - 7.0	7.1 - 8.0	>8.0				
C-organic (%)	2 – 5	1 - 2; 5 - 10	0.5 - 1.0; 10 - 15	<0.5; >15				
Cation exchange capacity (cmol)	>15	10 - 15	5 – 10	<5				
Base saturation (%)	>35	20-35	<20					
Nutrient availability (na):								
Availability of P (ppm)	>16	10 – 15	<10					

28 Remark: (Indonesian Directorate General of Plantations, 2014), modifed.

29 Meanwhile, in assessing land suitability using the parametric method, it is estimated that the 30 productivity of coffee uses several equations (Simbolon, 2018) based on the parameters of the

31 selected soil and land properties, namely:

32 Y = -2.672+0.026X (elevation) .....(1)

1	Y = 17,190-0.090X (slope)(2)	
2	Y = 3.055+0.005X (soil pH)(3)	
3	Y = 4.050-0.019X (C-organic)(4)	
4	Y = -28.796+0.621X (P availability)(5)	
5	Y = 32.450-0.109X (CEC)	
6	Y = 0.457-0.002X (base saturation)(7)	
7	In this case, Y = estimated production (t ha <sup>-1</sup> ), X = soil and land properties parameters, and CE	C =
8	cation exchange capacity. The assumption of optimal productivity of liberica coffee used is 0.75 t h	າa⁻¹

9 (Martono, 2018). In order to assess the accuracy of the estimated productivity of the liberica coffee,
10 it was analyzed using the Root Mean Square Error (RMSE) with the following equation:

- 10 It was analyzed using the root wear square error (rivise) with the following eq
- 12  $RMSE = \sqrt{\frac{\sum_{t=1}^{n} (At Ft)^2}{n}}$ .....(8)

where: RMSE = root mean square error, At = actual productivity (t ha<sup>-1</sup>), Ft = estimated productivity (t ha<sup>-1</sup>), and n = number of data. The smaller or closer to 0 the value of the RMSE, the more accurate
 the prediction results will be. Furthermore, land suitability assessment for liberica coffee uses a land
 index of root mean square (Khiddir, 1986), namely:

18  $LI = LC_{min} \sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}}$  .....(9)

where: LI = land index; LC<sub>min</sub> = minimum LC rating; A, B, C, ..., N = other LC in beside the minimum LC. Determination of land suitability classification based on LI is calculated from all LC which is influenced by the productivity of liberica coffee and has a certain land suitability class. LI score criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very 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 class N (not suitable) with value 0 – 25. All data and information obtained are described and presented in tabular form, while their spacial distribution is presented in map form.

#### 27 RESULTS

#### 28 Land Suitability Based on Limiting Factor Method

The result of matching the land suitability criteria with the land characteristics resulted in the actual 29 30 land suitability class for liberica coffee in Pinogu Plateau was shown to Table 2 and Figure 2. It seems 31 that the actual land suitability class was moderately suitable (S2) which was more dominant in an 32 area of 2,149.64 ha or 76.66% compared to the marginally suitable class (S3) which was only 654.64 33 ha or only 23.34%. Meanwhile the very suitable class (S1) and not suitable (N) has not found in the 34 results of this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee 35 land use in the Pinogu Plateau were nutrient retention (C-organic, base saturation and soil pH) and nutrients availability (P availability). In addition, there was an elevation limiting factor at LMU 1 and 36 37 LMU 7.

38

39 Table 2. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

LMU Elevation Slope pH C-Organic CEC BS Ava-P Actual Area

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	-															-	
	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	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

 Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS =

 base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

3 After making efforts to improve the actual land suitability class against the limiting factor, all LMUs 4 can be upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be 5 repaired because of the elevation limiting factor (Table 3, Figure 2). The limiting factors for nutrient 6 retention, both pH, C-organic, and low base saturation were improved with the addition of organic 7 matter, while the limiting factor for available nutrients of low P availability was improved with the 8 addition of P fertilizer. As a result, the most dominant potential land suitability class was S1 covering 9 an area of 1,980.30 ha or 70.62% and the rest including S2 class covering an area of 823.98 ha or 10 29.38% only.

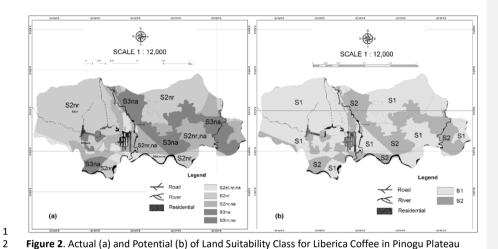
#### 11

#### 12 Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

		•	•			
LMU	Actual	Limiting Factors	Efforts	Potential	Area	Э
LIVIO	LSC	Limiting Factors	EHOILS	LSC	ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C- organic, base saturation), nutrient availability (available of P)	Can not be fixed (elevation)	S2	SC         ha           169,34         52           593,36         51           36,34         52           51         1.386,94	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability	- Addition of organic material	S1	593,36	8.95
		(available of P)	<ul> <li>Addition of P fertilizer</li> </ul>			
3	S3nr,na	Nutrient retention (C-organic),	<ul> <li>Addition of organic material</li> </ul>	S2	36,34	1.30
		nutrient availability (available of P)	- Addition of P fertilizer			
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	<ul> <li>Addition of organic material</li> </ul>	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
		Luas (Ha)			2.804,28	100
					-	

13 Remark: LMU = land mapping unit, LSC = land suitability class.

14



# Land Suitability Based on Parametric Method

The results of the productivity analysis (productivity) of liberica coffee based on each land characteristic showed that the highest productivity was obtained on the slope characteristics which averaged 1.69 t ha<sup>-1</sup>, while the lowest productivity was obtained on the available P characteristics which only ranged from 0.16 - 0.24 t ha<sup>-1</sup> with an average of 0.20 t ha<sup>-1</sup> (Table 4). The remaining land characteristics has an average productivity 0.30. The results of the RMSE analysis on the alleged productivity of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13 are smaller (0.51) compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE value of 0.52 12 (Table 4). The productivity of liberica coffee will affect the land characteristic index which will 13 ultimately determine the land index and land suitability class for liberica coffee.

14 It seems that the relative land characteristic index values follow the pattern of productivity for 15 liberica coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the 16 optimal value was the slope characteristic which averaged a value of 100 (Table 5), while the lowest land characteristic index value was obtained for the available P which an average of P availability 17 18 index of 26.39 only. The remaining land characteristics are relatively diverse but the average value of 19 the land characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land 20 characteristic index value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index, respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value 21 22 which was 50 only. The remaining LMUs get land index values ranged from 50 - 71.

23

24 Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

Characteristic							LMU						
/Productivity	1	2	3	4	5	6	7	8	9	10	11	12	13
Elev. (m sl)	293	307	313	302	311	305	290	288	338	300	334	306	310
Y (t ha-1)	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
Slo. (%)	3	3	3	3	3	3	3	3	3	8	3	8	3
Y (t ha-1)	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
рН	5.82	5.88	6.22	5.64	5.78	6.12	6.28	5.89	6.25	5.92	5.96	5.95	6.00

Characteristic							LMU						
/Productivity	1	2	3	4	5	6	7	8	9	10	11	12	13
Y (t ha-1)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
C-Org (%)	1.59	1.30	0.78	1.21	1.46	1.02	1.43	1.92	1.79	1.38	1.15	1.07	1.35
Y (t ha-1)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
CEC (cmol)	19.24	23.77	27.60	22.77	26.39	29.68	27.92	23.22	27.10	23.67	27.69	25.03	32.67
Y (t ha-1)	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
BS (%)	32.75	33.75	28.00	24.67	29.25	29.68	39.75	36.67	37.00	42.33	33.00	39.50	23.67
Y (t ha-1)	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
Av-P (ppm)	13.87	15.85	9.77	12.22	17.04	18.52	14.53	20.35	14.98	9.98	17.12	16.41	7.78
Y (t ha-1)	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
Ϋ́ (t ha⁻¹)	0.60	0.60	0.61	0.60	0.60	0.60	0.60	0.59	0.61	0.60	0.61	0.59	0.61
Stdev	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.49	0.48	0.49
RMSE	0.52	0.52	0.51	0.52	0.52	0.52	0.52	0.53	0.52	0.51	0.52	0.51	0.51

Remark: LMU = land mapping unit. Elev. = elevation. Slo. = slopes. C-Org = C-organic. Exc. = exchangeable. CEC = cation axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million, Stdev = standard deviation, RMSE = root mean square error.

3

4 Based on the land index values, the land suitability class for liberica coffee was more dominant S2

with covering an area of 88.77% (Table 5). Meanwhile, the S1 class was 7.21% and the S3 class was 5

6 4.02% only without not suitable class (N).

7

1

2

8 Table 5. Value of Land Characteristics Index, Land Index and Land Suitability Class for Liberica Coffee

Productivity							LMU						
/LC Value	1	2	3	4	5	6	7	8	9	10	11	12	13
Y-El. (t ha-1)	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
LC-El.	65.95	70.80	72.88	69.07	72.19	70.11	64.91	64.21	81.55	68.37	80.16	70.45	71.84
Y-SI. (t ha-1)	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
LC-Slo.	100	100	100	100	100	100	100	100	100	100	100	100	100
Y-pH (t ha-1)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
LC-pH	41.12	41.13	41.15	41.11	41.12	41.14	41.15	41.13	41.15	41.13	41.13	41.13	41.13
Y-Corg. (t	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
ha-1)													
LC-Corg.	53.60	53.67	53.80	53.69	53.63	53.74	53.64	53.51	53.55	53.65	53.71	53.73	53.66
Y-CEC (t ha <sup>-</sup>	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
<sup>1</sup> )													
LC-CEC	40.47	39.81	39.26	39.96	39.43	38.95	39.21	39.89	39.33	39.83	39.24	39.63	38.52
Y-BS (t ha-1)	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
LC-BS	52.20	51.93	53.47	54.36	53.13	53.02	50.33	51.16	51.07	49.64	52.13	50.40	54.62
Y-Ava.P (t	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
ha⁻¹)													
LC-Ava.P	26.91	25.27	30.31	28.28	24.29	23.06	26.37	21.54	25.99	30.13	24.22	24.81	31.95
LI	64	62	76	70	61	56	61	50	67	71	63	60	80
LSC	S2	S2	S1	S2	S2	S2	S2	S3	S2	S2	S2	S2	S1
Area (ha)	70.81	250.95	36.34	36.97	849.26	3.74	98.53	112.84	305.44	452.57	369.42	51.68	165.73
Area (%)	2.53	8.95	1.30	1.32	30.28	0.13	3.51	4.02	10.89	16.14	13.17	1.84	5.91

<sup>9</sup> 

Remark: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, Exc. = exchangeable, Ava. = availability, 10 El. = elevation, Sl. = slope, Corg. = C-organic, K = potassium, Ca = calcium, Mg = magnesium, Na = natrium, P = phosfor, CEC

11 = cation exchange capacity, BS = base saturatio, LI = land index, LSC = land suitability classes.

#### Comparison of Land Suitability Classes and their Recommendations on Land Management 13

14 Based on the results of the land suitability assessment between the limiting factor and the 15 parametric method were shown in Table 6 and Figure 3. The comparison between the two methods

shows the similarity of the land suitability class with the class pattern: S2 = S2 of 22.18% (LMU 1, 7 16 and LMU 10). But the most dominant class differences follow the pattern: S1 ≠ S2 of 66.59% (LMU 2, 17

4, 5, 6, 9, 11, and LMU 12), followed by class pattern: S2 ≠ S1 of 7.21% (LMU 3, and LMU 13), while 18

<sup>12</sup> 

1 the lowest was the class pattern:  $S1 \neq S3$  of 4.02% only (LMU 8). Thus, based on land suitability class 2 using the limiting factor method, the recommended land with priority I or equivalent to S1 was 3 70.62%, while land with priority II or equivalent to S2 was 29.38% without land priority III or 4 equivalent to S3 (0%). This was different from the land suitability class using the parametric method, 5 where the recommended land with priority I or equivalent to S1 was 7.21% only, while land with 6 priority II or equivalent to S2 was 88.77%, and land with priority III or equivalent to S3 was 4 ,20% 7 only.

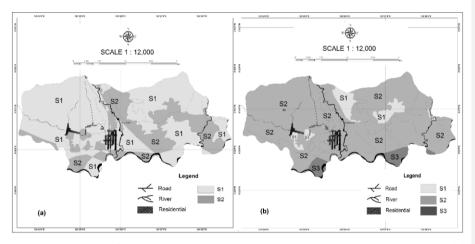
#### 8

**Table 6.** Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for
 Liberica Coffee in Pinogu Plateau

	Land Suitabi	lity Class		Area			
LMU	Limiting Factor Method	0		ha	%		
1, 7, 10	S2	S2	Priority I	621.91	22.18		
2, 4, 5, 6, 9, 11, 12	S1	S2	Priority II	1,867.46	66.59		
3, 13	S2	S1	Priority I	202.07	7.21		
8	S1 S3		Priority III	112.84	4.02		
	Area (ha		2,804.28	100.00			

11 Remark: LMU = land mapping unit.

12



#### 13

Figure 3. Comparison of Land Suitability Classes with Limiting Factors (a) and Parametric Methods (b)
 for Liberica Coffee in Pinogu Plateau
 16

#### 17 DISCUSSION

- 18 The suitability of land for liberica coffee with the limiting factor method and the parametric method
- 19 turned out to be different, both in terms of class and area. This study shown that the land suitability
- 20 class using the limiting factor method in Plato Pinogu was more dominant of very suitable, while the
- 21 land suitability class using the parametric method was more dominant of moderately suitable.
- 22 Although the land suitability class using this limiting factor method appears to be of a higher class

1 and wider distribution, it was only based on the characteristics of the land and has not been linked at 2 all with the productivity of liberica coffee. The limiting factor method has weaknesses, including 3 interactions between land characteristics that are difficult to explain (Elsheikh et al., 2013; Hartati, et al., 2018). In contrast to the land suitability class with the parametric method, besides being based 4 5 on the performance of land characteristics, it has also been directly related to the productivity of 6 liberica coffee in the research area, so that the interactions in it are easy to explain. According to 7 Sitorus (2018), the precision and reliability of parametric methods more greater than other land 8 evaluation methods. The advantage of the parametric method is that land evaluation is easy to carry 9 out and only consists of a few categories (Rodcha et al., 2019). Furthermore, Marbun et al. (2019) 10 stated that the superiority of this parametric method is not only calculating land suitability classes 11 based on soil properties but also taking into account all factors and mapping them in one land 12 suitability map. This parametric method with the square root of the land index uses a minimum 13 rating to assess land suitability classes (Juita et al., 2020). In fact, Mathewos et al. (2018) stated that 14 the square root land index value was higher than the Storie index. To improve the land evaluation 15 approach, qualitative and quantitative approaches must be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee using the limiting factor method, it turns out that 16 17 there were more limiting factors, while the parametric method most less. The minimum rating value in the parametric method was only the low availability of P nutrients. A low land suitability index 18 19 should be improved so that the plant grows optimally (Isramiranti et al., 2020). Land that has an S3 suitability class has the opportunity to be improved through various land improvement efforts, so 20 21 that it becomes a class S2 to class S1 (Refitri et al., 2016). Low nutrient availability was improved 22 through fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and 23 minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra 24 et al. (2019), land management can be done by adding organic matter and fertilizing according to the 25 recommended dose of fertilizer. The addition of organic matter can increase soil pH and organic C 26 (Afandi et al., 2015; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

27 Land suitability class assessment using the limiting factor method often contrasts between land 28 suitability classes and their real productivity. In fact, at LMU 4 and LMU 6, the existing land use 29 conditions are irrigated rice fields, rainfed rice fields and swamps that are often flooded, so the 30 actual land suitability class S2 and potential land suitability class S1 for liberica coffee still need to be 31 checked again in the field. While the parameteric method in principle gives values at different limiting levels to land properties on a normal scale with a maximum value of 100 to a minimum value 32 33 of 0 (Juita et al., 2020). The results of the land suitability assessment for liberica coffee in Plato 34 Pinogu with the parametric method following the class pattern S2 > S1 > S3. The advantage of this 35 parametric method is not only calculating land suitability classes based on soil properties but also 36 taking into account all factors and mapping them in one land suitability map (Marbun et al., 2019). It 37 seems that the land index obtained by the parametric method is closer to the real conditions in the 38 field, where the average liberica coffee production in the Pinogu Plateau ranges from 0.51 to 0.61 t 39 ha-1, while the productivity of Pinogu coffee currently reaches 0.75. t ha-1 (Martono, 2018). 40 Ghazanchaii & Fariabi (2014) state that there is a significant relationship between land index and production, where as the land index increases, the yield based on the range of land suitability classes 41 42 also increases quantitatively.

43 This research uses both land suitability assessment methods to be the same and consistent in terms

1 of the type and number of land characteristics used, so that the difference in the results of the land 2 suitability assessment is not caused by differences in the characteristics of the land but because of 3 the final value produced by the two methods. In the limiting factor method, the most limiting factor has a dominant role, so that other factors can be ignored (Nugroho & Istianto, 2013). The limiting 4 5 factor method makes it possible to determine the suitability class but without further specification 6 (Abbasi et al., 2019). While in the parametric method, the use of land characteristics is based on the 7 availability of mathematical equations to estimate the productivity of liberica coffee because only 8 LMU 3, 9, 10 and LMU 13 has liberica coffee plants and has been producing. Other LMUs do not have 9 liberica coffee plants, so their productivity must be estimated. In determining land suitability using 10 the parametric method, the most limiting factor will have less effect because it is covered by the 11 cumulative value of all factors (Nugroho & Istianto, 2013). Diagnostic criteria in the parametric 12 method are assessed numerically and mathematically to obtain land suitability classes (Marbun et 13 al., 2019). The parametric method is able to describe the degree of land suitability that does not depend on class boundaries (Abbasi et al., 2019). Limitations in the type and number of land 14 characteristics used in this study are a challenge for future research to be added or expanded to 15 other land characteristics. In fact, it can include environmental and socioeconomic variables 16 17 (Mathewos et al., 2018). However, the use of the parametric method is more significant for the 18 increase or decrease in productivity (Ghazanchaii & Fariabi, 2014) and is more realistic (Mathewos et 19 al., 2018). Meanwhile, the use of the limiting factor method, although the land suitability class for 20 liberica coffee is higher, often contrasts with the facts on the ground, so it must be re-checked.

Research on land suitability for liberica coffee in Plato Pinogu is the first research conducted in this 21 22 area and in the province of Gorontalo. Therefore, Liberika coffee, which is endemic to the Pinogu Plateau, Bone Bolango Regency, Gorontalo Province, needs to be maintained in the future. In 23 24 addition to the Pinogu area, Liberica coffee is also found in the East Bolaang Mongondow Regency, 25 North Sulawesi Province (Lasabuda et al., 2015) and South Sulawesi (Kahpi, 2017) which are still on 26 the island of Sulawesi and are endemic in the province. Thus, future research can focus on the 27 comparison of land suitability classes for liberica coffee in each of these areas along with their 28 agronomic performance and productivity.

#### 30 CONCLUSION

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The actual land suitability class for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, it has the potential became very suitable class (S1) and S2 class. The parametric method consists of S1, S2 and S3 classes because of low phosphorus nutrients. Land management recommendations for liberica coffee were priority I and II.

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# Response to the Reviewer's comments

# **REVIEWER B**

Page number	Line number	Reviewer's Comment	Author's Revision

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# **REVIEWER D**

Page number	Line number	Reviewer's Comment	Author's Revision

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# THE COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC COFFEA LIBERICA PINOGU HP. WITH DIFFERENT METHODS, AND THEIR RECOMMENDATIONS OF LAND MANAGEMENT IN PINOGU PLATEAU, BONE BOLANGO REGENCY

#### ABSTRACT

8 Coffee is a national strategic commodity that contributes to the country's foreign exchange but these 9 productivity is still low due to cultivation on low potential land. Study aimed to determine the land 10 suitability value of endemic liberica coffee with two different methods and their impact on land 11 management in Pinogu Plateau. The 13 land units were surveyed and analyzed the soil samples in the 12 laboratory to obtain data of the land characteristic selected. Comparison of different land suitability 13 values using the limiting factor method and the parametric method. The results showed that the land 14 suitability class for liberica coffee using the limiting factor method actually consisted of a moderately 15 suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention and available 16 nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, so that it 17 has the potential to become a very suitable class (S1) and S2 class. Meanwhile, the land suitability class 18 using the parametric method consisted of S1, S2 and S3 classes due to low P nutrients. Land 19 management recommendations for liberica coffee were priority I and II based on parametric methods. 20

21 Keywords: Land, suitability, coffee, liberica, endemic, Pinogu.

#### 23 INTRODUCTION

22

5 6

7

24 Coffee has long been a refreshing drink in the world. The distribution of world coffee includes Arabica 25 coffee with a distribution area of 80%, Robusta coffee by 20% and Liberica coffee with a distribution 26 area of only <1% (Nillian et al., 2020). It is relatively difficult to get research references on liberica 27 coffee in the world because of its limited area, so that publications are also relatively limited. It is 28 predicted that by 2050, the land suitable for robusta coffee cultivation is 83%, while arabica coffee is 29 only 17% in the world (Magrach & Ghazoul, 2015). However, according to Claude et al (2019), liberica 30 coffee based on pedoclimatic zoning is more potential to be cultivated than robusta and arabica coffee 31 because agro-climatic zoning shows an increase in the potential for this coffee production in the 32 coming years.

- Coffee in Indonesia is still a strategic commodity because it is able to contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 ts, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 ts or an increase of 2.62% from the previous year with a value of 809,158,900 US\$ (Indonesian Central Bureau of Statistics, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 ts or 0.02% of the total national coffee production (Indonesian Directorate General of Plantations, 2021).
- Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively
  flat and wide (496 km2) at an altitude of > 300 m above sea level, and is surrounded by hills and
- 42 mountains so that it can be called the Pinogu Plateau. This district has long been known as a coffee

producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021).
According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee
plantation and makes it their main commodity because the productivity level of this coffee is the
highest compared to other commodities. The advantages of pinogu coffee include the fact that local
farmers do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin,
2020), so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes
from robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021).

8 Liberica coffee (Coffea liberica) has been planted since 1875 (Sancayaningsih et al., 2016) and is 9 endemic because this species exists and grows in the Pinogu District only. Liberica coffee has the 10 advantage of good taste (Gusfarina, D, 2014), and a distinctive taste of jackfruit (Saidi & Suryani, 2021). 11 This condition makes pinogu coffee an icon of the superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have so far 12 13 encountered several obstacles, one of which is the low productivity of the coffee. Martono (2018) 14 reports that although Pinogu Coffee has become global, its productivity is still low at only 0.75 t ha<sup>-1</sup> year<sup>-1</sup>. In fact, the productivity of liberica coffee can reach 1.69 - 1.98 t ha<sup>-1</sup> (Indonesia Research 15 16 Institute for Industrial Plants and Refreshments, 2015). Pinogu sub-district has a coffee plantation area 17 of 282.63 ha or the largest in this district (66.21%) with new production of 36.34 t (Humola et al., 2021). Such conditions will affect the availability of coffee raw materials to meet market demand later. The 18 19 low productivity of coffee is thought to be because coffee cultivation is carried out on land that is not

20 in accordance with the potential of the land.

21 Until now there is no available information about the potential of land for the development of Liberika 22 Coffee in the Pinogu Plateau area, except for the potential of land for robusta coffee because it is more 23 developed. Land suitability for robusta coffee in Bone Bolango Regency is marginally suitable or S3 24 class (Taslim, 2018; Indrianti, 2020). Meanwhile, other plantation commodities such as coconut, cocoa, 25 cloves, candlenut and vanilla are included in the S2 class in Bone Bolango Regency (Taslim, 2018). 26 Liberica coffee is not only endemic, it is also more resistant to pests and plant diseases (Harni et al., 27 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests (Gusfarina, D, 2014). 28 Ignorance of coffee planters regarding land potential will greatly affect the productivity of liberica 29 coffee itself, because differences in land potential will be responded by variously by plants according 30 to growing conditions based on land characteristics (Sukarman et al., 2018).

31 Land management requires land suitability assessment so that a land can be used productively and 32 sustainably (Mustafa et al., 2014), including land suitability assessment for liberica coffee. Different 33 land evaluation methods have different data requirements and varying guality of estimates, but there 34 is no fixed rule that defines when and what method to use when there is a need for more complex 35 analyzes (Mathewos et al., 2018; Mugiyo et al., 2021). Previous research on land suitability assessment 36 for coffee mostly used the limiting factor method. The limiting factor method is used to determine the 37 class based on the lowest constraint, while the parametric method is determined based on the 38 correlation between all variables (Rabia & Terribile, 2013). In the parametric method, there is a 39 combination of soil characteristics that affect agricultural production using mathematical equations 40 (Elaalem, 2013) so that the interaction between land characteristics can be minimized. Furthermore, 41 Bagherzadeh & Gholizadeh (2016) stated that in the parametric approach, different land suitability 42 classes are defined as completely separate groups and separated from each other with different and

1 consistent ranges. Differences in land suitability values due to the use of different methods on a land

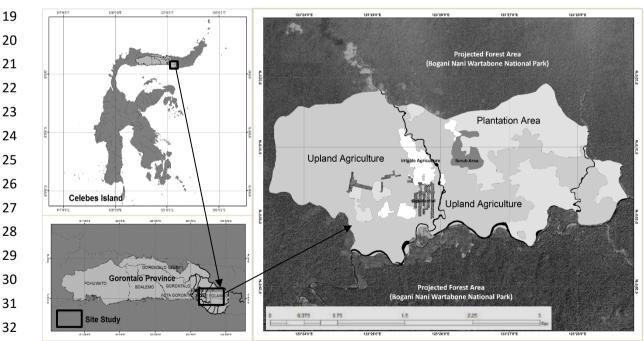
- 2 will have an impact on differences in land management. Therefore, the aim of the study was to
- 3 determine the land suitability value of endemic liberica coffee with two different methods and
- 4 recommendations for land management in Pinogu Plateau, Bone Bolango Regency.
- 5

# 6 MATERIAL AND METHODS

# 7 Site Study

8 This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Geographically, the research location is located at 0°24'5.4" - 0°38'29.04" North Latitude to 9 10 123°18'38.52" – 123°33'15.48" South Latitude covering an area of 2,804.28 ha with an elevation of 11 300 – 338 m above sea level (Fig. 1). Annual rainfall is 2,541.90 mm with an average monthly rainfall ranging from 19.00 mm to 408.18 mm, so the research area is included in the agro-climatic zone C1 12 because the dry month (<100 mm) is only 1 month and 6 months is wet (>200 mm). The monthly air 13 14 temperature in the study area fluctuates between 24.34°C to 25.79°C while the relative humidity is between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52% to 70.50%. while 15 16 the monthly wind speed is between 2 knots to 2.60 knots. The research area is the upstream of the 17 Bone watershed which flows to Tomini Bay.





# 33 Figure 1. Research Location Map

# 34 Soil Survey and Land Observation

A set of soil survey tools, including: soil knife, pH meter, meter, hoe, spade, machete, clinometer and F marker. Meanwhile, the materials used consist of: soil maps, geological maps, slope maps, landform maps, land use maps, maps 1 : 12,000 scale land unit, soil profile card, plastic bag, rubber band, label paper, climate data from the local BMKG station for 5 years (2015-2021) and soil samples for laboratory

- 1 analysis. This field research uses a soil survey method on a scale of 1: 12,000 by observing the
- 2 characteristics of the land in 13 land units. Furthermore, field observations were carried out to
- 3 determine the characteristics of the land in the form of elevation and slope. After that, 1 kg of soil
- 4 samples were taken for analysis in the laboratory.

# 5 Soil Laboratory Analysis

- 6 Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil
- 7 properties based on research parameters refers to the soil analysis procedure according to Eviyati &
- 8 Sulaeman (2009). Soil reaction parameters (pH H<sub>2</sub>O) were determined with a pH meter extracted in a
- 9 solution of 1:2.5 soil and water. Organic carbon content using the Walkley and Black method. The P
- content was available using the Olsen method, while the cation exchange capacity (CEC) was extracted
   with 1N NH<sub>4</sub>OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, while base saturation was
- 12 determined by calculation. All soil data and selected land characteristic data are input in dbf or xls
- 13 format.

# 14 Land Suitability Assesment

15 The deskwork in the suitability assessment is carried out based on the parameters of the selected land

- 16 characteristics which are the same between the limiting factor method and the parametric method.
- 17 Assessment of land suitability classes using the limiting factor method follows the land evaluation
- 18 framework according to FAO (1976) from the order and class categories (suitable, not suitable) to units.
- 19 Furthermore, the data on land characteristics and quality were compared with the selected *Coffea*
- 20 *liberica* HP. land suitability criteria (Table 1) according to the Indonesian Directorate General of
- Plantations (2014), in order to obtain the actual land suitability class along with the limiting factors for
- 22 land use. The limiting factor is then improved, so that the potential land suitability class is obtained.
- 23

# 24 **Table 1**. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements /land		Land suitabi	lity class	
characteristics	S1	S2	S3	Ν
Elevation-el (m sl)	300 – 500	600 - 800; 0 - 300	800 - 1.000	>1,000
Slopes-sl (%)	0-8	8 – 25	25 – 45	>45
Nutrient retention (nr):				
Soil pH	5.5 – 6.0	6.1 - 7.0	7.1 - 8.0	>8.0
C-organic (%)	2 – 5	1 – 2; 5 – 10	0.5 - 1.0; 10 - 15	<0.5; >15
Cation exchange capacity (cmol)	>15	10 – 15	5 - 10	<5
Base saturation (%)	>35	20-35	<20	
Nutrient availability (na):				
Availability of P (ppm)	>16	10 – 15	<10	

25 Remark: (Indonesian Directorate General of Plantations, 2014), modifed.

26 Meanwhile, in assessing land suitability using the parametric method, it is estimated that the

27 productivity of coffee uses several equations (Simbolon, 2018) based on the parameters of the 28 selected soil and land properties, namely:

29	Y = -2.672+0.026X (elevation)	(1)
30	Y = 17,190-0.090X (slope)	(2)
31	Y = 3.055+0.005X (soil pH)	(3)
32	Y = 4.050-0.019X (C-organic)	(4)

 1
 Y = -28.796+0.621X (P availability)
 (5)

 2
 Y = 32.450-0.109X (CEC)
 (6)

 3
 Y = 0.457-0.002X (base saturation)
 (7)

 4
 In this case, Y = estimated production (t ha<sup>-1</sup>), X = soil and land properties parameters, and CEC = cation

 5
 exchange capacity. The assumption of optimal productivity of liberica coffee used is 0.75 t ha<sup>-1</sup>

 6
 (Martono, 2018). In order to assess the accuracy of the estimated productivity of the liberica coffee, it

 7
 was analyzed using the Root Mean Square Error (RMSE) with the following equation:

8

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

where: RMSE = root mean square error, At = actual productivity (t ha<sup>-1</sup>), Ft = estimated productivity (t ha<sup>-1</sup>), and n = number of data. The smaller or closer to 0 the value of the RMSE, the more accurate the
 prediction results will be. Furthermore, land suitability assessment for liberica coffee uses a land index
 of root mean square (Khiddir, 1986), namely:

14

15  $LI = LC_{min} \sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}}$  ....(9)

where: LI = land index;  $LC_{min}$  = minimum LC rating; A, B, C, ..., N = other LC in beside the minimum LC. Determination of land suitability classification based on LI is calculated from all LC which is influenced by the productivity of liberica coffee and has a certain land suitability class. LI score criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very 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 class N (not suitable) with value 0 – 25. All data and information obtained are described and presented in tabular form, while their spacial distribution is presented in map form.

23

#### 24 **RESULTS**

#### 25 Land Suitability Based on Limiting Factor Method

26 The result of matching the land suitability criteria with the land characteristics resulted in the actual 27 land suitability class for liberica coffee in Pinogu Plateau was shown to Table 2 and Figure 2. It seems 28 that the actual land suitability class was moderately suitable (S2) which was more dominant in an area 29 of 2,149.64 ha or 76.66% compared to the marginally suitable class (S3) which was only 654.64 ha or 30 only 23.34%. Meanwhile the very suitable class (S1) and not suitable (N) has not found in the results 31 of this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use 32 in the Pinogu Plateau were nutrient retention (C-organic, base saturation and soil pH) and nutrients 33 availability (P availability). In addition, there was an elevation limiting factor at LMU 1 and LMU 7.

34

#### 35 Table 2. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

	Eleva	tion	Slo	Slope		Н	C-Organic		CEC		BS		Ava-P			Area	a
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual 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
							ŀ	Area (ha)								2,804.28	100

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS =
 base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

3 After making efforts to improve the actual land suitability class against the limiting factor, all LMUs can

4 be upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be repaired

5 because of the elevation limiting factor (Table 3, Figure 2). The limiting factors for nutrient retention,

6 both pH, C-organic, and low base saturation were improved with the addition of organic matter, while

7 the limiting factor for available nutrients of low P availability was improved with the addition of P

8 fertilizer. As a result, the most dominant potential land suitability class was S1 covering an area of

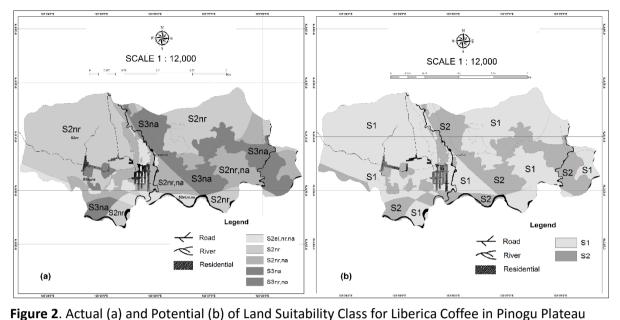
- 9 1,980.30 ha or 70.62% and the rest including S2 class covering an area of 823.98 ha or 29.38% only.
- 10

#### 11 Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual	Limiting Factors	Efforts	Potential	Area	a
LIVIO	LSC	Entitling Factors	Elloits	LSC	ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C- organic, base saturation), nutrient availability (available of P)	Can not 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)	<ul> <li>Addition of organic</li> <li>material</li> <li>Addition of P fertilizer</li> </ul>	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic material	S2	36,34	1.30
		nutrient availability (available of P)	- Addition of P fertilizer			
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic material	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
		Luas (Ha)			2.804,28	100

12 Remark: LMU = land mapping unit, LSC = land suitability class.

13



# 1 2 3 4

Figure 2. Actual (a) and Potential (b) of Land Suitability Class for Liberica Conee in Pinogi

# 4 Land Suitability Based on Parametric Method

5 The results of the productivity analysis (productivity) of liberica coffee based on each land characteristic showed that the highest productivity was obtained on the slope characteristics which 6 7 averaged 1.69 t ha<sup>-1</sup>, while the lowest productivity was obtained on the available P characteristics 8 which only ranged from 0.16 - 0.24 t ha<sup>-1</sup> with an average of 0.20 t ha<sup>-1</sup> (Table 4). The remaining land 9 characteristics has an average productivity 0.30. The results of the RMSE analysis on the alleged 10 productivity of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13 are smaller (0.51) 11 compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE value of 0.52 (Table 4). The productivity of liberica coffee will affect the land characteristic index which will ultimately 12 13 determine the land index and land suitability class for liberica coffee. 14 It seems that the relative land characteristic index values follow the pattern of productivity for liberica 15 coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the optimal value was the slope characteristic which averaged a value of 100 (Table 5), while the lowest land 16

characteristic index value was obtained for the available P which an average of P availability index of
26.39 only. The remaining land characteristics are relatively diverse but the average value of the land
characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index
value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index,

- respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value which was 50 only. The
- remaining LMUs get land index values ranged from 50 71.
- 23

24 Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

Characteristic	-						LMU						
/Productivity	1	2	3	4	5	6	7	8	9	10	11	12	13
Elev. (m sl)	293	307	313	302	311	305	290	288	338	300	334	306	310
Y (t ha-1)	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
Slo. (%)	3	3	3	3	3	3	3	3	3	8	3	8	3
Y (t ha-1)	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
рН	5.82	5.88	6.22	5.64	5.78	6.12	6.28	5.89	6.25	5.92	5.96	5.95	6.00

Characteristic							LMU						
/Productivity	1	2	3	4	5	6	7	8	9	10	11	12	13
Y (t ha⁻¹)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
C-Org (%)	1.59	1.30	0.78	1.21	1.46	1.02	1.43	1.92	1.79	1.38	1.15	1.07	1.35
Y (t ha⁻¹)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
CEC (cmol)	19.24	23.77	27.60	22.77	26.39	29.68	27.92	23.22	27.10	23.67	27.69	25.03	32.67
Y (t ha⁻¹)	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
BS (%)	32.75	33.75	28.00	24.67	29.25	29.68	39.75	36.67	37.00	42.33	33.00	39.50	23.67
Y (t ha⁻¹)	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
Av-P (ppm)	13.87	15.85	9.77	12.22	17.04	18.52	14.53	20.35	14.98	9.98	17.12	16.41	7.78
Y (t ha⁻¹)	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
Ϋ́ (t ha⁻¹)	0.60	0.60	0.61	0.60	0.60	0.60	0.60	0.59	0.61	0.60	0.61	0.59	0.61
Stdev	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.49	0.48	0.49
RMSE	0.52	0.52	0.51	0.52	0.52	0.52	0.52	0.53	0.52	0.51	0.52	0.51	0.51

1 Remark: LMU = land mapping unit, Elev. = elevation, Slo. = slopes, C-Org = C-organic, Exc. = exchangeable, CEC = cation

axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million, Stdev = standard
 deviation, RMSE = root mean square error.

4 Based on the land index values, the land suitability class for liberica coffee was more dominant S2 with

5 covering an area of 88.77% (Table 5). Meanwhile, the S1 class was 7.21% and the S3 class was 4.02%

6 only without not suitable class (N).

7

8 Table 5. Value of Land Characteristics Index, Land Index and Land Suitability Class for Liberica Coffee

Productivity							LMU						
/LC Value	1	2	3	4	5	6	7	8	9	10	11	12	13
Y-El. (t ha⁻¹)	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
LC-EI.	65.95	70.80	72.88	69.07	72.19	70.11	64.91	64.21	81.55	68.37	80.16	70.45	71.84
Y-SI. (t ha⁻¹)	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
LC-Slo.	100	100	100	100	100	100	100	100	100	100	100	100	100
Y-pH (t ha⁻¹)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
LC-pH	41.12	41.13	41.15	41.11	41.12	41.14	41.15	41.13	41.15	41.13	41.13	41.13	41.13
Y-Corg. (t ha⁻¹)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
LC-Corg.	53.60	53.67	53.80	53.69	53.63	53.74	53.64	53.51	53.55	53.65	53.71	53.73	53.66
Y-CEC (t ha⁻ ¹)	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
LC-CEC	40.47	39.81	39.26	39.96	39.43	38.95	39.21	39.89	39.33	39.83	39.24	39.63	38.52
Y-BS (t ha⁻¹)	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
LC-BS	52.20	51.93	53.47	54.36	53.13	53.02	50.33	51.16	51.07	49.64	52.13	50.40	54.62
Y-Ava.P (t ha⁻¹)	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
LC-Ava.P	26.91	25.27	30.31	28.28	24.29	23.06	26.37	21.54	25.99	30.13	24.22	24.81	31.95
LI	64	62	76	70	61	56	61	50	67	71	63	60	80
LSC	S2	S2	S1	S2	S2	S2	S2	S3	S2	S2	S2	S2	S1
Area (ha)	70.81	250.95	36.34	36.97	849.26	3.74	98.53	112.84	305.44	452.57	369.42	51.68	165.73
Area (%)	2.53	8.95	1.30	1.32	30.28	0.13	3.51	4.02	10.89	16.14	13.17	1.84	5.91

9 Remark: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, Exc. = exchangeable, Ava. = availability, El.

= elevation, SI. = slope, Corg. = C-organic, K = potassium, Ca = calcium, Mg = magnesium, Na = natrium, P = phosfor, CEC =
 cation exchange capacity, BS = base saturatio, LI = land index, LSC = land suitability classes.

12

#### 13 Comparison of Land Suitability Classes and their Recommendations on Land Management

14 Based on the results of the land suitability assessment between the limiting factor and the parametric

15 method were shown in Table 6 and Figure 3. The comparison between the two methods shows the

similarity of the land suitability class with the class pattern: S2 = S2 of 22.18% (LMU 1, 7 and LMU 10).

17 But the most dominant class differences follow the pattern: S1  $\neq$  S2 of 66.59% (LMU 2, 4, 5, 6, 9, 11,

and LMU 12), followed by class pattern: S2  $\neq$  S1 of 7.21% (LMU 3, and LMU 13), while the lowest was

the class pattern: S1 ≠ S3 of 4.02% only (LMU 8). Thus, based on land suitability class using the limiting factor method, the recommended land with priority I or equivalent to S1 was 70.62%, while land with priority II or equivalent to S2 was 29.38% without land priority III or equivalent to S3 (0%). This was different from the land suitability class using the parametric method, where the recommended land with priority I or equivalent to S1 was 7.21% only, while land with priority II or equivalent to S2 was

6 88.77%, and land with priority III or equivalent to S3 was 4 ,20% only.

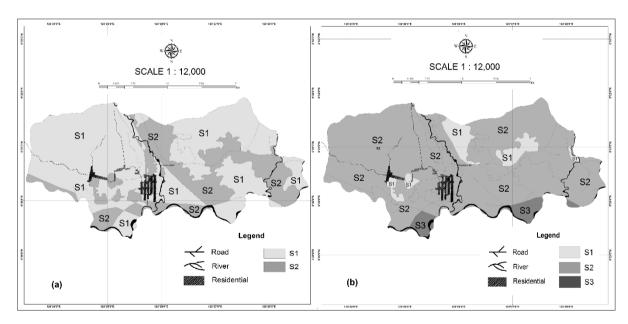
7

8	Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for
9	Liberica Coffee in Pinogu Plateau

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

10 Remark: LMU = land mapping unit.

11



12

Figure 3. Comparison of Land Suitability Classes with Limiting Factors (a) and Parametric Methods (b)
 for Liberica Coffee in Pinogu Plateau

15

# 16 DISCUSSION

17 The suitability of land for liberica coffee with the limiting factor method and the parametric method 18 turned out to be different, both in terms of class and area. This study shown that the land suitability

10 class using the limiting factor method in Plate Dinegu was more dominant of yory suitable, while the

- 19 class using the limiting factor method in Plato Pinogu was more dominant of very suitable, while the
- 20 land suitability class using the parametric method was more dominant of moderately suitable.
- Although the land suitability class using this limiting factor method appears to be of a higher class and wider distribution, it was only based on the characteristics of the land and has not been linked at all

1 with the productivity of liberica coffee. The limiting factor method has weaknesses, including

- 2 interactions between land characteristics that are difficult to explain (Elsheikh et al., 2013; Hartati, et
- al., 2018). In contrast to the land suitability class with the parametric method, besides being based on
- 4 the performance of land characteristics, it has also been directly related to the productivity of liberica
- 5 coffee in the research area, so that the interactions in it are easy to explain. According to Sitorus (2018),
- the precision and reliability of parametric methods more greater than other land evaluation methods.
  The advantage of the parametric method is that land evaluation is easy to carry out and only consists
- The advantage of the parametric method is that land evaluation is easy to carry out and only consists
  of a few categories (Rodcha et al., 2019). Furthermore, Marbun et al. (2019) stated that the superiority
- 9 of this parametric method is not only calculating land suitability classes based on soil properties but
- also taking into account all factors and mapping them in one land suitability map. This parametric
- 11 method with the square root of the land index uses a minimum rating to assess land suitability classes
- 12 (Juita et al., 2020). In fact, Mathewos et al. (2018) stated that the square root land index value was
- 13 higher than the Storie index. To improve the land evaluation approach, qualitative and quantitative
- 14 approaches must be integrated (Mugiyo et al., 2021).

15 In the land suitability assessment for liberica coffee using the limiting factor method, it turns out that 16 there were more limiting factors, while the parametric method most less. The minimum rating value 17 in the parametric method was only the low availability of P nutrients. A low land suitability index 18 should be improved so that the plant grows optimally (Isramiranti et al., 2020). Land that has an S3 19 suitability class has the opportunity to be improved through various land improvement efforts, so that 20 it becomes a class S2 to class S1 (Refitri et al., 2016). Low nutrient availability was improved through

- 21 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),
- 23 land management can be done by adding organic matter and fertilizing according to the recommended
- 24 dose of fertilizer. The addition of organic matter can increase soil pH and organic C (Afandi et al., 2015;
- 25 Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

26 Land suitability class assessment using the limiting factor method often contrasts between land 27 suitability classes and their real productivity. In fact, at LMU 4 and LMU 6, the existing land use 28 conditions are irrigated rice fields, rainfed rice fields and swamps that are often flooded, so the actual 29 land suitability class S2 and potential land suitability class S1 for liberica coffee still need to be checked 30 again in the field. While the parameteric method in principle gives values at different limiting levels to 31 land properties on a normal scale with a maximum value of 100 to a minimum value of 0 (Juita et al., 32 2020). The results of the land suitability assessment for liberica coffee in Plato Pinogu with the 33 parametric method following the class pattern S2 > S1 > S3. The advantage of this parametric method 34 is not only calculating land suitability classes based on soil properties but also taking into account all 35 factors and mapping them in one land suitability map (Marbun et al., 2019). It seems that the land 36 index obtained by the parametric method is closer to the real conditions in the field, where the average 37 liberica coffee production in the Pinogu Plateau ranges from 0.51 to 0.61 t ha-1, while the productivity 38 of Pinogu coffee currently reaches 0.75. t ha-1 (Martono, 2018). Ghazanchaii & Fariabi (2014) state 39 that there is a significant relationship between land index and production, where as the land index 40 increases, the yield based on the range of land suitability classes also increases quantitatively.

- This research uses both land suitability assessment methods to be the same and consistent in terms of the type and number of land characteristics used, so that the difference in the results of the land
- 43 suitability assessment is not caused by differences in the characteristics of the land but because of the

1 final value produced by the two methods. In the limiting factor method, the most limiting factor has a 2 dominant role, so that other factors can be ignored (Nugroho & Istianto, 2013). The limiting factor 3 method makes it possible to determine the suitability class but without further specification (Abbasi 4 et al., 2019). While in the parametric method, the use of land characteristics is based on the availability 5 of mathematical equations to estimate the productivity of liberica coffee because only LMU 3, 9, 10 6 and LMU 13 has liberica coffee plants and has been producing. Other LMUs do not have liberica coffee 7 plants, so their productivity must be estimated. In determining land suitability using the parametric 8 method, the most limiting factor will have less effect because it is covered by the cumulative value of 9 all factors (Nugroho & Istianto, 2013). Diagnostic criteria in the parametric method are assessed 10 numerically and mathematically to obtain land suitability classes (Marbun et al., 2019). The parametric method is able to describe the degree of land suitability that does not depend on class boundaries 11 12 (Abbasi et al., 2019). Limitations in the type and number of land characteristics used in this study are 13 a challenge for future research to be added or expanded to other land characteristics. In fact, it can 14 include environmental and socioeconomic variables (Mathewos et al., 2018). However, the use of the 15 parametric method is more significant for the increase or decrease in productivity (Ghazanchaii & 16 Fariabi, 2014) and is more realistic (Mathewos et al., 2018). Meanwhile, the use of the limiting factor 17 method, although the land suitability class for liberica coffee is higher, often contrasts with the facts 18 on the ground, so it must be re-checked. Research on land suitability for liberica coffee in Plato Pinogu is the first research conducted in this

Research on land suitability for liberica coffee in Plato Pinogu is the first research conducted in this area and in the province of Gorontalo. Therefore, Liberika coffee, which is endemic to the Pinogu Plateau, Bone Bolango Regency, Gorontalo Province, needs to be maintained in the future. In addition to the Pinogu area, Liberica coffee is also found in the East Bolaang Mongondow Regency, North Sulawesi Province (Lasabuda et al., 2015) and South Sulawesi (Kahpi, 2017) which are still on the island of Sulawesi and are endemic in the province. Thus, future research can focus on the comparison of land suitability classes for liberica coffee in each of these areas along with their agronomic performance and productivity.

27

# 28 CONCLUSION

The actual land suitability class for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, it has the potential became very suitable class (S1) and S2 class. The parametric method consists of S1, S2 and S3 classes because of low phosphorus nutrients. Land management recommendations for liberica coffee were priority I and II.

35 36

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# THE COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC COFFEA LIBERICA PINOGU HP. WITH DIFFERENT METHODS, AND THEIR RECOMMENDATIONS OF LAND MANAGEMENT IN PINOGU PLATEAU, BONE BOLANGO REGENCY

#### ABSTRACT

8 Coffee is a national strategic commodity that contributes to the country's foreign exchange but these 9 productivity is still low due to cultivation on low potential land. Study aimed to determine the land 10 suitability value of endemic liberica coffee with two different methods and their impact on land 11 management in Pinogu Plateau. The 13 land units were surveyed and analyzed the soil samples in the 12 laboratory to obtain data of the land characteristic selected. Comparison of different land suitability 13 values using the limiting factor method and the parametric method. The results showed that the land 14 suitability class for liberica coffee using the limiting factor method actually consisted of a moderately 15 suitable class (S2) and a marginally suitable class (S3) with elevation, nutrient retention and available 16 nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, so that it 17 has the potential to become a very suitable class (S1) and S2 class. Meanwhile, the land suitability class 18 using the parametric method consisted of S1, S2 and S3 classes due to low P nutrients. Land 19 management recommendations for liberica coffee were priority I and II based on parametric methods. 20

21 Keywords: Land, suitability, coffee, liberica, endemic, Pinogu.

#### 23 INTRODUCTION

22

5 6

7

24 Coffee has long been a refreshing drink in the world. The distribution of world coffee includes Arabica 25 coffee with a distribution area of 80%, Robusta coffee by 20% and Liberica coffee with a distribution 26 area of only <1% (Nillian et al., 2020). It is relatively difficult to get research references on liberica 27 coffee in the world because of its limited area, so that publications are also relatively limited. It is 28 predicted that by 2050, the land suitable for robusta coffee cultivation is 83%, while arabica coffee is 29 only 17% in the world (Magrach & Ghazoul, 2015). However, according to Claude et al (2019), liberica 30 coffee based on pedoclimatic zoning is more potential to be cultivated than robusta and arabica coffee 31 because agro-climatic zoning shows an increase in the potential for this coffee production in the 32 coming years.

- Coffee in Indonesia is still a strategic commodity because it is able to contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 ts, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 ts or an increase of 2.62% from the previous year with a value of 809,158,900 US\$ (Indonesian Central Bureau of Statistics, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 ts or 0.02% of the total national coffee production (Indonesian Directorate General of Plantations, 2021).
- Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively
  flat and wide (496 km2) at an altitude of > 300 m above sea level, and is surrounded by hills and
- 42 mountains so that it can be called the Pinogu Plateau. This district has long been known as a coffee

producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021).
According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee
plantation and makes it their main commodity because the productivity level of this coffee is the
highest compared to other commodities. The advantages of pinogu coffee include the fact that local
farmers do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin,
2020), so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes
from robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021).

8 Liberica coffee (Coffea liberica) has been planted since 1875 (Sancayaningsih et al., 2016) and is 9 endemic because this species exists and grows in the Pinogu District only. Liberica coffee has the 10 advantage of good taste (Gusfarina, D, 2014), and a distinctive taste of jackfruit (Saidi & Suryani, 2021). 11 This condition makes pinogu coffee an icon of the superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have so far 12 13 encountered several obstacles, one of which is the low productivity of the coffee. Martono (2018) 14 reports that although Pinogu Coffee has become global, its productivity is still low at only 0.75 t ha<sup>-1</sup> year<sup>-1</sup>. In fact, the productivity of liberica coffee can reach 1.69 - 1.98 t ha<sup>-1</sup> (Indonesia Research 15 16 Institute for Industrial Plants and Refreshments, 2015). Pinogu sub-district has a coffee plantation area 17 of 282.63 ha or the largest in this district (66.21%) with new production of 36.34 t (Humola et al., 2021). Such conditions will affect the availability of coffee raw materials to meet market demand later. The 18 19 low productivity of coffee is thought to be because coffee cultivation is carried out on land that is not

20 in accordance with the potential of the land.

21 Until now there is no available information about the potential of land for the development of Liberika 22 Coffee in the Pinogu Plateau area, except for the potential of land for robusta coffee because it is more 23 developed. Land suitability for robusta coffee in Bone Bolango Regency is marginally suitable or S3 24 class (Taslim, 2018; Indrianti, 2020). Meanwhile, other plantation commodities such as coconut, cocoa, 25 cloves, candlenut and vanilla are included in the S2 class in Bone Bolango Regency (Taslim, 2018). 26 Liberica coffee is not only endemic, it is also more resistant to pests and plant diseases (Harni et al., 27 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests (Gusfarina, D, 2014). 28 Ignorance of coffee planters regarding land potential will greatly affect the productivity of liberica 29 coffee itself, because differences in land potential will be responded by variously by plants according 30 to growing conditions based on land characteristics (Sukarman et al., 2018).

31 Land management requires land suitability assessment so that a land can be used productively and 32 sustainably (Mustafa et al., 2014), including land suitability assessment for liberica coffee. Different 33 land evaluation methods have different data requirements and varying guality of estimates, but there 34 is no fixed rule that defines when and what method to use when there is a need for more complex 35 analyzes (Mathewos et al., 2018; Mugiyo et al., 2021). Previous research on land suitability assessment 36 for coffee mostly used the limiting factor method. The limiting factor method is used to determine the 37 class based on the lowest constraint, while the parametric method is determined based on the 38 correlation between all variables (Rabia & Terribile, 2013). In the parametric method, there is a 39 combination of soil characteristics that affect agricultural production using mathematical equations 40 (Elaalem, 2013) so that the interaction between land characteristics can be minimized. Furthermore, 41 Bagherzadeh & Gholizadeh (2016) stated that in the parametric approach, different land suitability 42 classes are defined as completely separate groups and separated from each other with different and

1 consistent ranges. Differences in land suitability values due to the use of different methods on a land

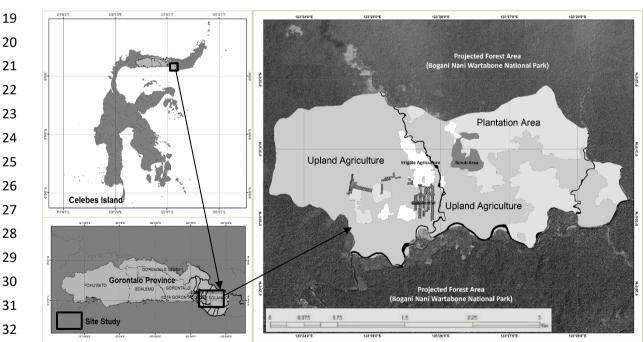
- 2 will have an impact on differences in land management. Therefore, the aim of the study was to
- 3 determine the land suitability value of endemic liberica coffee with two different methods and
- 4 recommendations for land management in Pinogu Plateau, Bone Bolango Regency.
- 5

# 6 MATERIAL AND METHODS

#### 7 Site Study

8 This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Geographically, the research location is located at 0°24'5.4" - 0°38'29.04" North Latitude to 9 10 123°18'38.52" – 123°33'15.48" South Latitude covering an area of 2,804.28 ha with an elevation of 11 300 – 338 m above sea level (Fig. 1). Annual rainfall is 2,541.90 mm with an average monthly rainfall ranging from 19.00 mm to 408.18 mm, so the research area is included in the agro-climatic zone C1 12 because the dry month (<100 mm) is only 1 month and 6 months is wet (>200 mm). The monthly air 13 14 temperature in the study area fluctuates between 24.34°C to 25.79°C while the relative humidity is between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52% to 70.50%. while 15 16 the monthly wind speed is between 2 knots to 2.60 knots. The research area is the upstream of the 17 Bone watershed which flows to Tomini Bay.





#### 33 Figure 1. Research Location Map

# 34 Soil Survey and Land Observation

A set of soil survey tools, including: soil knife, pH meter, meter, hoe, spade, machete, clinometer and F marker. Meanwhile, the materials used consist of: soil maps, geological maps, slope maps, landform maps, land use maps, maps 1 : 12,000 scale land unit, soil profile card, plastic bag, rubber band, label paper, climate data from the local BMKG station for 5 years (2015-2021) and soil samples for laboratory

- 1 analysis. This field research uses a soil survey method on a scale of 1: 12,000 by observing the
- 2 characteristics of the land in 13 land units. Furthermore, field observations were carried out to
- 3 determine the characteristics of the land in the form of elevation and slope. After that, 1 kg of soil
- 4 samples were taken for analysis in the laboratory.

# 5 Soil Laboratory Analysis

- 6 Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil
- 7 properties based on research parameters refers to the soil analysis procedure according to Eviyati &
- 8 Sulaeman (2009). Soil reaction parameters (pH H<sub>2</sub>O) were determined with a pH meter extracted in a
- 9 solution of 1:2.5 soil and water. Organic carbon content using the Walkley and Black method. The P
- content was available using the Olsen method, while the cation exchange capacity (CEC) was extracted
   with 1N NH<sub>4</sub>OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, while base saturation was
- 12 determined by calculation. All soil data and selected land characteristic data are input in dbf or xls
- 13 format.

# 14 Land Suitability Assesment

15 The deskwork in the suitability assessment is carried out based on the parameters of the selected land

- 16 characteristics which are the same between the limiting factor method and the parametric method.
- 17 Assessment of land suitability classes using the limiting factor method follows the land evaluation
- 18 framework according to FAO (1976) from the order and class categories (suitable, not suitable) to units.
- 19 Furthermore, the data on land characteristics and quality were compared with the selected *Coffea*
- 20 *liberica* HP. land suitability criteria (Table 1) according to the Indonesian Directorate General of
- Plantations (2014), in order to obtain the actual land suitability class along with the limiting factors for
- 22 land use. The limiting factor is then improved, so that the potential land suitability class is obtained.
- 23

# 24 **Table 1**. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements /land		Land suitabi	lity class	
characteristics	S1	S2	S3	N
Elevation-el (m sl)	300 – 500	600 - 800; 0 - 300	800 - 1.000	>1,000
Slopes-sl (%)	0-8	8 – 25	25 – 45	>45
Nutrient retention (nr):				
Soil pH	5.5 – 6.0	6.1 - 7.0	7.1 - 8.0	>8.0
C-organic (%)	2 – 5	1 – 2; 5 – 10	0.5 - 1.0; 10 - 15	<0.5; >15
Cation exchange capacity (cmol)	>15	10 – 15	5 - 10	<5
Base saturation (%)	>35	20-35	<20	
Nutrient availability (na):				
Availability of P (ppm)	>16	10 – 15	<10	

25 Remark: (Indonesian Directorate General of Plantations, 2014), modifed.

26 Meanwhile, in assessing land suitability using the parametric method, it is estimated that the

27 productivity of coffee uses several equations (Simbolon, 2018) based on the parameters of the 28 selected soil and land properties, namely:

29	Y = -2.672+0.026X (elevation)	(1)
30	Y = 17,190-0.090X (slope)	(2)
31	Y = 3.055+0.005X (soil pH)	(3)
32	Y = 4.050-0.019X (C-organic)	(4)

1Y = -28.796+0.621X (P availability)(5)2Y = 32.450-0.109X (CEC)(6)3Y = 0.457-0.002X (base saturation)(7)4In this case, Y = estimated production (t ha<sup>-1</sup>), X = soil and land properties parameters, and CEC = cation5exchange capacity. The assumption of optimal productivity of liberica coffee used is 0.75 t ha<sup>-1</sup>6(Martono, 2018). In order to assess the accuracy of the estimated productivity of the liberica coffee, it7was analyzed using the Root Mean Square Error (RMSE) with the following equation:

8

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

where: RMSE = root mean square error, At = actual productivity (t ha<sup>-1</sup>), Ft = estimated productivity (t ha<sup>-1</sup>), and n = number of data. The smaller or closer to 0 the value of the RMSE, the more accurate the
 prediction results will be. Furthermore, land suitability assessment for liberica coffee uses a land index
 of root mean square (Khiddir, 1986), namely:

14

15  $LI = LC_{min} \sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}}$  ....(9)

where: LI = land index;  $LC_{min}$  = minimum LC rating; A, B, C, ..., N = other LC in beside the minimum LC. Determination of land suitability classification based on LI is calculated from all LC which is influenced by the productivity of liberica coffee and has a certain land suitability class. LI score criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very 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 class N (not suitable) with value 0 – 25. All data and information obtained are described and presented in tabular form, while their spacial distribution is presented in map form.

23

#### 24 **RESULTS**

#### 25 Land Suitability Based on Limiting Factor Method

26 The result of matching the land suitability criteria with the land characteristics resulted in the actual 27 land suitability class for liberica coffee in Pinogu Plateau was shown to Table 2 and Figure 2. It seems 28 that the actual land suitability class was moderately suitable (S2) which was more dominant in an area 29 of 2,149.64 ha or 76.66% compared to the marginally suitable class (S3) which was only 654.64 ha or 30 only 23.34%. Meanwhile the very suitable class (S1) and not suitable (N) has not found in the results 31 of this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use 32 in the Pinogu Plateau were nutrient retention (C-organic, base saturation and soil pH) and nutrients 33 availability (P availability). In addition, there was an elevation limiting factor at LMU 1 and LMU 7.

34

#### 35 Table 2. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

	Eleva	tion	Slo	ре	р	Н	C-Or	ganic	CE	0	B	s	Ava	I-P		Area	a
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual 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
							ŀ	Area (ha)								2,804.28	100

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS =
 base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

3 After making efforts to improve the actual land suitability class against the limiting factor, all LMUs can

4 be upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be repaired

5 because of the elevation limiting factor (Table 3, Figure 2). The limiting factors for nutrient retention,

6 both pH, C-organic, and low base saturation were improved with the addition of organic matter, while

7 the limiting factor for available nutrients of low P availability was improved with the addition of P

8 fertilizer. As a result, the most dominant potential land suitability class was S1 covering an area of

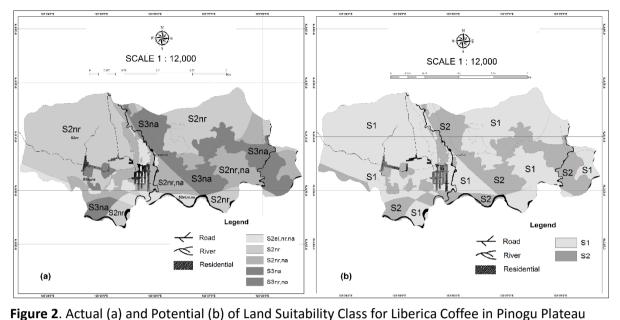
- 9 1,980.30 ha or 70.62% and the rest including S2 class covering an area of 823.98 ha or 29.38% only.
- 10

#### 11 Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual	Limiting Factors	Efforts	Potential	Area	a
LIVIO	LSC	Entitling Factors	Elloits	LSC	ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C- organic, base saturation), nutrient availability (available of P)	Can not 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)	<ul> <li>Addition of organic</li> <li>material</li> <li>Addition of P fertilizer</li> </ul>	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	- Addition of organic material	S2	36,34	1.30
		nutrient availability (available of P)	- Addition of P fertilizer			
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic material	S1	1.386,94	30.28
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.14
		Luas (Ha)			2.804,28	100

12 Remark: LMU = land mapping unit, LSC = land suitability class.

13



# 1 2 3 4

Figure 2. Actual (a) and Potential (b) of Land Suitability Class for Liberica Conee in Pinogi

# 4 Land Suitability Based on Parametric Method

5 The results of the productivity analysis (productivity) of liberica coffee based on each land characteristic showed that the highest productivity was obtained on the slope characteristics which 6 7 averaged 1.69 t ha<sup>-1</sup>, while the lowest productivity was obtained on the available P characteristics 8 which only ranged from 0.16 - 0.24 t ha<sup>-1</sup> with an average of 0.20 t ha<sup>-1</sup> (Table 4). The remaining land 9 characteristics has an average productivity 0.30. The results of the RMSE analysis on the alleged 10 productivity of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13 are smaller (0.51) 11 compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE value of 0.52 (Table 4). The productivity of liberica coffee will affect the land characteristic index which will ultimately 12 13 determine the land index and land suitability class for liberica coffee. 14 It seems that the relative land characteristic index values follow the pattern of productivity for liberica 15 coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the optimal value was the slope characteristic which averaged a value of 100 (Table 5), while the lowest land 16

characteristic index value was obtained for the available P which an average of P availability index of
26.39 only. The remaining land characteristics are relatively diverse but the average value of the land
characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index
value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index,

- respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value which was 50 only. The
- remaining LMUs get land index values ranged from 50 71.
- 23

24 Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

Characteristic	LMU												
/Productivity	1	2	3	4	5	6	7	8	9	10	11	12	13
Elev. (m sl)	293	307	313	302	311	305	290	288	338	300	334	306	310
Y (t ha-1)	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
Slo. (%)	3	3	3	3	3	3	3	3	3	8	3	8	3
Y (t ha-1)	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
рН	5.82	5.88	6.22	5.64	5.78	6.12	6.28	5.89	6.25	5.92	5.96	5.95	6.00

Characteristic							LMU						
/Productivity	1	2	3	4	5	6	7	8	9	10	11	12	13
Y (t ha⁻¹)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
C-Org (%)	1.59	1.30	0.78	1.21	1.46	1.02	1.43	1.92	1.79	1.38	1.15	1.07	1.35
Y (t ha⁻¹)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
CEC (cmol)	19.24	23.77	27.60	22.77	26.39	29.68	27.92	23.22	27.10	23.67	27.69	25.03	32.67
Y (t ha⁻¹)	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
BS (%)	32.75	33.75	28.00	24.67	29.25	29.68	39.75	36.67	37.00	42.33	33.00	39.50	23.67
Y (t ha⁻¹)	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
Av-P (ppm)	13.87	15.85	9.77	12.22	17.04	18.52	14.53	20.35	14.98	9.98	17.12	16.41	7.78
Y (t ha⁻¹)	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
Ϋ́ (t ha⁻¹)	0.60	0.60	0.61	0.60	0.60	0.60	0.60	0.59	0.61	0.60	0.61	0.59	0.61
Stdev	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.49	0.48	0.49
RMSE	0.52	0.52	0.51	0.52	0.52	0.52	0.52	0.53	0.52	0.51	0.52	0.51	0.51

1 Remark: LMU = land mapping unit, Elev. = elevation, Slo. = slopes, C-Org = C-organic, Exc. = exchangeable, CEC = cation

axchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million, Stdev = standard
 deviation, RMSE = root mean square error.

4 Based on the land index values, the land suitability class for liberica coffee was more dominant S2 with

5 covering an area of 88.77% (Table 5). Meanwhile, the S1 class was 7.21% and the S3 class was 4.02%

6 only without not suitable class (N).

7

8 Table 5. Value of Land Characteristics Index, Land Index and Land Suitability Class for Liberica Coffee

Productivity							LMU						
/LC Value	1	2	3	4	5	6	7	8	9	10	11	12	13
Y-El. (t ha⁻¹)	0.49	0.53	0.55	0.52	0.54	0.53	0.49	0.48	0.61	0.51	0.60	0.53	0.54
LC-EI.	65.95	70.80	72.88	69.07	72.19	70.11	64.91	64.21	81.55	68.37	80.16	70.45	71.84
Y-SI. (t ha⁻¹)	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.65	1.69	1.65	1.69
LC-Slo.	100	100	100	100	100	100	100	100	100	100	100	100	100
Y-pH (t ha⁻¹)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
LC-pH	41.12	41.13	41.15	41.11	41.12	41.14	41.15	41.13	41.15	41.13	41.13	41.13	41.13
Y-Corg. (t ha⁻¹)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
LC-Corg.	53.60	53.67	53.80	53.69	53.63	53.74	53.64	53.51	53.55	53.65	53.71	53.73	53.66
Y-CEC (t ha⁻ ¹)	0.30	0.30	0.29	0.30	0.30	0.29	0.29	0.30	0.29	0.30	0.29	0.30	0.29
LC-CEC	40.47	39.81	39.26	39.96	39.43	38.95	39.21	39.89	39.33	39.83	39.24	39.63	38.52
Y-BS (t ha⁻¹)	0.39	0.39	0.40	0.41	0.40	0.40	0.38	0.38	0.38	0.37	0.39	0.38	0.41
LC-BS	52.20	51.93	53.47	54.36	53.13	53.02	50.33	51.16	51.07	49.64	52.13	50.40	54.62
Y-Ava.P (t ha⁻¹)	0.20	0.19	0.23	0.21	0.18	0.17	0.20	0.16	0.19	0.23	0.18	0.19	0.24
LC-Ava.P	26.91	25.27	30.31	28.28	24.29	23.06	26.37	21.54	25.99	30.13	24.22	24.81	31.95
LI	64	62	76	70	61	56	61	50	67	71	63	60	80
LSC	S2	S2	S1	S2	S2	S2	S2	S3	S2	S2	S2	S2	S1
Area (ha)	70.81	250.95	36.34	36.97	849.26	3.74	98.53	112.84	305.44	452.57	369.42	51.68	165.73
Area (%)	2.53	8.95	1.30	1.32	30.28	0.13	3.51	4.02	10.89	16.14	13.17	1.84	5.91

9 Remark: LMU = land mapping unit, Y = productivity, LC = land characteristic rating, Exc. = exchangeable, Ava. = availability, El.

= elevation, SI. = slope, Corg. = C-organic, K = potassium, Ca = calcium, Mg = magnesium, Na = natrium, P = phosfor, CEC =
 cation exchange capacity, BS = base saturatio, LI = land index, LSC = land suitability classes.

12

#### 13 Comparison of Land Suitability Classes and their Recommendations on Land Management

14 Based on the results of the land suitability assessment between the limiting factor and the parametric

15 method were shown in Table 6 and Figure 3. The comparison between the two methods shows the

similarity of the land suitability class with the class pattern: S2 = S2 of 22.18% (LMU 1, 7 and LMU 10).

17 But the most dominant class differences follow the pattern: S1  $\neq$  S2 of 66.59% (LMU 2, 4, 5, 6, 9, 11,

and LMU 12), followed by class pattern: S2  $\neq$  S1 of 7.21% (LMU 3, and LMU 13), while the lowest was

the class pattern: S1 ≠ S3 of 4.02% only (LMU 8). Thus, based on land suitability class using the limiting factor method, the recommended land with priority I or equivalent to S1 was 70.62%, while land with priority II or equivalent to S2 was 29.38% without land priority III or equivalent to S3 (0%). This was different from the land suitability class using the parametric method, where the recommended land with priority I or equivalent to S1 was 7.21% only, while land with priority II or equivalent to S2 was

6 88.77%, and land with priority III or equivalent to S3 was 4 ,20% only.

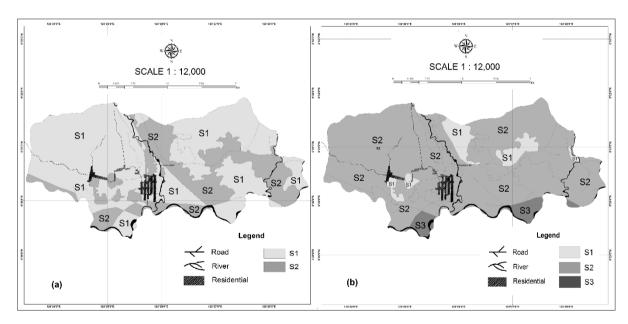
7

8	Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for
9	Liberica Coffee in Pinogu Plateau

	Land Suitabi	ility Class		Area			
LMU	Limiting Factor Method	Parametric Method	Recomendation	ha	%		
1, 7, 10	S2	S2	Priority I	621.91	22.18		
2, 4, 5, 6, 9, 11, 12	S1	S2	Priority II	1,867.46	66.59		
3, 13	S2	S1	Priority I	202.07	7.21		
8	S1	S3	Priority III	112.84	4.02		
Area (ha) 2,804.2							

10 Remark: LMU = land mapping unit.

11



12

Figure 3. Comparison of Land Suitability Classes with Limiting Factors (a) and Parametric Methods (b)
 for Liberica Coffee in Pinogu Plateau

15

# 16 DISCUSSION

17 The suitability of land for liberica coffee with the limiting factor method and the parametric method 18 turned out to be different, both in terms of class and area. This study shown that the land suitability

10 class using the limiting factor method in Plate Dinegu was more dominant of yory suitable, while the

- 19 class using the limiting factor method in Plato Pinogu was more dominant of very suitable, while the
- 20 land suitability class using the parametric method was more dominant of moderately suitable.
- Although the land suitability class using this limiting factor method appears to be of a higher class and wider distribution, it was only based on the characteristics of the land and has not been linked at all

1 with the productivity of liberica coffee. The limiting factor method has weaknesses, including

- 2 interactions between land characteristics that are difficult to explain (Elsheikh et al., 2013; Hartati, et
- al., 2018). In contrast to the land suitability class with the parametric method, besides being based on
- 4 the performance of land characteristics, it has also been directly related to the productivity of liberica
- 5 coffee in the research area, so that the interactions in it are easy to explain. According to Sitorus (2018),
- the precision and reliability of parametric methods more greater than other land evaluation methods.
  The advantage of the parametric method is that land evaluation is easy to carry out and only consists
- The advantage of the parametric method is that land evaluation is easy to carry out and only consists
  of a few categories (Rodcha et al., 2019). Furthermore, Marbun et al. (2019) stated that the superiority
- 9 of this parametric method is not only calculating land suitability classes based on soil properties but
- also taking into account all factors and mapping them in one land suitability map. This parametric
- 11 method with the square root of the land index uses a minimum rating to assess land suitability classes
- 12 (Juita et al., 2020). In fact, Mathewos et al. (2018) stated that the square root land index value was
- 13 higher than the Storie index. To improve the land evaluation approach, qualitative and quantitative
- 14 approaches must be integrated (Mugiyo et al., 2021).

15 In the land suitability assessment for liberica coffee using the limiting factor method, it turns out that 16 there were more limiting factors, while the parametric method most less. The minimum rating value 17 in the parametric method was only the low availability of P nutrients. A low land suitability index 18 should be improved so that the plant grows optimally (Isramiranti et al., 2020). Land that has an S3 19 suitability class has the opportunity to be improved through various land improvement efforts, so that 20 it becomes a class S2 to class S1 (Refitri et al., 2016). Low nutrient availability was improved through

- 21 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),
- 23 land management can be done by adding organic matter and fertilizing according to the recommended
- 24 dose of fertilizer. The addition of organic matter can increase soil pH and organic C (Afandi et al., 2015;
- 25 Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

26 Land suitability class assessment using the limiting factor method often contrasts between land 27 suitability classes and their real productivity. In fact, at LMU 4 and LMU 6, the existing land use 28 conditions are irrigated rice fields, rainfed rice fields and swamps that are often flooded, so the actual 29 land suitability class S2 and potential land suitability class S1 for liberica coffee still need to be checked 30 again in the field. While the parameteric method in principle gives values at different limiting levels to 31 land properties on a normal scale with a maximum value of 100 to a minimum value of 0 (Juita et al., 32 2020). The results of the land suitability assessment for liberica coffee in Plato Pinogu with the 33 parametric method following the class pattern S2 > S1 > S3. The advantage of this parametric method 34 is not only calculating land suitability classes based on soil properties but also taking into account all 35 factors and mapping them in one land suitability map (Marbun et al., 2019). It seems that the land 36 index obtained by the parametric method is closer to the real conditions in the field, where the average 37 liberica coffee production in the Pinogu Plateau ranges from 0.51 to 0.61 t ha-1, while the productivity 38 of Pinogu coffee currently reaches 0.75. t ha-1 (Martono, 2018). Ghazanchaii & Fariabi (2014) state 39 that there is a significant relationship between land index and production, where as the land index 40 increases, the yield based on the range of land suitability classes also increases quantitatively.

- This research uses both land suitability assessment methods to be the same and consistent in terms of the type and number of land characteristics used, so that the difference in the results of the land
- 43 suitability assessment is not caused by differences in the characteristics of the land but because of the

1 final value produced by the two methods. In the limiting factor method, the most limiting factor has a 2 dominant role, so that other factors can be ignored (Nugroho & Istianto, 2013). The limiting factor 3 method makes it possible to determine the suitability class but without further specification (Abbasi 4 et al., 2019). While in the parametric method, the use of land characteristics is based on the availability 5 of mathematical equations to estimate the productivity of liberica coffee because only LMU 3, 9, 10 6 and LMU 13 has liberica coffee plants and has been producing. Other LMUs do not have liberica coffee 7 plants, so their productivity must be estimated. In determining land suitability using the parametric 8 method, the most limiting factor will have less effect because it is covered by the cumulative value of 9 all factors (Nugroho & Istianto, 2013). Diagnostic criteria in the parametric method are assessed 10 numerically and mathematically to obtain land suitability classes (Marbun et al., 2019). The parametric method is able to describe the degree of land suitability that does not depend on class boundaries 11 12 (Abbasi et al., 2019). Limitations in the type and number of land characteristics used in this study are 13 a challenge for future research to be added or expanded to other land characteristics. In fact, it can 14 include environmental and socioeconomic variables (Mathewos et al., 2018). However, the use of the 15 parametric method is more significant for the increase or decrease in productivity (Ghazanchaii & 16 Fariabi, 2014) and is more realistic (Mathewos et al., 2018). Meanwhile, the use of the limiting factor 17 method, although the land suitability class for liberica coffee is higher, often contrasts with the facts 18 on the ground, so it must be re-checked. Research on land suitability for liberica coffee in Plato Pinogu is the first research conducted in this

Research on land suitability for liberica coffee in Plato Pinogu is the first research conducted in this area and in the province of Gorontalo. Therefore, Liberika coffee, which is endemic to the Pinogu Plateau, Bone Bolango Regency, Gorontalo Province, needs to be maintained in the future. In addition to the Pinogu area, Liberica coffee is also found in the East Bolaang Mongondow Regency, North Sulawesi Province (Lasabuda et al., 2015) and South Sulawesi (Kahpi, 2017) which are still on the island of Sulawesi and are endemic in the province. Thus, future research can focus on the comparison of land suitability classes for liberica coffee in each of these areas along with their agronomic performance and productivity.

27

#### 28 CONCLUSION

The actual land suitability class for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, it has the potential became very suitable class (S1) and S2 class. The parametric method consists of S1, S2 and S3 classes because of low phosphorus nutrients. Land management recommendations for liberica coffee were priority I and II.

35 36

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# PLEASE REVISE IN THIS FILE!

# Response to the Reviewer's comments

# REVIEWER B

Page number	Line number	Reviewer's Comment	Author's Revision
1	9, 10, 11	Tidak sesuai antara tujuan di abstrak dan di naskah/pendahuluan. Mana yang benar?	Study aimed to determine the land suitability value of endemic liberica coffee with two different methods and to formulate recommendations for land management in Pinogu Plateau.
1	11	lya kah? Tidak ada survey dijelaskan di metode	already explained in the method
1	12	? dudung	Comparison of different land suitability classes (LSC) was implemented using the limiting factor and the parametric methods. Meanwhile, the land management were referred to recommendation I or equal to very suitable (S1), II or equal to moderately suitable (S2), III or equal to marginaly suitable (S3) and recommendation IV or equal to not suitable (N).
1	13-19	Abtstrak tidak mengulang kesimpulan	The results showed that the actual LSC for liberica coffee using the limiting factor method were consisted of S2 and S3 classes. After improvement of LSC, the potentialof LSC to became of S1 and S2 classes. Coversely the LSC using the parametric method consisted of S1, S2 and S3 classes. The land for liberica coffee with the limiting factor method consist of recommendation I and II, while the parametric method consist of recommendation I, II and III. The results revealed that the parametric method was more realistic on land characteristics in relation to liberica coffee productivity than the limiting factor method.
1	21	Ikuti standard untuk keywords Land suitability evaluation, liberica coffea, Pinogu Plateu, Sulawesi Keyword adalah kata untuk pencarian di perpustakaan atau web yang mencerminkan isi tulisan	Land suitability evaluation, liberica coffea, Pinogu Plateau, Sulawesi
1	40	Kecamatan=district	District
1	41	km2)	km <sup>2</sup>
2	9	Juga dijumpai di Jambi, Riau, Bengkulu. Cek lagi	become an endemic plant because this species only exists and grows in Pinogu District for the northern part of Sulawesi.
2	21, 22	Cek penulisan. Liberika vs Liberica. Lihat baris 8.	Liberica coffee

			Madavataly avitable
2	25	? jangan dikode, tp deskripsi; agak sesuai	Moderately suitable
3	4	Rekomendasai belum banyak dibahas di naskah hanya prioritas saja. Apa maksud rekomendasai di sini?	already repaired
3	9	North	North
3	36	<mark>?</mark>	Soil belt
3	36	<mark>?</mark>	Was removed
3	37	<mark>?</mark>	permanent spidol
3	38	maps 1 : 12,000 scale land unit	already repaired
3	38	rubber band	fastening rubber
4	10	using	were determined
4	16	Agar kalimat diperbaiki, maknanya tidak jelas	The land suitability assessment was carried out based on the parameters of selected land characteristics which were the same between the limiting factor method and the parametric method
4	23, 24	Ini diperbaiki kalimatnya	Furthermore, the limiting factor of the actual land suitability class was carried out improvement efforts, in order to obtain a potential land suitability class.
4	26	Ini dijelaskan di catatan di bawah tabel. Artinya apa?	already repaired
4	28, 29, 30	Diperbaiki kailimatnya. Buat kalimat sederhana saja	already repaired
5	20-25	Diperbaiki kalimatnya, tidak begitu mudah difahami	The determination of land suitability class based on land index (LI) was calculated from all LC values that affect of the liberica coffee productivity. The LI score criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very 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 value 0 – 25. The formulation recommendations of land management for liberica coffee was determined based on the final suitability class. Recommendation I was the land with land suitability of S1 class, II was the land with land suitability of S2 class and recommendation III was the land with land suitability of S3 class. Meanwhile, not recommended was the land with land suitability of N class. All data and information obtained were described and presented in tabular form, while their spatial distribution was presented in map form.
6	3	Ini harus dibahas di metode. Buat sub bab LMU	LMU sub-chapter has been made

<b></b>	1		already discussed in the method
6	12	Ini diuraikan di metode sebagai data input. Jelaskan juka data karakteristik lahan di metode	already discussed in the method
7	2	Dicek lagi petanya, kecil peluang batas peta berupa garis lurus seperti yang bagian tengah	The change in the shape of the map is thought to be due to a different Microsoft Office application, so it changes
7	5 – 8	Kalimat ini kepanjangan dsn sulit difahami. Buat yang kalimat sederehana dan efisien. Table 4 show that	Table 4 show that the highest productivity of liberica coffee was obtained on the slope characteristics with an average of 1.69 ton ha <sup>-1</sup> , while the lowest was on the P availability with an average of 0.20 ton ha <sup>-1</sup> .
7	24	Dibuat kagi format tabel yang mudah difahami oleh pembaca	the table has been rearranged
8	4-5	Persentase dari mana? 4.02% of total area?	Based on the land index values, the land suitability class for liberica coffee was more dominant S2 with covering an area of 88.77% of total area (Table 5). Meanwhile, the S1 class was 7.21% of total area and the S3 class was 4.02% of total area without not suitable class (N).
8	8	Susun tabel ini lebih sederhana, boleh juga dibuat beberapa tabel. Membingungkan bagi pembaca.	the table has been rearranged
8	14-15	Hindari pengulangan, ini sudah di metode. Dalam bahasa inggris, buat kalimat sederhana, singkat, langsung ke point, selalu hemat kata (jangan wordy) Table 6 show	Table 6 show that the comparison between the two methods shows the similarity of the land suitability class (S2 : S2) of 22.18% of total area (LMU 1, 7 and LMU 10). But the most dominant class differences (S1 : S2) of 66.59% of total area (LMU 2, 4, 5, 6, 9, 11, and LMU 12), class S2 : S1 of 7.21% of total area (LMU 3, and LMU 13), while the lowest was the class (S1 : S3) of 4.02% of total area (LMU 8).
9	1-6	Kalimat ini sulit difahami oleh pembaca. Kata only dalam bahasa inggris hanya untuk mata uang	Based on land suitability class of the limiting factor method, the land that was included in recommendation I (S1) was 70.62% of the total area, while recommendation II (S2) was 29.38% of the total area, without land recommendation III (S3) and recommendation IV (N). In contrast to the parametric method, where land that was included in recommendation I (S1) was 7.21% of the total area, recommendation II (S2) was 88.77% of the total area, while land with recomendation III (S3) was 4.20% of the total area without land recommendation IV (N).

9	18-19	This study shown that, by limiting factor method, the dominant suitability class is very suitable (S1). Yet, by paramettric method, the dominat suitability class is moderately suitable (S2).	This study shown that, by limiting factor method, the dominant suitability class is very suitable (S1). Yet, by paramettric method, the dominat suitability class is moderately suitable (S2).
10	15	Cari yg satu kata	Evidently
10	26	Paragraph terlalu panjang. Bisa dibagi 2. Semakin panjang paragraf semakin sulit dimengerti Semakin panjang kalimat semakin sulit difahami	Land suitability class assessment using the limiting factor method often contrasts between land suitability classes and their real productivity. In fact, at LMU 4 and LMU 6, the existing land use were irrigated rice fields and swamps that often inundated was classified as very suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role, so that other factors can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment were without further specifications (Abbasi et al., 2019). Meanwhile, with the parametric method, LMU 4 and LMU 6 are included in the quite appropriate class (S2) which is more realistic with the conditions of land use. The parameteric method in principle assigns values at different limiting levels to land properties on a normal scale with a maximum value of 100 to a minimum value of 0 (Juita et al., 2020). On the parametric method, the most limiting factor will reduce its effect because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013).
11	41-43	Ini mau menulis apa? Apa yang ingin disampaikan.	already repaired
		Sebelum menulis, selalu tulis pikiran utamanya	

Remarks: in the revised copy, it must include highlighted changes and modifications recommended

in the revision to ensure that all editor/reviewer(s)' comments were considered.

# **REVIEWER D**

Page number	Line number	Reviewer's Comment	Author's Revision
1	12-13	A complete sentence with the practical meaning but missing the linguistic meaning	Comparison of different land suitability classes (LSC) was implemented using the limiting factor and the parametric methods.
1	16-17	A complete sentence with the practical meaning but missing the linguistic meaning	After improvement of LSC, the potential LSC to became of S1 and S2 classes. Coversely the LSC using the parametric method consisted of S1, S2 and S3 classes.
3	33-42	I recommend to read the following article to be added in this portion:	already cited in the manuscript
5	25	I think a small comparison between using the limiting factor method and the parametric method is needed here at the end of the methodology.	already repaired
11	31-36	Not enough, more detailed could be added.	The actual land suitability class for liberica coffee using the limiting factor method consists of moderately suitable (S2) and marginally suitable class (S3) with elevation, nutrient retention and available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, it has the potential became very suitable class (S1) and S2 class. The parametric method consists of S1, S2 and S3 classes because of low P nutrients. The land for liberica coffee with the limiting factor method consist of recommendation I and II. Meanwhile, the parametric method consist of recommendation I, II and III for liberica coffee. Land suitability assessment using the parametric method was more realistic on land characteristics in relation to liberica coffee productivity than the limiting factor method.

Remarks: in the revised copy, it must include highlighted changes and modifications recommended

in the revision to ensure that all editor/reviewer(s)' comments were considered.

# THE COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC COFFEA LIBERICA PINOGU HP. WITH DIFFERENT METHODS, AND THEIR RECOMMENDATIONS OF LAND MANAGEMENT IN PINOGU PLATEAU, BONE BOLANGO REGENCY

#### ABSTRACT

8 Coffee is a national strategic commodity that contributes to the country's foreign exchange but these 9 productivity is still low due to cultivation on low potential land. Study aimed to determine the land 10 suitability value of endemic liberica coffee with two different methods and to formulate 11 recommendations for land management in Pinogu Plateau. The 13 land units were surveyed and 12 analyzed the soil samples in the laboratory to obtain data of the land characteristic selected. 13 Comparison of different land suitability classes (LSC) was implemented using the limiting factor and 14 the parametric methods. Meanwhile, the land management were referred to recommendation I or 15 equal to very suitable (S1), II or equal to moderately suitable (S2), III or equal to marginaly suitable (S3) 16 and recommendation IV or equal to not suitable (N). The results showed that the actual LSC for liberica 17 coffee using the limiting factor method were consisted of S2 and S3 classes. After improvement of LSC, 18 the potential of LSC to became of S1 and S2 classes. Coversely the LSC using the parametric method 19 consisted of S1, S2 and S3 classes. The land for liberica coffee with the limiting factor method consist 20 of recommendation I and II, while the parametric method consist of recommendation I, II and III. The 21 results revealed that the parametric method was more realistic on land characteristics in relation to 22 liberica coffee productivity than the limiting factor method.

23

5 6

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24 Keywords: Land, suitability, coffee, liberica, endemic, Pinogu.

# 25

26 INTRODUCTION

27 Coffee has long been a refreshing drink in the world. The distribution of world coffee includes Arabica 28 coffee with a distribution area of 80%, Robusta coffee by 20% and Liberica coffee with a distribution 29 area of only <1% (Nillian et al., 2020). It is relatively difficult to get research references on liberica 30 coffee in the world because of its limited area, so that publications are also relatively limited. It is 31 predicted that by 2050, the land suitable for robusta coffee cultivation is 83%, while arabica coffee is 32 only 17% in the world (Magrach & Ghazoul, 2015). However, according to Claude et al (2019), liberica coffee based on pedoclimatic zoning is more potential to be cultivated than robusta and arabica coffee 33 34 because agro-climatic zoning shows an increase in the potential for this coffee production in the 35 coming years.

Coffee in Indonesia is still a strategic commodity because it is able to contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 tons, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 tons or an increase of 2.62% from the previous year with a value of 809,158,900 US\$ (Indonesian Central Bureau of Statistics, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 tons or 0.02% of the total national coffee production (Indonesian Directorate General of Plantations, 2021).

1 Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively 2 flat and wide (496 km<sup>2</sup>) at an altitude of > 300 m above sea level, and is surrounded by hills and 3 mountains so that it can be called the Pinogu Plateau. This district has long been known as a coffee 4 producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021). 5 According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee 6 plantation and makes it their main commodity because the productivity level of this coffee is the 7 highest compared to other commodities. The advantages of pinogu coffee include the fact that local 8 farmers do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin, 9 2020), so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes 10 from robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021).

11 Liberica coffee (Coffea liberica) has been planted since 1875 (Sancayaningsih et al., 2016) and become 12 an endemic plant because this species only exists and grows in Pinogu District for the northern part of 13 Celebes. Liberica coffee has the advantage of good taste (Gusfarina, 2014), and a distinctive taste of 14 jackfruit (Saidi & Suryani, 2021). This condition makes pinogu coffee an icon of the superior commodity 15 of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee 16 products have so far encountered several obstacles, one of which is the low productivity of the coffee. 17 Martono (2018) reports that although Pinogu Coffee has become global, its productivity is still low at only 0.75 ton ha<sup>-1</sup> year<sup>-1</sup>. In fact, the productivity of liberica coffee can reach 1.69 - 1.98 ton ha<sup>-1</sup> 18 19 (Indonesian Industrial and Beverage Crops Research Institute, 2015). Pinogu sub-district has a coffee 20 plantation area of 282.63 ha or the largest in this district (66.21%) with new production of 36.34 ton 21 (Humola et al., 2021). Such conditions will affect the availability of coffee raw materials to meet market 22 demand later. The low productivity of coffee is thought to be because coffee cultivation is carried out 23 on land that is not in accordance with the potential of the land.

24 Until now there is no available information about the potential of land for the development of Liberica 25 Coffee in the Pinogu Plateau area, except for the potential of land for robusta coffee because it is more 26 developed. Land suitability for robusta coffee in Bone Bolango Regency is marginally suitable (S3) class 27 (Taslim, 2018; Indrianti, 2020). Meanwhile, other plantation commodities such as coconut, cocoa, 28 cloves, candlenut and vanilla are included in the moderately suitable class in Bone Bolango Regency 29 (Taslim, 2018). Liberica coffee is not only endemic, it is also more resistant to pests and plant diseases 30 (Harni et al., 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests (Gusfarina, 31 2014). Ignorance of coffee planters regarding land potential will greatly affect the productivity of 32 liberica coffee itself, because differences in land potential will be responded by variously by plants 33 according to growing conditions based on land characteristics (Sukarman et al., 2018).

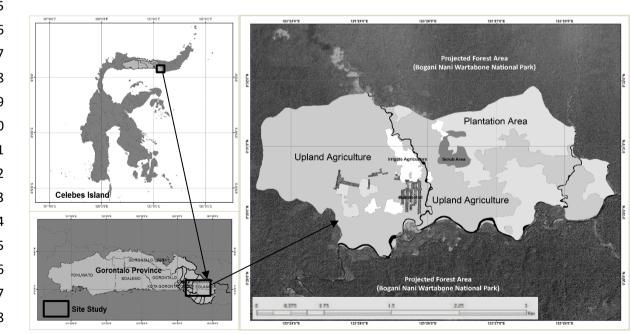
34 Land management requires land suitability assessment so that a land can be used productively and 35 sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is an important 36 contribution in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use 37 (Abdelrahman et al., 2016) and efficient use in agriculture land (Zakarya et al., 2021). Information of 38 the land use potential forms were presented on the output of the land evaluation, including of their 39 consequences, beneficial and adverse of each degree class (Shalaby et al., 2017). Likewise with land 40 use planning for liberica coffee. Different land evaluation methods have different data requirements 41 and varying quality of estimates, but there is no fixed rule that defines when and what method to use 42 when there is a need for more complex analyzes (Mathewos et al., 2018; Mugiyo et al., 2021).

1 Previous research on land suitability assessment for coffee mostly used the limiting factor method. 2 The limiting factor method is used to determine the class based on the lowest constraint, while the 3 parametric method is determined based on the correlation between all variables (Rabia & Terribile, 4 2013). In the parametric method, there is a combination of soil characteristics that affect agricultural 5 production using mathematical equations (Elaalem, 2013) so that the interaction between land 6 characteristics can be minimized. Furthermore, Bagherzadeh & Gholizadeh (2016) stated that in the 7 parametric approach, different land suitability classes are defined as completely separate groups and 8 separated from each other with different and consistent ranges. Differences in land suitability values 9 due to the use of different methods on a land will have an impact on differences in land management. 10 Therefore, the aim of the study was to determine the land suitability value of endemic liberica coffee with two different methods and to formulate recommendations for land management in Pinogu 11 12 Plateau, Bone Bolango Regency.

#### 13 MATERIAL AND METHODS

#### 14 Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. 15 Geographically, the research location is located at 0°24'5.4" – 0°38'29.04" North to 123°18'38.52" – 16 123°33'15.48" East covering an area of 2,804.28 ha with the elevation of 300 – 338 m above sea level 17 18 (Fig. 1). The annual rainfall is 2,541.90 mm and the monthly rainfall ranging from 19.00 mm to 408.18 19 mm, so the study area is included in the agro-climatic zone of C1 because the number of dry month 20 (montly rainfall less than 100 mm) is only 1 month and the number of wet month (monthly rainfall 21 more than 200 mm) is 6 months is wet. The monthly air temperature fluctuates between 24.34°C to 22 25.79°C while the relative humidity is between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52% to 70.50%, while the monthly wind speed is between 2 knots to 2.60 23 24 knots. The study area is the upstream of the Bone watershed which flows to Tomini Bay.



39 **Figure 1**. Research Location Map

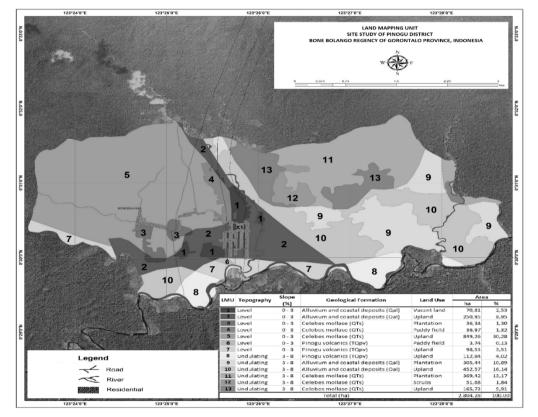
#### 1 Land Mapping Unit

2 Before carrying out soil survey and land observations, it begins with making a map of the land unit at

3 a scale of 1: 12,000 (Fig. 2). This map contains of 13 land units which were the result of basic map

4 overlays that has been adjusted to map scale, included: landform maps, slope maps, geological maps

- 5 and maps of existing land use. Furthermore, this land unit map becames a reference in carrying out of
- 6 soil survey and land observations, especially in determining soil observation points.
- 7



8

# 9 Figure 2. Land Mapping Unit

#### 10 Soil Survey and Land Observation

A set of soil survey tools, included: soil knife, pH meter, soil belt, hoe, spade, clinometer and permanent spidol. Meanwhile, the materials used: 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. This field research used a soil survey method on a scale of 1: 12,000 by observing the soil properties on 13 land units (Fig.2). Furthermore, field observations were carried out to determine the land characteristics such as elevation and slope. After that, 1 kg of soil samples were taken for analysis in the laboratory.

# 18 Soil Laboratory Analysis

- 19 Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil
- 20 properties based on research parameters refers to the soil analysis procedure according to Eviyati &
- 21 Sulaeman (2009). Soil reaction parameters (pH H<sub>2</sub>O) were determined with a pH meter extracted in a

- 1 solution of 1:2.5 soil and water. Organic carbon content were determined with the Walkley and Black
- 2 method. The P content was available using the Olsen method, while the cation exchange capacity (CEC)
- 3 was extracted with 1N NH<sub>4</sub>OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, while base
- 4 saturation was determined by calculation. All soil data and selected land characteristic data are input
- 5 in spreasheet.

#### 6 Land Suitability Assesment

7 The land suitability assessment was carried out based on the parameters of selected land 8 characteristics which were the same between the limiting factor method and the parametric method. 9 The assessment of land suitability classes used the limiting factor method followings the land 10 evaluation framework (FAO, 1976). Land characteristics and quality were compared with the selected 11 land suitability criteria (Table 1) from the Indonesian Directorate General of Plantations (2014), in order 12 to obtain the actual land suitability class along with the limiting factors for land use. Furthermore, the limiting factor of the actual land suitability class was carried out improvement efforts, in order to 13 14 obtain a potential land suitability class.

### 15 **Table 1**. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/	Simbol	Unit		Land suita	ability class		
land characteristics	SIMBOI	Unit	S1	S2	S3	Ν	
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 <sub>2</sub> O 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 (NH4.OAc pH 7 Extraction)	nr	cmol kg <sup>-1</sup>	>15	10 – 15	5 – 10	<5	
Base saturation (NH4.OAc pH 7 Extraction)		%	>35	20-35	<20	-	
Nutrient availability: P-availability ( <i>Olsen</i> )	na	ppm	>16	10 – 15	<10	-	

16 Source: (Indonesian Directorate General of Plantations, 2014), modifed.

Remark: S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable. m asl = mean above sea level,
 ppm = part per million.

19 Meanwhile, in assessing land suitability using the parametric method, it is estimated that the 20 productivity (Y) of coffee uses several equations (Simbolon, 2018) namely:

21	Y = -2.672 + 0.026 Elevation(1)
22	Y = 17,190 - 0.090 Slope
23	Y = 3.055 + 0.005 pH H <sub>2</sub> O
24	Y = 4.050 - 0.019 C organic
25	Y = -28.796 + 0.621 P Olsen
26	Y = 32.450 - 0.109 Cation exchange capacity
27	Y = 0.457 - 0.002 Base saturation(7)
28	In this case, Y = estimated production (ton $ha^{-1}$ ). The assumption of the liberica coffee optimal
29	productivity used of 0.75 ton ha <sup>-1</sup> (Martono, 2018). In order to assess the accuracy of the estimated

- 30 productivity of the liberica coffee, it was analyzed using the Root Mean Square Error (RMSE) with the
- 31 following equation:

8 
$$LI = LC_{min} \sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}}$$
 .....(9)

9 where: LI = land index; LC = land characteristic; LC<sub>min</sub> = minimum LC rating; A, B, C, ..., N = other LC in
10 beside the minimum LC.

The determination of land suitability class based on land index (LI) was calculated from all LC values that affect of the liberica coffee productivity. The LI score criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very 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 value 0 –

15 25.

16 The formulation recommendations of land management for liberica coffee was determined based on 17 the final suitability class. Recommendation I was the land with land suitability of S1 class, II was the 18 land with land suitability of S2 class and recommendation III was the land with land suitability of S3 19 class. Meanwhile, not recommended was the land with land suitability of N class. All data and

information obtained were described and presented in tabular form, while their spatial distributionwas presented in map form.

# 22

#### 23 **RESULTS**

#### 24 Land Suitability Class Based on Limiting Factor Method

25 The result of matching the land suitability criteria with the land characteristics resulted in the actual

26 land suitability class for liberica coffee in Pinogu Plateau was shown to Table 2 and Figure 3. It seems

27 that the actual land suitability class was moderately suitable (S2) which was more dominant in an area

of 2,149.64 ha or 76.66% compared to the marginally suitable class (S3) which was only 654.64 ha or

29 only 23.34%. Meanwhile the very suitable class (S1) and not suitable (N) has not found in the results

30 of this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use

31 in the Pinogu Plateau were nutrient retention (C-organic, base saturation and soil pH) and nutrients

32 availability (P availability). In addition, there was an elevation limiting factor at LMU 1 and LMU 7.

33 **Table 2**. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

	Eleva	tion	Slo	ре	р	н	C-Or	ganic	CE	С	B	5	Ava	i-P		Area	a
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual 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

1

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
							A	Area (ha)								2,804.28	100

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS =
 base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

3 The potential land suitability class was dominatly of S1 that covering an area of 1,980.30 ha or 70.62%

4 of total area and the rest including S2 class covering an area of 823.98 ha or 29.38% of total area. After

5 making efforts to improve the actual land suitability class against the limiting factor, all LMUs can be

- 6 upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be repaired
- 7 because of the elevation limiting factor (Table 3, Figure 3). The limiting factors for nutrient retention,
- 8 both pH, C-organic, and low base saturation were improved with the addition of organic matter, while
- 9 the limiting factor for available nutrients of low P availability was improved with the addition of P
- 10 fertilizer.

11 Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

1.5.41.1	Actual	Lincitia e Feletene	Effe ato	Potential	Area	a
LMU	LSC	Limiting Factors	Efforts	LSC	ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C- organic, base saturation), nutrient availability (available of P)	Can not 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)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	<ul> <li>Addition of organic matter</li> </ul>	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

12 Remark: LMU = land mapping unit, LSC = land suitability class.

13 14  $\circledast$ 15 16 17 18 S2nr S3na **S**1 **S**1 S2nr 19 20 S2nr, S S2nr,na S3na 21 S1 <u>S1</u> **S**2 22 S2nr S1( 23 Lege Lege Road S2el.nr,na 24 Road **S**1 S2nr River  $\leq$  $\leq$ River S2 S2nr,na 25 Residential Residentia S3na (b) (a) S3nr.na 26



28 Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

#### 1 Land Suitability Class Based on Parametric Method

- 2 Table 4 show that the highest productivity of liberica coffee was obtained on the slope characteristics
- 3 with an average of 1.69 ton ha<sup>-1</sup>, while the lowest was on the P availability with an average of 0.20 ton
- 4 ha<sup>-1</sup>. The remaining land characteristics has an average productivity 0.30. The results of the RMSE
- 5 analysis on the alleged productivity of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13
- 6 are smaller (0.51) compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE
- 7 value of 0.52 (Table 4). The productivity of liberica coffee will affect the land characteristic index which
- 8 will ultimately determine the land index and land suitability class for liberica coffee.
- 9 It seems that the relative land characteristic index values follow the pattern of productivity for liberica
- 10 coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the optimal value
- 11 was the slope characteristic which the averaged value of 100 (Table 5), while the lowest land
- 12 characteristic index value was obtained for the available P which an average of P availability index of
- 13 26.39. The remaining land characteristics are relatively diverse but the average value of the land
- 14 characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index
- value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index,
- 16 respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value which was 50. The
- 17 remaining LMUs get land index values ranged from 50 71. The varous of land index values will greatly
- 18 affect the land suitability class for liberica coffee later.

#### 19 **Table 4**. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

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

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

23 Based on the land index values, the land suitability class for liberica coffee was more dominant S2 with

- covering an area of 88.77% of total area (Table 5). Meanwhile, the S1 class was 7.21% of total area and
- 25 the S3 class was 4.02% of total area without not suitable class (N).

26 Table 5. Value of Land Characteristics Rating, Land Index and Land Suitability Class for Liberica Coffee

	Elev	ation	Slop	ре	pН	H2O	C-Or	ganic	C	EC	BS		Ava-P				Area	
LMU	Y		Y		Y		Y		Y		Y		Y			LCS		
LIVIO	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	LI	LCS	ha	%
	ha⁻¹)		ha-1)		ha⁻¹)		ha-1)		ha-1)		ha⁻¹)		ha⁻¹)					
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)									2 004 20	100

Remark: 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.

2 3

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#### 4 Comparison of Land Suitability Classes and their Recommendations on Land Management

5 Table 6 show that the comparison between the two methods shows the similarity of the land suitability

6 class (S2 : S2) of 22.18% of total area (LMU 1, 7 and LMU 10). But the most dominant class differences

7 (S1: S2) of 66.59% of total area (LMU 2, 4, 5, 6, 9, 11, and LMU 12), class S2: S1 of 7.21% of total area

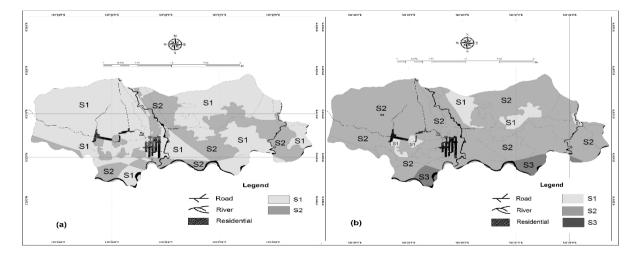
8 (LMU 3, and LMU 13), while the lowest was the class (S1 : S3) of 4.02% of total area (LMU 8).

9 Based on land suitability class of the limiting factor method, the land that was included in 10 recommendation I (S1) was 70.62% of the total area, while recommendation II (S2) was 29.38% of the 11 total area, without land recommendation III (S3) and recommendation IV (N). In contrast to the 12 parametric method, where land that was included in recommendation I (S1) was 7.21% of the total 13 area, recommendation II (S2) was 88.77% of the total area, while land with recomendation III (S3) was 14 4.20% of the total area without land recommendation IV (N).

15	Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for
16	Liberica Coffee in Pinogu Plateau

LMU	Land Suit	ability Class	Land S	uitability 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	7.22	
8	S1	I	S3	III	112.84	4.02	
		Total (ha)			2,804.28	100.0	

17 Remark: LMU = land mapping unit.



18

19 Figure 3. Comparison of Land Suitability Classes with Limiting Factors (a) and Parametric Methods (b)

20 for Liberica Coffee in Pinogu Plateau

#### 1 DISCUSSION

- 2 The land suitability for liberica coffee with the limiting factor method and the parametric method was
- 3 different, both in terms of class and areas. This study shown that, by limiting factor method, the
- dominant suitability class is very suitable (S1). Yet, by paramettric method, the dominat suitability class
- 5 is moderately suitable (S2). Although the land suitability class using this limiting factor method appears
- to be of a higher class and wider distribution, it was only based on the characteristics of the land and
  has not been linked at all with the productivity of liberica coffee. The limiting factor method has
- has not been linked at all with the productivity of liberica coffee. The limiting factor method has
   weaknesses, including interactions between land characteristics that are difficult to explain (Elsheikh)
- 9 et al., 2013; Hartati, et al., 2018).
- 10 In contrast to the land suitability class with the parametric method, besides being based on the 11 performance of land characteristics, it has also been directly related to the productivity of liberica
- 12 coffee in the research area, so that the interactions in it are easy to explain. According to Sitorus (2018),
- 13 the precision and reliability of parametric methods more greater than other land evaluation methods.
- 14 The advantage of the parametric method is that land evaluation is easy to carry out and only consists
- of a few categories (Rodcha et al., 2019). Furthermore, Marbun et al. (2019) stated that the superiority
- 16 of this parametric method is not only calculating land suitability classes based on soil properties but
- also taking into account all factors and mapping them in one land suitability map. This parametric
- method with the square root of the land index uses a minimum rating to assess land suitability classes
  (Juita et al., 2020). In fact, Mathewos et al. (2018) stated that the square root land index value was
- (Juita et al., 2020). In fact, Mathewos et al. (2018) stated that the square root land index value washigher than the Storie index. To improve the land evaluation approach, qualitative and quantitative
- 21 approaches must be integrated (Mugiyo et al., 2021).
- 22 In the land suitability assessment for liberica coffee using the limiting factor method, it evidently that 23 there were more limiting factors, while the parametric method most less. The minimum rating value 24 in the parametric method was only the low availability of P nutrients. A low land suitability index 25 should be improved so that the plant grows optimally (Isramiranti et al., 2020). Land that has an S3 26 suitability class has the opportunity to be improved through various land improvement efforts, so that 27 it becomes a class S2 to class S1 (Refitri et al., 2016). Low nutrient availability was improved through 28 fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing 29 nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), 30 land management can be done by adding organic matter and fertilizing according to the recommended 31 dose of fertilizer. The addition of organic matter can increase soil pH and C organic (Afandi et al., 2015;
- 32 Siregar et al., 2017), and base saturation (Sembiring et al., 2015).
- 33 Land suitability class assessment using the limiting factor method often contrasts between land suitability classes and their real productivity. In fact, at LMU 4 and LMU 6, the existing land use were 34 35 irrigated rice fields and swamps that often inundated was classified as very suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role, so that other factors 36 37 can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment were 38 without further specifications (Abbasi et al., 2019). Meanwhile, with the parametric method, LMU 4 39 and LMU 6 are included in the quite appropriate class (S2) which is more realistic with the conditions 40 of land use. The parameteric method in principle assigns values at different limiting levels to land 41 properties on a normal scale with a maximum value of 100 to a minimum value of 0 (Juita et al., 2020). 42 On the parametric method, the most limiting factor will reduce its effect because it is covered by the
- 43 cumulative value of all factors (Nugroho & Istianto, 2013).

1 The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric

- 2 method following the class pattern S2 > S1 > S3. The advantage of the parametric method in addition
- 3 to calculating land suitability classes based on soil properties is also calculating all factors and mapping
- 4 them in one land suitability map (Marbun et al., 2019). It seems that the land index obtained by the
- 5 parametric method was closer to the real conditions in the field, where the average of liberica coffee
- 6 productivity in the Pinogu Plateau ranges from 0.51 to 0.61 ton ha<sup>-1</sup>, while the productivity of Pinogu
- 7 coffee currently reaches 0.75 ton ha<sup>-1</sup> (Martono, 2018). Ghazanchaii & Fariabi (2014) state that there
- 8 was a significant relationship between land index and production, where as the land index increases,
- 9 the yield based on the range of land suitability classes also increases quantitatively. Diagnostic criteria
- in the parametric method were assessed numerically and mathematically to obtain land suitability
   classes (Marbun et al., 2019), so as to describe the degree of land suitability that does not depend on
- 12 class boundaries (Abbasi et al., 2019).

13 The land for liberica coffee with the limiting factor method was dominated by recommendation I 14 followed by recommendation II because the land with class of S1 was wider than class of S2. 15 Meanwhile, the parametric method was more dominant by recommendation II followed by recommendation I and III because the land with class of S2 was wider than class of S1 and S3. In order 16 17 to optimize land use for liberica coffee, it was necessary to improve the cultivation system including 18 through fertilization (Nugroho, 2015). In addition, the position of liberica coffee plantations in the 19 Bogani-Nani Wartabone National Park and upstream Bone watershed needs to implement 20 conservation agriculture. Coffee-based agroforestry can be applied because it affects growth and 21 production, land and water conservation, and adds nutrients (Supriadi & Pranowo, 2015). The 22 distribution of land suitability classes and land recommendations for liberica coffee in Plato Pinogu 23 were very important for developing this coffee. According to Saidi & Suryani (2021), the existence of 24 land suitability maps was very important to providing information on the suitability of various 25 agricultural commodities, limiting factors, widely and it distribution in an area.

# 27 CONCLUSION

28 The actual land suitability class for liberica coffee using the limiting factor method consists of 29 moderately suitable (S2) and marginally suitable class (S3) with elevation, nutrient retention and 30 available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, it 31 has the potential became very suitable class (S1) and S2 class. The parametric method consists of S1, 32 S2 and S3 classes because of low P nutrients. The land for liberica coffee with the limiting factor 33 method consist of recommendation I and II. Meanwhile, the parametric method consist of 34 recommendation I, II and III for liberica coffee. Land suitability assessment using the parametric 35 method was more realistic on land characteristics in relation to liberica coffee productivity than the 36 limiting factor method.

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26

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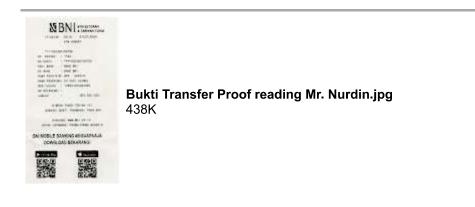
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# THE COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC COFFEA LIBERICA PINOGU HP. WITH DIFFERENT METHODS, AND THEIR RECOMMENDATIONS OF LAND MANAGEMENT IN PINOGU PLATEAU, BONE BOLANGO REGENCY

#### ABSTRACT

8 Coffee is a national strategic commodity that contributes to the country's foreign exchange but these 9 productivity is still low due to cultivation on low potential land. Study aimed to determine the land 10 suitability value of endemic liberica coffee with two different methods and to formulate 11 recommendations for land management in Pinogu Plateau. The 13 land units were surveyed and 12 analyzed the soil samples in the laboratory to obtain data of the land characteristic selected. 13 Comparison of different land suitability classes (LSC) was implemented using the limiting factor and 14 the parametric methods. Meanwhile, the land management were referred to recommendation I or 15 equal to very suitable (S1), II or equal to moderately suitable (S2), III or equal to marginaly suitable (S3) 16 and recommendation IV or equal to not suitable (N). The results showed that the actual LSC for liberica 17 coffee using the limiting factor method were consisted of S2 and S3 classes. After improvement of LSC, 18 the potential of LSC to became of S1 and S2 classes. Coversely the LSC using the parametric method 19 consisted of S1, S2 and S3 classes. The land for liberica coffee with the limiting factor method consist 20 of recommendation I and II, while the parametric method consist of recommendation I, II and III. The 21 results revealed that the parametric method was more realistic on land characteristics in relation to 22 liberica coffee productivity than the limiting factor method.

23

5 6

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24 Keywords: Land, suitability, coffee, liberica, endemic, Pinogu.

#### 25

#### 26 INTRODUCTION

27 Coffee has long been a refreshing drink in the world. The distribution of world coffee includes Arabica 28 coffee with a distribution area of 80%, Robusta coffee by 20% and Liberica coffee with a distribution 29 area of only <1% (Nillian et al., 2020). It is relatively difficult to get research references on liberica 30 coffee in the world because of its limited area, so that publications are also relatively limited. It is 31 predicted that by 2050, the land suitable for robusta coffee cultivation is 83%, while arabica coffee is 32 only 17% in the world (Magrach & Ghazoul, 2015). However, according to Claude et al (2019), liberica coffee based on pedoclimatic zoning is more potential to be cultivated than robusta and arabica coffee 33 34 because agro-climatic zoning shows an increase in the potential for this coffee production in the 35 coming years.

Coffee in Indonesia is still a strategic commodity because it is able to contribute to the country's foreign exchange from the export value of the commodity. Until 2020, national coffee production reached 753,941 tons, an increase of 0.19% from the previous year, while exports of national coffee commodities reached 375,555.9 tons or an increase of 2.62% from the previous year with a value of 809,158,900 US\$ (Indonesian Central Bureau of Statistics, 2020). From this achievement of national coffee production, the contribution of Gorontalo Province is only 139 tons or 0.02% of the total national coffee production (Indonesian Directorate General of Plantations, 2021).

1 Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which is relatively 2 flat and wide (496 km<sup>2</sup>) at an altitude of > 300 m above sea level, and is surrounded by hills and 3 mountains so that it can be called the Pinogu Plateau. This district has long been known as a coffee 4 producer, even since the Dutch colonial era (Sancayaningsih et al., 2016; Humola et al., 2021). 5 According to Ahmad & Paserangi (2018), almost every family in Pinogu Plateau owns a coffee 6 plantation and makes it their main commodity because the productivity level of this coffee is the 7 highest compared to other commodities. The advantages of pinogu coffee include the fact that local 8 farmers do not use pesticides, herbicides or other chemical fertilizers in coffee cultivation (Zainuddin, 9 2020), so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). Pinogu coffee comes 10 from robusta coffee and liberica coffee (Zainuddin, 2020; Susilo et al., 2021).

11 Liberica coffee (Coffea liberica) has been planted since 1875 (Sancayaningsih et al., 2016) and become 12 an endemic plant because this species only exists and grows in Pinogu District for the northern part of 13 Celebes. Liberica coffee has the advantage of good taste (Gusfarina, 2014), and a distinctive taste of 14 jackfruit (Saidi & Suryani, 2021). This condition makes pinogu coffee an icon of the superior commodity 15 of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee 16 products have so far encountered several obstacles, one of which is the low productivity of the coffee. 17 Martono (2018) reports that although Pinogu Coffee has become global, its productivity is still low at only 0.75 ton ha<sup>-1</sup> year<sup>-1</sup>. In fact, the productivity of liberica coffee can reach 1.69 - 1.98 ton ha<sup>-1</sup> 18 19 (Indonesian Industrial and Beverage Crops Research Institute, 2015). Pinogu sub-district has a coffee 20 plantation area of 282.63 ha or the largest in this district (66.21%) with new production of 36.34 ton 21 (Humola et al., 2021). Such conditions will affect the availability of coffee raw materials to meet market 22 demand later. The low productivity of coffee is thought to be because coffee cultivation is carried out 23 on land that is not in accordance with the potential of the land.

24 Until now there is no available information about the potential of land for the development of Liberica 25 Coffee in the Pinogu Plateau area, except for the potential of land for robusta coffee because it is more 26 developed. Land suitability for robusta coffee in Bone Bolango Regency is marginally suitable (S3) class 27 (Taslim, 2018; Indrianti, 2020). Meanwhile, other plantation commodities such as coconut, cocoa, 28 cloves, candlenut and vanilla are included in the moderately suitable class in Bone Bolango Regency 29 (Taslim, 2018). Liberica coffee is not only endemic, it is also more resistant to pests and plant diseases 30 (Harni et al., 2015), resistant to leaf rust and somewhat resistant to coffee berry borer pests (Gusfarina, 31 2014). Ignorance of coffee planters regarding land potential will greatly affect the productivity of 32 liberica coffee itself, because differences in land potential will be responded by variously by plants 33 according to growing conditions based on land characteristics (Sukarman et al., 2018).

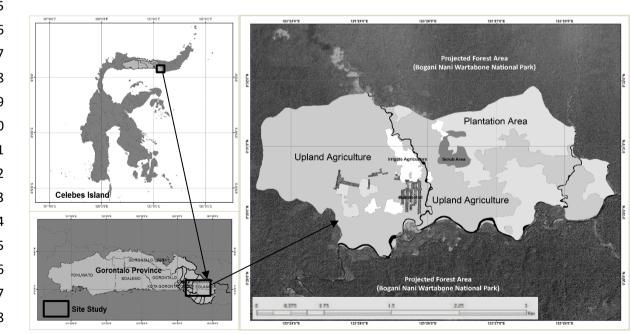
34 Land management requires land suitability assessment so that a land can be used productively and 35 sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is an important 36 contribution in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use 37 (Abdelrahman et al., 2016) and efficient use in agriculture land (Zakarya et al., 2021). Information of 38 the land use potential forms were presented on the output of the land evaluation, including of their 39 consequences, beneficial and adverse of each degree class (Shalaby et al., 2017). Likewise with land 40 use planning for liberica coffee. Different land evaluation methods have different data requirements 41 and varying quality of estimates, but there is no fixed rule that defines when and what method to use 42 when there is a need for more complex analyzes (Mathewos et al., 2018; Mugiyo et al., 2021).

1 Previous research on land suitability assessment for coffee mostly used the limiting factor method. 2 The limiting factor method is used to determine the class based on the lowest constraint, while the 3 parametric method is determined based on the correlation between all variables (Rabia & Terribile, 4 2013). In the parametric method, there is a combination of soil characteristics that affect agricultural 5 production using mathematical equations (Elaalem, 2013) so that the interaction between land 6 characteristics can be minimized. Furthermore, Bagherzadeh & Gholizadeh (2016) stated that in the 7 parametric approach, different land suitability classes are defined as completely separate groups and 8 separated from each other with different and consistent ranges. Differences in land suitability values 9 due to the use of different methods on a land will have an impact on differences in land management. 10 Therefore, the aim of the study was to determine the land suitability value of endemic liberica coffee with two different methods and to formulate recommendations for land management in Pinogu 11 12 Plateau, Bone Bolango Regency.

# 13 MATERIAL AND METHODS

# 14 Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. 15 Geographically, the research location is located at 0°24'5.4" – 0°38'29.04" North to 123°18'38.52" – 16 123°33'15.48" East covering an area of 2,804.28 ha with the elevation of 300 – 338 m above sea level 17 18 (Fig. 1). The annual rainfall is 2,541.90 mm and the monthly rainfall ranging from 19.00 mm to 408.18 19 mm, so the study area is included in the agro-climatic zone of C1 because the number of dry month 20 (montly rainfall less than 100 mm) is only 1 month and the number of wet month (monthly rainfall 21 more than 200 mm) is 6 months is wet. The monthly air temperature fluctuates between 24.34°C to 22 25.79°C while the relative humidity is between 78.60% to 84.40% and the duration of monthly sunshine is between 44.52% to 70.50%, while the monthly wind speed is between 2 knots to 2.60 23 24 knots. The study area is the upstream of the Bone watershed which flows to Tomini Bay.



39 **Figure 1**. Research Location Map

# 1 Land Mapping Unit

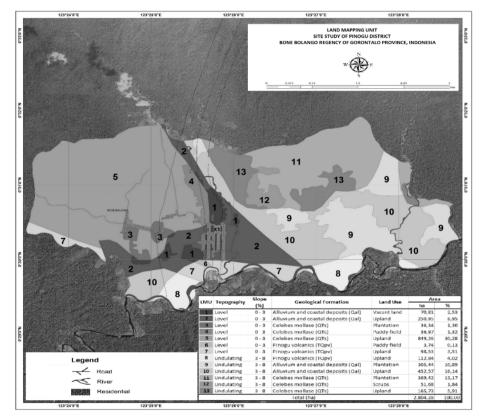
2 Before carrying out soil survey and land observations, it begins with making a map of the land unit at

3 a scale of 1: 12,000 (Fig. 2). This map contains of 13 land units which were the result of basic map

4 overlays that has been adjusted to map scale, included: landform maps, slope maps, geological maps

5 and maps of existing land use. Furthermore, this land unit map becames a reference in carrying out of

- 6 soil survey and land observations, especially in determining soil observation points.
- 7



8

# 9 Figure 2. Land Mapping Unit

# 10 Soil Survey and Land Observation

A set of soil survey tools, included: soil knife, pH meter, soil belt, hoe, spade, clinometer and permanent spidol. Meanwhile, the materials used: 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. This field research used a soil survey method on a scale of 1: 12,000 by observing the soil properties on 13 land units (Fig.2). Furthermore, field observations were carried out to determine the land characteristics such as elevation and slope. After that, 1 kg of soil samples were taken for analysis in the laboratory.

# 18 Soil Laboratory Analysis

19 Soil samples were air-dried for 3 days, then sieved through a 2 mesh sieve. The analysis of selected soil

- 20 properties based on research parameters refers to the soil analysis procedure according to Eviyati &
- 21 Sulaeman (2009). Soil reaction parameters (pH H<sub>2</sub>O) were determined with a pH meter extracted in a

- 1 solution of 1:2.5 soil and water. Organic carbon content were determined with the Walkley and Black
- 2 method. The P content was available using the Olsen method, while the cation exchange capacity (CEC)
- 3 was extracted with 1N NH<sub>4</sub>OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, while base
- 4 saturation was determined by calculation. All soil data and selected land characteristic data are input
- 5 in spreasheet.

# 6 Land Suitability Assesment

7 The land suitability assessment was carried out based on the parameters of selected land 8 characteristics which were the same between the limiting factor method and the parametric method. 9 The assessment of land suitability classes used the limiting factor method followings the land 10 evaluation framework (FAO, 1976). Land characteristics and quality were compared with the selected 11 land suitability criteria (Table 1) from the Indonesian Directorate General of Plantations (2014), in order 12 to obtain the actual land suitability class along with the limiting factors for land use. Furthermore, the limiting factor of the actual land suitability class was carried out improvement efforts, in order to 13 14 obtain a potential land suitability class.

# 15 **Table 1**. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/	Simbol	Unit		Land suita	ability class	
land characteristics	SIMBOI	Unit	S1	S2	S3	Ν
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 <sub>2</sub> O 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 (NH4.OAc pH 7 Extraction)	nr	cmol kg <sup>-1</sup>	>15	10 – 15	5 – 10	<5
Base saturation (NH4.OAc pH 7 Extraction)		%	>35	20-35	<20	-
Nutrient availability: P-availability ( <i>Olsen</i> )	na	ppm	>16	10 – 15	<10	-

16 Source: (Indonesian Directorate General of Plantations, 2014), modifed.

Remark: S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable. m asl = mean above sea level,
 ppm = part per million.

19 Meanwhile, in assessing land suitability using the parametric method, it is estimated that the 20 productivity (Y) of coffee uses several equations (Simbolon, 2018) namely:

21	Y = -2.672 + 0.026 Elevation(1)
22	Y = 17,190 - 0.090 Slope
23	Y = 3.055 + 0.005 pH H <sub>2</sub> O
24	Y = 4.050 - 0.019 C organic
25	Y = -28.796 + 0.621 P Olsen
26	Y = 32.450 - 0.109 Cation exchange capacity
27	Y = 0.457 - 0.002 Base saturation(7)
28	In this case, Y = estimated production (ton $ha^{-1}$ ). The assumption of the liberica coffee optimal
29	productivity used of 0.75 ton ha <sup>-1</sup> (Martono, 2018). In order to assess the accuracy of the estimated

- 30 productivity of the liberica coffee, it was analyzed using the Root Mean Square Error (RMSE) with the
- 31 following equation:

8 
$$LI = LC_{min} \sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}}$$
 .....(9)

9 where: LI = land index; LC = land characteristic; LC<sub>min</sub> = minimum LC rating; A, B, C, ..., N = other LC in
10 beside the minimum LC.

The determination of land suitability class based on land index (LI) was calculated from all LC values that affect of the liberica coffee productivity. The LI score criteria using LI value criteria (Sys et al., 1991), namely: S1 class (very 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 value 0 –

15 25.

16 The formulation recommendations of land management for liberica coffee was determined based on 17 the final suitability class. Recommendation I was the land with land suitability of S1 class, II was the 18 land with land suitability of S2 class and recommendation III was the land with land suitability of S3 19 class. Meanwhile, not recommended was the land with land suitability of N class. All data and

information obtained were described and presented in tabular form, while their spatial distributionwas presented in map form.

# 22

# 23 **RESULTS**

# 24 Land Suitability Class Based on Limiting Factor Method

25 The result of matching the land suitability criteria with the land characteristics resulted in the actual

26 land suitability class for liberica coffee in Pinogu Plateau was shown to Table 2 and Figure 3. It seems

27 that the actual land suitability class was moderately suitable (S2) which was more dominant in an area

of 2,149.64 ha or 76.66% compared to the marginally suitable class (S3) which was only 654.64 ha or

29 only 23.34%. Meanwhile the very suitable class (S1) and not suitable (N) has not found in the results

30 of this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use

31 in the Pinogu Plateau were nutrient retention (C-organic, base saturation and soil pH) and nutrients

32 availability (P availability). In addition, there was an elevation limiting factor at LMU 1 and LMU 7.

33 **Table 2**. The Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

	Eleva	tion	Slo	ре	р	н	C-Or	ganic	CE	С	B	5	Ava	i-P		Area	a
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual 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
							A	Area (ha)								2,804.28	100

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchange capacity, BS =
 base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

3 The potential land suitability class was dominatly of S1 that covering an area of 1,980.30 ha or 70.62%

4 of total area and the rest including S2 class covering an area of 823.98 ha or 29.38% of total area. After

5 making efforts to improve the actual land suitability class against the limiting factor, all LMUs can be

- 6 upgraded to potential land suitability class, except for LMU 1 and LMU 7 which cannot be repaired
- 7 because of the elevation limiting factor (Table 3, Figure 3). The limiting factors for nutrient retention,
- 8 both pH, C-organic, and low base saturation were improved with the addition of organic matter, while
- 9 the limiting factor for available nutrients of low P availability was improved with the addition of P
- 10 fertilizer.

11 Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

1.5.41.1	Actual	Lincitia e Feletene	Effe ato	Potential	Area	a
LMU	LSC	Limiting Factors	Efforts	LSC	ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C- organic, base saturation), nutrient availability (available of P)	Can not 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)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	<ul> <li>Addition of organic matter</li> </ul>	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

12 Remark: LMU = land mapping unit, LSC = land suitability class.

13 14  $\circledast$ 15 16 17 18 S2nr S3na **S**1 **S**1 S2nr 19 20 S2nr, S S2nr,na S3na 21 S1 <u>S1</u> **S**2 22 S2nr S1( 23 Lege Lege Road S2el.nr,na 24 Road **S**1 S2nr River  $\leq$  $\leq$ River S2 S2nr,na 25 Residential Residentia S3na (b) (a) S3nr.na 26



28 Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

# 1 Land Suitability Class Based on Parametric Method

- 2 Table 4 show that the highest productivity of liberica coffee was obtained on the slope characteristics
- 3 with an average of 1.69 ton ha<sup>-1</sup>, while the lowest was on the P availability with an average of 0.20 ton
- 4 ha<sup>-1</sup>. The remaining land characteristics has an average productivity 0.30. The results of the RMSE
- 5 analysis on the alleged productivity of liberica coffee were all close to 0, but LMU 3, 10,12 and LMU 13
- 6 are smaller (0.51) compared to LMU 8 which is the highest (0.53). The remaining LMUs has an RMSE
- 7 value of 0.52 (Table 4). The productivity of liberica coffee will affect the land characteristic index which
- 8 will ultimately determine the land index and land suitability class for liberica coffee.
- 9 It seems that the relative land characteristic index values follow the pattern of productivity for liberica
- 10 coffee in the Pinogu Plateau. The highest land characteristic index value and reaching the optimal value
- 11 was the slope characteristic which the averaged value of 100 (Table 5), while the lowest land
- 12 characteristic index value was obtained for the available P which an average of P availability index of
- 13 26.39. The remaining land characteristics are relatively diverse but the average value of the land
- 14 characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index
- value affects the land index value which results in LMU 3 and LMU 13 obtaining the highest land index,
- 16 respectively 76 and 80. Meanwhile, the LMU 8 as the lowest land index value which was 50. The
- 17 remaining LMUs get land index values ranged from 50 71. The varous of land index values will greatly
- 18 affect the land suitability class for liberica coffee later.

### 19 **Table 4**. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

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

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

23 Based on the land index values, the land suitability class for liberica coffee was more dominant S2 with

- covering an area of 88.77% of total area (Table 5). Meanwhile, the S1 class was 7.21% of total area and
- 25 the S3 class was 4.02% of total area without not suitable class (N).

26 Table 5. Value of Land Characteristics Rating, Land Index and Land Suitability Class for Liberica Coffee

	Elev	ation	Slop	ре	pН	H2O	C-Or	ganic	C	EC	E	3S	Av	/a-P			Area	
LMU	Y		Y		Y		Y		Y		Y		Y			LCS		
LIVIO	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	LI	LCS	ha	%
	ha⁻¹)		ha-1)		ha⁻¹)		ha-1)		ha-1)		ha⁻¹)		ha⁻¹)					
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
								īotal (ha)									2.804,28	100

Remark: 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.

2 3

1

# 4 Comparison of Land Suitability Classes and their Recommendations on Land Management

5 Table 6 show that the comparison between the two methods shows the similarity of the land suitability

6 class (S2 : S2) of 22.18% of total area (LMU 1, 7 and LMU 10). But the most dominant class differences

7 (S1: S2) of 66.59% of total area (LMU 2, 4, 5, 6, 9, 11, and LMU 12), class S2: S1 of 7.21% of total area

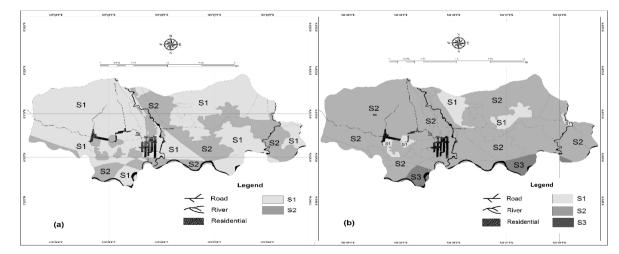
8 (LMU 3, and LMU 13), while the lowest was the class (S1 : S3) of 4.02% of total area (LMU 8).

9 Based on land suitability class of the limiting factor method, the land that was included in 10 recommendation I (S1) was 70.62% of the total area, while recommendation II (S2) was 29.38% of the 11 total area, without land recommendation III (S3) and recommendation IV (N). In contrast to the 12 parametric method, where land that was included in recommendation I (S1) was 7.21% of the total 13 area, recommendation II (S2) was 88.77% of the total area, while land with recomendation III (S3) was 14 4.20% of the total area without land recommendation IV (N).

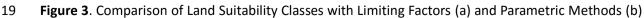
15	Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for
16	Liberica Coffee in Pinogu Plateau

	Land Suit	ability Class	Land S	uitability Class	Area	1
LMU	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	7.22
8	S1	I	S3	III	112.84	4.0
		Total (ha)			2,804.28	100.0

17 Remark: LMU = land mapping unit.



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20 for Liberica Coffee in Pinogu Plateau

# 1 DISCUSSION

- 2 The land suitability for liberica coffee with the limiting factor method and the parametric method was
- 3 different, both in terms of class and areas. This study shown that, by limiting factor method, the
- dominant suitability class is very suitable (S1). Yet, by paramettric method, the dominat suitability class
- 5 is moderately suitable (S2). Although the land suitability class using this limiting factor method appears
- to be of a higher class and wider distribution, it was only based on the characteristics of the land and
  has not been linked at all with the productivity of liberica coffee. The limiting factor method has
- has not been linked at all with the productivity of liberica coffee. The limiting factor method has
   weaknesses, including interactions between land characteristics that are difficult to explain (Elsheikh)
- 9 et al., 2013; Hartati, et al., 2018).
- 10 In contrast to the land suitability class with the parametric method, besides being based on the 11 performance of land characteristics, it has also been directly related to the productivity of liberica
- 12 coffee in the research area, so that the interactions in it are easy to explain. According to Sitorus (2018),
- 13 the precision and reliability of parametric methods more greater than other land evaluation methods.
- 14 The advantage of the parametric method is that land evaluation is easy to carry out and only consists
- of a few categories (Rodcha et al., 2019). Furthermore, Marbun et al. (2019) stated that the superiority
- 16 of this parametric method is not only calculating land suitability classes based on soil properties but
- also taking into account all factors and mapping them in one land suitability map. This parametric
- method with the square root of the land index uses a minimum rating to assess land suitability classes
  (Juita et al., 2020). In fact, Mathewos et al. (2018) stated that the square root land index value was
- (Juita et al., 2020). In fact, Mathewos et al. (2018) stated that the square root land index value washigher than the Storie index. To improve the land evaluation approach, qualitative and quantitative
- 21 approaches must be integrated (Mugiyo et al., 2021).
- 22 In the land suitability assessment for liberica coffee using the limiting factor method, it evidently that 23 there were more limiting factors, while the parametric method most less. The minimum rating value 24 in the parametric method was only the low availability of P nutrients. A low land suitability index 25 should be improved so that the plant grows optimally (Isramiranti et al., 2020). Land that has an S3 26 suitability class has the opportunity to be improved through various land improvement efforts, so that 27 it becomes a class S2 to class S1 (Refitri et al., 2016). Low nutrient availability was improved through 28 fertilization on liberica coffee plants by maximizing nutrient absorption by coffee roots and minimizing 29 nutrient loss from the coffee root zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), 30 land management can be done by adding organic matter and fertilizing according to the recommended 31 dose of fertilizer. The addition of organic matter can increase soil pH and C organic (Afandi et al., 2015;
- 32 Siregar et al., 2017), and base saturation (Sembiring et al., 2015).
- 33 Land suitability class assessment using the limiting factor method often contrasts between land suitability classes and their real productivity. In fact, at LMU 4 and LMU 6, the existing land use were 34 35 irrigated rice fields and swamps that often inundated was classified as very suitable (S1) for liberica coffee. In the limiting factor method, the most limiting factor has a dominant role, so that other factors 36 37 can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment were 38 without further specifications (Abbasi et al., 2019). Meanwhile, with the parametric method, LMU 4 39 and LMU 6 are included in the quite appropriate class (S2) which is more realistic with the conditions 40 of land use. The parameteric method in principle assigns values at different limiting levels to land 41 properties on a normal scale with a maximum value of 100 to a minimum value of 0 (Juita et al., 2020). 42 On the parametric method, the most limiting factor will reduce its effect because it is covered by the
- 43 cumulative value of all factors (Nugroho & Istianto, 2013).

1 The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric

- 2 method following the class pattern S2 > S1 > S3. The advantage of the parametric method in addition
- 3 to calculating land suitability classes based on soil properties is also calculating all factors and mapping
- 4 them in one land suitability map (Marbun et al., 2019). It seems that the land index obtained by the
- 5 parametric method was closer to the real conditions in the field, where the average of liberica coffee
- 6 productivity in the Pinogu Plateau ranges from 0.51 to 0.61 ton ha<sup>-1</sup>, while the productivity of Pinogu
- 7 coffee currently reaches 0.75 ton ha<sup>-1</sup> (Martono, 2018). Ghazanchaii & Fariabi (2014) state that there
- 8 was a significant relationship between land index and production, where as the land index increases,
- 9 the yield based on the range of land suitability classes also increases quantitatively. Diagnostic criteria
- in the parametric method were assessed numerically and mathematically to obtain land suitability
   classes (Marbun et al., 2019), so as to describe the degree of land suitability that does not depend on
- 12 class boundaries (Abbasi et al., 2019).

13 The land for liberica coffee with the limiting factor method was dominated by recommendation I 14 followed by recommendation II because the land with class of S1 was wider than class of S2. 15 Meanwhile, the parametric method was more dominant by recommendation II followed by recommendation I and III because the land with class of S2 was wider than class of S1 and S3. In order 16 17 to optimize land use for liberica coffee, it was necessary to improve the cultivation system including 18 through fertilization (Nugroho, 2015). In addition, the position of liberica coffee plantations in the 19 Bogani-Nani Wartabone National Park and upstream Bone watershed needs to implement 20 conservation agriculture. Coffee-based agroforestry can be applied because it affects growth and 21 production, land and water conservation, and adds nutrients (Supriadi & Pranowo, 2015). The 22 distribution of land suitability classes and land recommendations for liberica coffee in Plato Pinogu 23 were very important for developing this coffee. According to Saidi & Suryani (2021), the existence of 24 land suitability maps was very important to providing information on the suitability of various 25 agricultural commodities, limiting factors, widely and it distribution in an area.

# 27 CONCLUSION

28 The actual land suitability class for liberica coffee using the limiting factor method consists of 29 moderately suitable (S2) and marginally suitable class (S3) with elevation, nutrient retention and 30 available nutrient constraints. Efforts to improve the class by adding organic matter and fertilization, it 31 has the potential became very suitable class (S1) and S2 class. The parametric method consists of S1, 32 S2 and S3 classes because of low P nutrients. The land for liberica coffee with the limiting factor 33 method consist of recommendation I and II. Meanwhile, the parametric method consist of 34 recommendation I, II and III for liberica coffee. Land suitability assessment using the parametric 35 method was more realistic on land characteristics in relation to liberica coffee productivity than the 36 limiting factor method.

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# **EDITOR'S NOTES**

*From your editor:* Dear Author:

Thank you for entrusting us with your manuscript and opting for our editing service.

We have edited your assignment for basic language and grammar, from the aspect of fluency, and would like to share our experience in editing your manuscript. Overall, we have made minor revisions to the manuscript in terms of language and grammar. We have also made a few revisions for accuracy and enhanced clarity.

We hope that the revisions meet your expectations from our service. We wish you the very best and look forward to working with you again and good luck with the publication.

Sincerely, Your Editor Hollie

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This is to certify that the following manuscript :

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			LIBERICA PINOGU HP. ACQUIRED USING DIFFERENT METHODS AND
			RECOMMENDATIONS FOR LAND MANAGEMENT IN PINOGU
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was proofread and edited by a native speaker of English for proper English language, spelling, grammar, and punctuation. During the review, we attempted not to change the author's intended meaning in the text. Since all changes were tracked using the 'Track Changes' feature in the Microsoft. Word, authors are free to reject or accept the changes.

Date: 17 February 2022

Co-Director,

awarmy Kent

Dr. Anthony Kent

# THE COMPARISON OF LAND SUITABILITY CLASS FOR ENDEMIC COFFEA LIBERICA PINOGU HP. WITHACQUIRED USING DIFFERENT METHODS, AND THEIR RECOMMENDATIONS OFFOR LAND MANAGEMENT IN PINOGU PLATEAU, BONE BOLANGO REGENCY

#### ABSTRACT

8 Coffee is a national strategic commodity that contributes to the country'sIndonesia's foreign 9 exchange, but these its productivity is still remains low due to cultivation on low-potential potential 10 land. StudyThis study aimed to determine the land suitability value of endemic liberica coffee with using two different methods and to-formulate recommendations for land management in Pinogu 11 12 Plateau. The 13Thirteen land units were surveyed, and soil samples were collected and analyzed the 13 soil samples in the laboratory to obtain data of identify the land characteristic selected. Comparison of different land characteristics. Land suitability classes (LSC) was implemented using the LSCs) were 14 15 compared by limiting factor and the parametric methods. Meanwhile, the land management were 16 referred to Land managements were classified as follows: recommendation I or equal to very suitable 17 (S1), II or equal to moderately suitable (S2), III or equal to marginaly marginally suitable (S3), and recommendation IV or equal to not suitable (N). The results Analysis using the limiting factor method 18 showed that the actual LSC for liberica coffee using the limiting factor method were consisted of S2 19 20 and S3 classes. After Efforts for -improvement of LSC, could increase the potential of LSC to 21 became of-S1 and S2 classes. CoverselyMeanwhile, the LSC using assessment with the parametric 22 method indicated that the LSC consisted of S1, S2, and S3 classes. The land for liberica coffee with 23 the limiting factor method consist of recommendation I and II, while the parametric method consist 24 of recommendation I, II and III. The These results revealed that the parametric method wasprovides 25 more realistic on-land characteristics-in relation to liberica coffee productivity than the limiting factor 26 method.

28 Keywords: Landland, suitability, coffee, liberica, endemic, Pinogu-

#### 30 INTRODUCTION

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31 Coffee has long been recognized as a refreshing drink-in the world. The Its global distribution is 32 composed of worldarabica coffee includes Arabica at 80%, robusta coffee with a distribution area of 33 80%, Robustaat 20%, and liberica coffee by 20% and Liberica coffee with a distribution area ofat only 34 <1% (Nillian et al., 2020). It is relatively difficult to get research references References and 35 publications on liberica coffee in the worldare scarce because of its limited planting area, so that 36 publications are also relatively limited. It is predicted that by. By 2050, the land suitable for robusta 37 coffee cultivation is will reach 83%, while and that for arabica coffee is will only be 17% in the world 38 (Magrach & Ghazoul, 2015). However, according to Claude et al. (2019), liberica coffee reported that 39 based on pedoclimatic zoning-is-more, liberica coffee shows higher potential to be cultivated for 40 cultivation than robusta and arabica coffee-because agro-climatic zoning shows an increase in the 41 potential for this coffeeincreases its production potential in the coming years.

42 Coffee in Indonesia is still a strategic commodity in Indonesia because it is able to contributeits

Commented [Editor1]: Remark: Consider indicating the country.

Commented [Editor2]: Remark: In American English, a comma (called serial or Oxford comma) is inserted before "and" in a series of three or more items. 1 export value contributes to the country's foreign exchange-from the export value of the commodity. 2 Until 2020, national. National coffee production and export in 2020 separately reached 753,941 tons, 3 an increase of 0.19% from the previous year, while exports of national coffee commodities reached and 375,555.9 tons or an increase of 2.62% from the previous year with a (value of 4 5 809,158,900 US\$\$) with increases of 0.19% and 2.62%, respectively, from the previous year 6 (Indonesian Central Bureau of Statistics, 2020). From this achievement of national coffee production, 7 the contribution of Gorontalo Province iscontributed only 139 tons or 0.02% of the total national 8 coffee production (Indonesian Directorate General of Plantations, 2021). 9 Pinogu is one of the sub-districts in the Bone Bolango Regency, Gorontalo Province which. This area

10 is relatively flat and wide (496 km<sup>2</sup>) at with an altitude of > 300 m above sea level, and is surrounded by hills and mountains-so that it can be called, hence the name Pinogu Plateau. This sub-district has 11 12 long been known as a coffee producer, even sinceduring the Dutch colonial era (Sancayaningsih et 13 al., 2016; Humola et al., 2021). According to Almost every family in Pinogu Plateau owns a coffee 14 plantation as their main crop because of its highest productivity level among other commodities 15 (Ahmad & Paserangi-(, 2018), almost every family in Pinogu Plateau owns a coffee plantation and 16 makes it their main commodity because the productivity level of this coffee is the highest compared to other commodities. The advantages of pinogu coffee include the fact that local farmers do not use 17 pesticides, herbicides or other chemical fertilizers in coffee. Pinogu coffee is organic (Fatmalasari et 18 19 al., 2016) because local farmers do not use pesticides, herbicides, or other chemical fertilizers during 20 cultivation (Zainuddin, 2020), so this coffee can be said to be organic coffee (Fatmalasari et al., 2016). 21 Pinogu coffee comes from robusta coffee and liberica coffee. This coffee is processed from robusta 22 and liberica varieties (Zainuddin, 2020; Susilo et al., 2021).

23 Liberica coffee (Coffea liberica) has been planted since 1875 (Sancayaningsih et al., 2016) and 24 become anis now classified as endemic plantin the northern part of Celebes because this speciesit 25 only exists and grows in Pinogu District-for the northern part of Celebes. Liberica coffee. This variety 26 has the advantageadvantages of good taste (Gusfarina, 2014), and a distinctive taste of jackfruit flavor (Saidi & Suryani, 2021). This condition makes pinogu, which make Pinogu coffee an icon of 27 28 thea superior commodity of Bone Bolango Regency (Zainuddin, 2020). Efforts to maintain the 29 sustainability of liberica coffee products have so far encountered several obstacles, one of which is 30 the low productivity of the coffee. Martono (2018) reports reported that although Pinogu 31 Coffeecoffee has becomereached global recognition, its productivity is still low at only 0.75 ton ha-1 32 year<sup>-1</sup>. In factBy comparison, the productivity of liberica coffee can reach 1.69---1.98 ton ha<sup>-1</sup> 33 (Indonesian Industrial and Beverage Crops Research Institute, 2015). Pinogu sub-district has a coffee Coffee plantation area of 282.63 ha oraccounts for the largest proportion in this district at 34 35 282.63 ha (66.21%) withand new production of 36.34 tontons (Humola et al., 2021). Such conditions 36 will-affect the availability of coffee raw materials to meet market demand-later. The low-coffee 37 productivity of coffee is thought to below possibly because coffee cultivationit is carried outbeing 38 cultivated on land that is not in accordance with the low potential of the land.

39 Until now there is no available information Information about the land potential of land for the

- 40 development of Liberica Coffee in the Pinogu Plateau area, except for the potential of land for
   41 robusta coffee because it is more is available only for the highly developed-robusta coffee but not for
- 42 <u>liberica coffee</u>. Land suitability for robusta coffee in Bone Bolango Regency is <u>classified as</u> marginally

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1 suitable (S3) classfor robusta coffee (Taslim, 2018; Indrianti, 2020). Meanwhile, and other plantation 2 commodities such as coconut, cocoa, cloves, candlenut, and vanilla-are included in the moderately 3 suitable class in Bone Bolango Regency (Taslim, 2018). Liberica coffee is not only endemic, it is also morehighly resistant to pests and plant diseases (Harni et al., 2015), resistant to leaf rust, and 4 5 somewhatslightly resistant to coffee berry borer pests (Gusfarina, 2014). Ignorance of land potential 6 among coffee planters regarding land potential will greatly affect the productivity of liberica coffee 7 itself, because differences in; land potential will be responded by variously by plantsvaries for every plant according to growinggrowth conditions based on land characteristics (Sukarman et al., 2018). 8

9 Land management requires land suitability assessment soto ensure that a land can be used 10 productively and sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is an important-contribution in agricultural land use planning (AbdelRahman et al., 2018), appropriate 11 12 land use (Abdelrahman et al., 2016), and efficient use in agriculture land use (Zakarya et al., 2021). 13 Information of the on land use potential forms wereis presented on as the output of the land 14 evaluation, including of their consequences, beneficial, and adverseseverity of each degree class 15 (Shalaby et al., 2017). Likewise with This scheme is also suitable for land use planning for liberica coffee. Different land evaluation methods have different varying data requirements and varying 16 17 quality of estimates, but there is estimate qualities; to date, no fixed rule that defines has been 18 imposed to define when and what evaluation method to use and when there is a need for more 19 complex analyzes analysis necessary (Mathewos et al., 2018; Mugiyo et al., 2021).

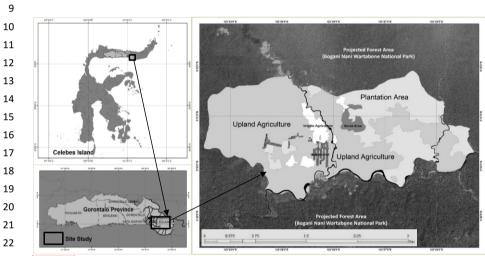
20 Limiting factor method is mainly used in assessing land suitability for coffee. Parametric method 21 identifies the combination of soil characteristics affecting agricultural production by using 22 mathematical equations (Elaalem, 2013) Previous research on land suitability assessment for coffee mostly used the limiting factor method. The limiting factor method is used to determine the class 23 24 based on the lowest constraint, while the parametric method is determined based onto minimize the 25 interaction between land characteristics. The former uses the lowest constraint for classification, and 26 the latter employs the correlation between all variables (Rabia & Terribile, 2013). In the parametric 27 method, there is a combination of soil characteristics that affect agricultural production using 28 mathematical equations (Elaalem, 2013) so that the interaction between land characteristics can be 29 minimized. Furthermore, Bagherzadeh & Gholizadeh (2016) stated that in the parametric approach, 30 different land suitability classes.(LSCs) are defined as completely separate groups and separated from each other with different and but consistent ranges. Differences in land suitability values due to the 31 32 use of differentvarying methods on a land will have an impact on differences in land management. 33 Therefore, the aim of thethis study wasaimed to determine the land suitability value of endemic liberica coffee withby using two different methods and to formulate recommendations for land 34 35 management in Pinogu Plateau, Bone Bolango Regency.

#### 36 MATERIAL AND METHODS

#### 37 Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province.
 Geographically, the researchIts geographical location is located at 0°24'5.4" — 0°38'29.04" Northnorth
 to 123°18'38.52"—123°33'15.48" Easteast covering an area of 2,804.28 ha with the elevation of 300
 —338 m above sea level (Fig. 1). The annual rainfall is 2,541.90 mm, and the monthly rainfall

**Commented [Editor5]:** Remark: Impact denotes collision. Check if this can be replaced with effect or influence. rangingranges from 19.00 mm to 408.18 mm, so the. The study area is included in the agro-climatic zone of C1 because the number of dry month (monthymonths (monthly rainfall less than 100 mm) is only 1-month, and the number of wet monthmonths (monthly rainfall more than 200 mm) is 6 months is wet. The monthly air temperature fluctuates between 24.34 °C to and 25.79 °C while, and the relative humidity is between 78.60% to and 84.40% and the duration of %. The monthly sunshine duration is between 44.52% to and 70.50%, while and the monthly wind speed is between 2 knots to and 2.60 knots. The study area is the located upstream of the Bone watershed which flowsflowing to Tomini Bay.



23 **Figure 1**. Research Location Map

#### 24 Land Mapping Unit

25 Before carrying out-Prior to soil surveysurveying and land observations, it begins with making a map 26 of the land unit was drawn at a scale of 1: 12,000 (Fig. 2). This map contains of 13 land units which 27 were the result ofgenerated from basic map overlays that has been adjusted to map scale, included:, 28 namely, landform maps, slope maps, geological maps, and maps of existing land use. Furthermore, 29 this, which were adjusted to the map scale. This land unit map becamesserved as a reference in 30 carrying out of soil survey and land observations, especially in determining soil observation points. **Commented [Editor6]:** Remark: For all tables and figures, consider using the full forms of all acronyms/abbreviations when used only once or at first mention (with the abbreviations or initialisms indicated in a parentheses); use the abbreviations or initialisms in subsequent mentions. Note that the instruction of most journals is that tables and figures should be able to stand on their own (without need for reference to the text).

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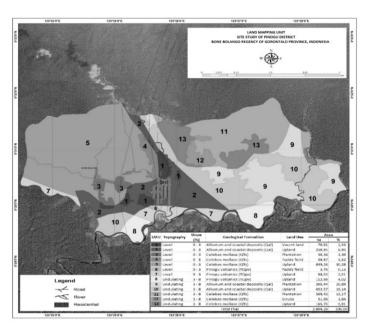
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#### 2 Figure 2. Land Mapping Unit

#### Soil Survey and Land Observation 3

4 A set of The following soil survey tools, included were used: soil knife, pH meter, soil belt, hoe, spade, 5 clinometer, and permanent whiteboard markerspidel Meanwhile, the. The materials used;included soil 6 profile card, plastic bag, fastening rubber, label paper, climate data from the local BMKG station for 5 7 years (2015-\_2021-)), and soil samples for laboratory analysis. This field research used aA soil survey 8 method on a scale of 1: 12,000 was adopted by observing the soil properties on 13 land units (Fig.2). Furthermore, field Field observations were carried out to determine the land characteristics, such as 9 10 elevation and slope. After that, Approximately 1 kg of soil samples were taken for analysis in the 11 laboratory analysis.

#### 12 **Soil Laboratory Analysis**

13 Soil-The soil samples were air-dried for 3 days, and then sieved filtered through a 2 mesh sieve. The 14 analysis of selected soil soil properties based on research parameters refers towere analyzed 15 following the soil analysis procedure according tomethod of Eviyati & Sulaeman (2009). Soil reaction 16 parameters (pH H<sub>2</sub>O) were determined with a pH meter extracted in a solution of 1:2.5 soil and 17 water. Organic carbon content were determined withwas measured using the Walkley and Black method. The Available P content was available computed using the Olsen method, while the cation 18 exchange capacity (CEC) was  $\frac{\text{extracted}\text{evaluated}}{\text{with 1N NH}_4\text{OAc pH 7.0}}$  (ammonium acetate) on a 19 20 dry sample of 105°C, while 105°C, and base saturation was determined by calculation.calculated. All

21 soil data and selected land characteristic data are input were inputted in spreasheeta spreadsheet. Commented [Editor7]: Remark: Consider the use of English term (whiteboard marker) for consistency.

#### 1 Land Suitability Assessment Assessment

2 The landLand suitability assessment was -carried out based onusing the parameters of selected land 3 characteristics which were the same betweenfor both methods. For the limiting factor method-and 4 the parametric method. The assessment of land suitability classes used the limiting factor method followings, the land evaluation framework was adopted (FAO, 1976). Land , and the land 5 6 characteristics and qualitygualities were compared withaccording to the selected land suitability 7 criteria (Table 1) selected from the Indonesian Directorate General of Plantations (2014), in order to 8 obtainchoose the actual land suitability class along with theand limiting factors for land use. 9 Furthermore, Optimization was further performed on the limiting factor of the actual land suitability 10 class was carried out improvement efforts, in order to obtain a potential land suitability class.

11 Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land was requirements (	Simbo	ŧ		Land suita	ability class	
Land use requirements/ land characteristics	Symbo	Unit	S1	S2	S3	Ν
	<u>1</u>					
Elevation	el	m asl	300500	600800; 0300	800-1.000	>1,000
Slopes	sl	%	0-8	825	25-45	>45
Nutrient retention:						
Soil pH (H <sub>2</sub> O Extraction)			5.5-6.0	6.1-7.0	7.1-8.0	>8.0
C-organic (Walkley & Black)	)	%	25	12; 510	0.5-1.0; 10-15	<0.5; >1
Cation exchange capacity (NH4.OAc pH 7 Extraction)	nr	cmol kg=1	>15	10—15	510	<5
Base saturation (NH4.OAc pH 7 Extraction)		%	>35	20 <u>–</u> 35	<20	-
Nutrient availability: Pavailability ( <i>Olsen</i> )	na	ppm	>16	1015	<10	-

12 Source: (Indonesian Directorate General of Plantations, 2014), modified.modified.

Remark: S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable. m asl = mean above sea
 level, ppm = part per million.

15	Meanwhile, in assessing land suitability using the For the parametric method, it is estimated that the
16	productivity (Y) of coffee uses several was estimated using the following equations (Simbolon, 2018)
17	namely:
18	1
19	Y = -2.672 + 0.026 Elevation
20	Y = 17,1900.090 Slope

21	Y = 3.055 + 0.005 pH H <sub>2</sub> O	(3)
	Y = 4.050 0.019 Corganic	
	Y = -28.796 + 0.621 P Olsen	
24	Y = 32.450 <u></u> 0.109 Cation exchange capacity	(6)
	Y = 0.457 0.002 Base saturation	
26	In this case, where Y = estimated production (ton ha <sup>=-1</sup> ). The assumption of the liberica coffe	e-optimal

productivity used of of liberica coffee was 0.75 ton  $ha^{-1}$  (Martono, 2018). In order to assess the The

- 28 accuracy of the estimated productivity of the liberica coffee, it productivity was analyzed using the
- 29 <u>rRoot mMean s</u>quare <u>e</u>Error (RMSE) with the following equation:

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$$LI = LC_{min} \sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}} - \dots$$
 (9)

suitability assessment for liberica coffee and calculated as follows:

9 where: LI = land index; LC = land characteristic; LC<sub>min</sub> = minimum LC rating; A, B, C, ..., N = other LC in
10 beside the minimum LC.

11 The determination of land suitability class based on land index (LI) was calculated from all LC values 12 that affect of affecting the liberica coffee productivity. The LI score criteria and scored using the 13 following LI value criteria (Sys et al., 1991), namely: S1 class (very suitable) with a value of 75--100, 14 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 <u>a</u> value 0--25.

16 The formulation recommendations<u>Recommendations</u> of land management for liberica coffee was 17 determined basedwere formulated on the basis of the final suitability class. Recommendation I was 18 the land with land-suitability of S1 class, II was the land with land-suitability of S2 class, and 19 recommendation III was the land with land-suitability of S3 class. Meanwhile, not<u>Not</u> recommended 20 was the land with-land suitability of N class. All data and information obtained were described and 21 presented in tabular form, whileand their spatial distribution was presented in map form.

#### 23 RESULTS

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#### 24 Land Suitability Class Based on Limiting Factor Method

The resultresults of matching the land suitability criteria with the land characteristics resulted in the 25 26 actual land suitability class for liberica coffee in Pinogu Plateau wasare shown to in Table 2 and Figure 27 3. It seems that the The actual land suitability class was moderately suitable (S2), which was more 28 dominant in andominated a total area of 2,149.64 ha or 76.66% compared to%. By comparison, the 29 marginally suitable class (S3) which was only accounted for 654.64 ha or only 23.34%. Meanwhile the 30 veryVery suitable class (S1) and not suitable (N) has were not found in the results of obtained from 31 this assessment. The most dominant limiting factors in almost all LMUs for liberica coffee land use in the Pinogu Plateau were nutrient retention (C-organic, base saturation, and soil pH) and 32 33 nutrients nutrient availability (P availability). In addition, there was an elevation limiting factor at 34 LMUwas identified in LMUs 1 and LMU-7.

35	Table 2.4	<del>'he</del> Actua	Land Suital	bility Clas	s for Liberica	Coffee in Pir	ogu Platea	iu
	Elev	ation	Slope	рН	C-Organic	CEC	BS	Ava-P

-	Elevation		Slo	Slope		рН		C-Organic		CEC		BS		a-P		Area	1
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual 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	

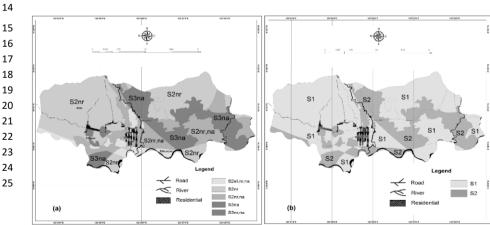
1 2 Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation axchangeexchange capacity, BS = base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

3 The potential land suitability class was dominated of dominated by S1-that covering an area of 1,980.30 ha or 70.62% of total area%, and the rest includingremaining part was classified as S2 class 4 5 covering an area of 823.98 ha or 29.38% of total area.%. After making efforts to improve the improvement of the actual land suitability class against the limiting factor, all LMUs can be upgraded 6 7 to potential land suitability class, except for LMULMUs 1 and LMU-7 whichthat cannot be repaired 8 because of the elevation limiting factor (Table 3, Figure 3). The limiting factors for nutrient retention, 9 bothnamely, pH, C-organic, and low base saturation, were improved with the addition of organic 10 matter, while. Meanwhile, the limiting factor for available nutrients of nutrient, that is, low P 11 availability, was improvedenhanced with the addition of P fertilizer.

#### Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau 12

	Actual	Lincitia - Existence	Efft -	Potential	Area	Э
LMU	LSC	Limiting Factors	Efforts	LSC	ha	%
1, 7	S2el,nr,na	Elevation, nutrient retention (C- organic, base saturation), nutrient availability (available of P)	<del>Can not<u>Cannot</u> be fixed (elevation)</del>	S2	169,34	2.53
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	<ul> <li>Addition of organic matter</li> </ul>	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

Remark: LMU = land mapping unit, LSC = land suitability class.



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4 Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau 5 Land Suitability Class Based on Parametric Method

Table 4 show that shows the highest productivity of liberica coffee was obtained on the productivity 6 7 for slope characteristics with an average of 1.69 ton ha<sup>-1</sup>, while and the lowest was on thefor P 8 availability with an average of 0.20 ton  $ha^{-1}$ . The remaining land characteristics hashad an average 9 productivity 0.30. The results of the RMSE analysis values on the alleged productivity of liberica 10 coffee were all close to 0, but LMU 3, 10,12 and LMU 13 are smaller (0.51) compared to ; LMU 8 11 which is had the highest (0.53), value (0.53), which was higher than those for LMUs 3, 10,12, and 13 12 (0.51). The remaining LMUs has anhad a RMSE value of 0.52 (Table 4). The productivity of liberica 13 coffee will affectaffects the land characteristic index, which will ultimately determinedetermines the 14 land indexLl and land suitability class for liberica coffee.

15 It seems that the The relative land characteristic index values followfollowed the pattern of 16 productivity for liberica coffee productivity in the Pinogu Plateau. The highest land characteristic 17 index value and reaching the and optimal value was theland characteristic index was acquired for slope characteristic which the averaged value with an average of 100 (Table 5), while and the lowest 18 19 land characteristic index value was obtained for the available P which with an average of P availability 20 index of 26.39. The remaining land characteristics arewere relatively diverse, but the average value 21 of the land characteristic index was 30 in the remaining LMUs in the Pinogu Plateau. The land characteristic index value affects the land index value which results in LMULI. Hence, LMUs 3 and 22 23 LMU-13 obtaining obtained the highest land indexLis at 76 and 80, respectively 76 and 80. 24 Meanwhile, the LMU 8 ashad the lowest land index value which was <u>LI of</u> 50. The remaining LMUs 25 get land index values rangedachieved a LI ranging from 50 -to 71. The varous of land index values 26 willvariation in LI greatly affectaffects the land suitability class for liberica coffee-later.

#### 27 Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

		Eleva	ation	Slo	pe	pH I	H2O	C-Org	ganic	CE	С	B	5	Ava	-P	v		
	LMU	Value (m sl)	Y (ton ha <sup>1</sup> )	Value (%)	Y (ton ha <sup>1</sup> )	Value	Y (ton ha⊐¹)	Value (%)	Y (ton ha= 1)	Value (cmol)	Y (ton ha=- 1)	Value (%)	Y (ton ha= 1)	Value (ppm)	Y (ton ha=* 1)	(ton ha= 1)	Stdev	RMSE
Į.	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

28

1 2 3

Remark: LMU = land mapping unit, C-Org = C-organic, Exc. = exchangeable, CEC = cation axchangeexchange capacity, BS = 29 base saturation, Ava-P = P availability, m asl = mean above sea level, ppm = part per million, Stdev = standard deviation, 30 RMSE = root mean square error.

31	Based onOn the land index valuesbasis of Lis, the land suitability class for liberica coffee was more
32	dominantdominated by S2 with-covering an area of 88.77% of total area (Table 5). Meanwhile, the S1

- class was 7.21% of total area and the S3 class wasclasses accounted for 7.21% and 4.02% of total
   area without not %, respectively. Not suitable class (N)-, was not detected.
- 3 Table 5. Value of Land Characteristics Characteristic Rating, Land Index, and Land Suitability Class for
- 4 Liberica Coffee

	Eleva	ation	Slop	e	pH I	H2O	C-Or	ganic	C	EC	E	IS	Av	a-P			Area	
LMU	Y	LC	Y	LC	Y	16	Y	LC	Y	10	Y	LC	Y	LĊ	LI	LCS		%
	(ton ha=1)	LC	(ton ha=1)	LC	(ton ha=1)	LC	(ton ha=1)	LC	(ton ha=1)	LC	(ton ha=1)	LC	(ton ha=1)	LC			ha	%
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	2.5
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	8.9
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	1.3
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	1.3
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	30.2
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	0.1
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	3.5
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	4.0
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	16.3
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	13.1
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	5.9
							٦	otal (ha)									2.804.28	100

Remark: 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.

8 Comparison of Land Suitability Classes and their Recommendations on Land Management

9 <u>Comparison in Table 6 show shows</u> that the comparison between the two methods shows the exhibit

10 similarity of in the land suitability class (S2+:S2) of comprising 22.18% of total area (LMULMUs 1, 7,

11 and LMU-10). ButHowever, the most dominant class differences (difference was S1 -: : S2) of

accounting for 66.59% of total area (LMU\_LMUs 2, 4, 5, 6, 9, 11, and LMU-12), followed by class
 S2 ÷: S1 ofat 7.21% of total area (LMU(LMUs 3, and LMU-13), while-) and the lowest was the class

14 (S1÷:S3) of at 4.02% of total area (LMU 8).

15 Based on On the basis of the land suitability class offrom the limiting factor method, the land that 16 was included in recommendation I (S1) wasaccounted for 70.62% of the total area, while and that in 17 recommendation II (S2) was comprised 29.38% of the total area, without%. No land 18 recommendationrecommendations III (S3) and recommendation-IV (N). In contrast to) were noted. 19 For the parametric method, where the land that was included in recommendation I (S1) 20 wasaccounted for 7.21% of the total area, that in recommendation II (S2) wascomprised 88.77% of 21 the total area, while land with recomendation %, and that in recommendation III (S3) wasconstituted 22 4.20% of the total area without land%. Land recommendation IV (N)-) was not detected.

23 Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for 24 Liberica Coffee in Pinogu Plateau

	Land Suit	tability Class	Land S	uitability Class	Area		
LMU	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%	
1, 7, 10	S2	11	S2	Ш	621.91	22.18	
2, 4, 5, 6, 9, 11, 12	S1	I	S2	Ш	1,867.46	66.59	
3, 13	S2	11	S1	I	202.07	7.21	
8	S1	1	S3	111	112.84	4.02	
		Total (ha)			2,804.28	100.00	

**Commented [Editor8]:** Remark: To create an easy flow of ideas, transition words such as however, therefore, moreover, etc. can be used. This usage enhances coherence of ideas in the paragraph and the manuscript on the whole.

#### 1 Remark: LMU = land mapping unit.

2

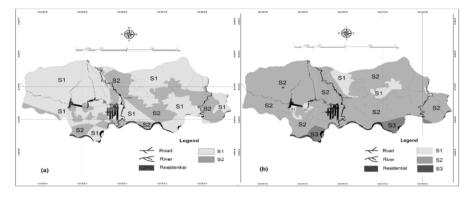


Figure 3. Comparison of Land Suitability Classes with for Liberica Coffee in Pinogu Plateau obtained
 using Limiting FactorsFactor (a) and Parametric (b) Methods (b) for Liberica Coffee in Pinogu Plateau
 DISCUSSION

6 The land suitability for liberica coffee with vary between the limiting factor method and the 7 parametric method was different, bothtwo methods in terms of class and areas. This study shown 8 that, by limiting factor method, the The dominant suitability class is was very suitable (S1). Yet, by 9 paramettric method, the dominat suitability class is) based on the limiting factor method but 10 moderately suitable (S2)-) according to the parametric method. Although the land suitability class using this limiting factor method from the former technique appears to be of a higherhigh class and 11 12 widerwide distribution, it was-is only based on the land characteristics of the land and has not been 13 linked at all with the productivity of liberica coffee- productivity. The limiting factor method has 14 weaknesses, including the complicated interactions between land characteristics that are difficult to explain (Elsheikh et al., 2013; Hartati, et al., 2018). 15

16 InBy contrast to, the land suitability class withfrom the parametric method, besides being is based on 17 the performance of land characteristics, it has also been and directly related to the productivity of 18 liberica coffee in the research area, so that. Hence, the interactions in it are easy to explain. 19 According to Sitorus (2018), the parametric method has greater precision and reliability of 20 parametric methods more greater than other land evaluation methods. Theirs advantage of the 21 parametric method is that land evaluation is easy to carry out and only consists of a few categories 22 (Rodcha et al., 2019). Furthermore, Marbun et al. (2019) also stated that the superiority of this parametric method is not onlytechnique is calculating LSCsland suitability classes based on soil 23 properties but also taking into accountand considering all factors and mapping them in one land 24 25 suitability map. This The parametric method with the square root of the land index LI uses a minimum 26 rating to assess LSCshand suitability classes (Juita et al., 2020). In fact, Mathewos et al. (2018) 27 statedreported that the square root land index value wasLl is higher than the Storie index. To 28 improve the For an improved land evaluation approach, qualitative and quantitative approaches must 29 be integrated (Mugiyo et al., 2021).

In the land suitability assessment for liberica coffee-using, the number of limiting factors was higher
 in the limiting factor method, it evidently that there were more limiting factors, while than in the
 parametric method most less. The only minimum rating value in the parametric method was only the

1 low P availability of P nutrients. A low land suitability index should be improved soto ensure that the 2 plant grows optimally (Isramiranti et al., 2020). Land that has anA land with S3 suitability class has 3 the opportunity to-can be improved enhanced through various land improvement efforts, so that it becomes a to become class S2 to classor even S1 (Refitri et al., 2016). Low nutrient availability was 4 5 improved can be ameliorated through fertilization on liberica coffee plants by maximizing nutrient 6 absorption by coffee roots and minimizing nutrient loss from the coffee root zone (Saidi & Suryani, 7 2021). According to Mahapatra et al. (2019), land management can be doneaccomplished by adding 8 organic matter and fertilizing according to the recommended dose of fertilizer dose. The addition of 9 organic matter can increase soil pH and C-organic content (Afandi et al., 2015; Siregar et al., 2017), 10 and base saturation (Sembiring et al., 2015).

Land suitability class assessment using the limiting factor method often contrasts between LSCsland 11 12 suitability classes and their real productivity. In fact, at LMUAt LMUs 4 and LMU-6, the existing land use wereuses, which are irrigated rice fields and swamps that are often inundated-was, were 13 14 classified as very suitable (S1) for liberica coffee. In the limiting factor method, the most limiting 15 factor has a dominant role, so that; hence, the other factors can be ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment were without do not have further 16 specifications (Abbasi et al., 2019). Meanwhile, withWith the parametric method, LMULMUS 4 and 17 18 LMU-6 are were included in the quite appropriate moderately suitable class (S2), which is more 19 realisticin accordance with the conditions of land use. The parameteric method in In principle, the 20 parametric method assigns values at different limiting levels to land properties on a normal scale 21 withfrom a maximum value of 100 to a minimum value of 0 (Juita et al., 2020). On the parametric 22 methodIn this case, the effect of the most limiting factor will reduce its effect is reduced because it is covered by the cumulative value of all factors (Nugroho & Istianto, 2013). 23

24 The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric 25 method followingfollowed the class pattern S2 > S1 > S3. The advantage of the parametric method 26 inIn addition to calculating LSCsland suitability classes based on soil properties is also calculating, this 27 technique calculates all factors and mappingplaces them in one land suitability map (Marbun et al., 28 2019). It seems that the The land index obtained by the parametric method was closerclose to the 29 realactual field conditions in the field, where; the average of liberica coffee productivity in the Pinogu Plateau ranges from 0.51 ton ha<sup>-1</sup> to 0.61 ton ha<sup>-1</sup>, while the productivity and that of Pinogu 30 31 coffee currently reaches 0.75 ton ha<sup>-1</sup> (Martono, 2018). Ghazanchaii & And Fariabi (2014) state that 32 there wasstated a significant relationship between land index and production, where as the land 33 index increasesthat is, the yield based on the range of LSCs and suitability classes also increases 34 quantitatively with the land index. Diagnostic criteria in the parametric method were assessed 35 numerically and mathematically in the parametric method to obtain LSCsland suitability classes 36 (Marbun et al., 2019), so as to and describe the degree of land suitability that does not depend on 37 class boundaries (Abbasi et al., 2019).

The land for liberica coffee with<u>With</u> the limiting factor method-<u>, the land for liberica coffee</u> was dominated by recommendation I<sub>2</sub> followed by recommendation II because the land with <u>S1</u> class of <u>S1</u>-was wider than <u>that with S2</u> class of <u>S2</u>. Meanwhile, <u>With</u> the parametric method, <u>the land</u> was more dominantdominated by recommendation II<sub>2</sub> followed by recommendation I and III because the land with <u>S2</u> class of <u>S2</u> was wider than <u>class of those with</u> S1 and S3. In order to optimize land use for

43 <u>classes. For optimal</u> liberica coffee, it was necessary to improve land use, the cultivation system

1 includingmust be improved, such as through fertilization (Nugroho, 2015). In addition, the position of liberica coffee plantations in the Bogani-Nani Wartabone National Park and upstream Bone 2 3 watershed needs tomust implement conservation agriculture. Coffee-based agroforestry can be applied because it affects growth and production, land and water conservation, and adds nutrients 4 5 (Supriadi & Pranowo, 2015). The distribution of LSCsland suitability classes and the land recommendations for liberica coffee in Plato Pinogu were veryare important for developing this 6 7 coffee-its development. According to Saidi & Suryani (2021), the existence of land suitability maps was very important to providingprovide information on the suitability of various agricultural 8 9 commodities, limiting factors, widely and it the distribution of limiting factors in an area.

# 11 CONCLUSION

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The actual land suitability class for liberica coffee using the limiting factor method consists of 12 13 moderately suitable (S2) and marginally suitable class (S3) classes with elevation, nutrient retention, and available nutrient constraints. Efforts to improve the S3 class by adding organic matter addition 14 and fertilization, could upgrade it has the potential became very to suitable class (S1) and moderately 15 suitable (S2-class-) classes. The parametric method consists of S1, S2, and S3 classes because of low P 16 17 nutrients. The land for liberica coffee with consists of recommendations I and II according to the 18 limiting factor method consistent is composed of recommendation recommendations I, II, and II. 19 Meanwhile, III according to the parametric method-consist of recommendation I, II and III for liberica 20 coffee.. Land suitability assessment using the parametric method wasprovides more realistic on-land 21 characteristics in relation to liberica coffee productivity than the limiting factor method.

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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

# ABSTRACT

8 Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange, but its 9 productivity remains low due to cultivation on low potential land. This study aimed to determine the 10 land suitability of endemic liberica coffee using two different methods and formulate 11 recommendations for land management in Pinogu Plateau. Thirteen land units were surveyed, and 12 soil samples were collected and analyzed in the laboratory to identify the land characteristics. Land 13 suitability classes (LSCs) were compared by limiting factor and parametric methods. Land 14 managements were classified as follows: recommendation I or very suitable (S1), II or moderately 15 suitable (S2), III or marginally suitable (S3), and IV or not suitable (N). Analysis using the limiting 16 factor method showed that the actual LSC for liberica coffee consisted of S2 and S3 classes. Efforts 17 for improvement could increase the potential of LSC to became S1 and S2 classes. Meanwhile, the 18 assessment with the parametric method indicated that the LSC consisted of S1, S2, and S3 classes. 19 These results revealed that the parametric method provides more realistic land characteristics than 20 the limiting factor method.

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22 Keywords: land, suitability, coffee, liberica, endemic, Pinogu

# 24 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 (Indonesian Central Bureau of Statistics, 2020). Gorontalo Province contributed only 139 tons or 0.02% of the total national coffee production (Indonesian Directorate General of Plantations, 2021).

Pinogu is one of the sub-districts in Bone Bolango Regency, Gorontalo Province. This area is relatively flat and wide (496 km<sup>2</sup>) 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 (Sancayaningsih et al., 2016; Humola et al., 2021). Almost every family in Pinogu Plateau owns a coffee plantation as their main crop because of its 1 highest productivity level among other commodities (Ahmad & Paserangi, 2018). Pinogu coffee is

2 organic (Fatmalasari et al., 2016) because local farmers do not use pesticides, herbicides, or other

3 chemical fertilizers during cultivation (Zainuddin, 2020). This coffee is processed from robusta and

4 liberica varieties (Zainuddin, 2020; Susilo et al., 2021).

5 Liberica coffee (Coffea liberica) has been planted since 1875 (Sancayaningsih et al., 2016) and is now 6 classified as endemic in the northern part of Celebes because it only exists and grows in Pinogu 7 District. This variety has the advantages of good taste (Gusfarina, 2014) and distinctive jackfruit 8 flavor (Saidi & Suryani, 2021), which make Pinogu coffee a superior commodity of Bone Bolango 9 Regency (Zainuddin, 2020). Efforts to maintain the sustainability of liberica coffee products have 10 encountered several obstacles, one of which is low productivity. Martono (2018) reported that 11 although Pinogu coffee has reached global recognition, its productivity is still low at only 0.75 ton ha<sup>-1</sup> year<sup>-1</sup>. By comparison, the productivity of liberica coffee can reach 1.69–1.98 ton ha<sup>-1</sup> 12 13 (Indonesian Industrial and Beverage Crops Research Institute, 2015). Coffee plantation area accounts 14 for the largest proportion in this district at 282.63 ha (66.21%) and new production of 36.34 tons 15 (Humola et al., 2021). Such conditions affect the availability of coffee raw materials to meet market 16 demand. The coffee productivity is low possibly because it is being cultivated on land with low 17 potential.

18 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 19 20 marginally suitable (S3) for robusta coffee (Taslim, 2018; Indrianti, 2020) and other plantation 21 commodities such as coconut, cocoa, cloves, candlenut, and vanilla (Taslim, 2018). Liberica coffee is 22 endemic, highly resistant to pests and plant diseases (Harni et al., 2015), resistant to leaf rust, and 23 slightly resistant to coffee berry borer pests (Gusfarina, 2014). Ignorance of land potential among 24 coffee planters greatly affect the productivity of liberica coffee; land potential varies for every plant 25 according to growth conditions based on land characteristics (Sukarman et al., 2018).

26 Land management requires land suitability assessment to ensure that a land can be used 27 productively and sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is 28 important in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use 29 (Abdelrahman et al., 2016), and efficient agriculture land use (Zakarya et al., 2021). Information on 30 land use potential is presented as the output of land evaluation, including their consequences, 31 beneficial, and severity of each degree class (Shalaby et al., 2017). This scheme is also suitable for 32 land use planning for liberica coffee. Different land evaluation methods have varying data 33 requirements and estimate qualities; to date, no rule has been imposed to define when and what 34 evaluation method to use and when is complex analysis necessary (Mathewos et al., 2018; Mugiyo et 35 al., 2021).

Limiting factor method is mainly used in assessing land suitability for coffee. 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 1 varying methods have an effect on land management. Therefore, this study aimed to determine the

2 land suitability of endemic liberica coffee by using two different methods and formulate

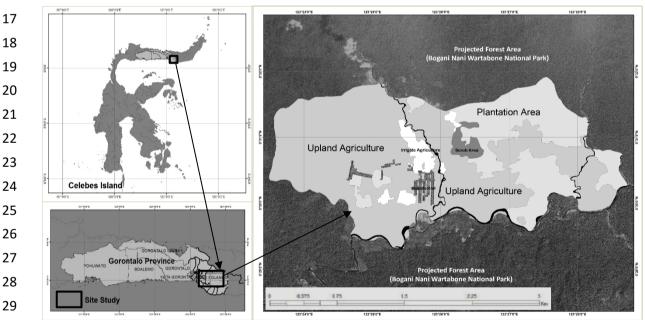
3 recommendations for land management in Pinogu Plateau, Bone Bolango Regency.

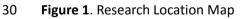
# 4 MATERIAL AND METHODS

# 5 Site Study

This research was conducted in Pinogu Plateau, Bone Bolango Regency, Gorontalo Province. Its 6 7 geographical location is at 0°24'5.4"-0°38'29.04" north to 123°18'38.52"-123°33'15.48" east 8 covering an area of 2,804.28 ha with elevation of 300-338 m above sea level (Fig. 1). The annual 9 rainfall is 2,541.90 mm, and the monthly rainfall ranges from 19.00 mm to 408.18 mm. The study 10 area is included in the agro-climatic zone of C1 because the number of dry months (monthly rainfall 11 less than 100 mm) is only 1, and the number of wet months (monthly rainfall more than 200 mm) is 12 6. The monthly air temperature fluctuates between 24.34 °C and 25.79 °C, and the relative humidity 13 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 14 15 watershed flowing to Tomini Bay.

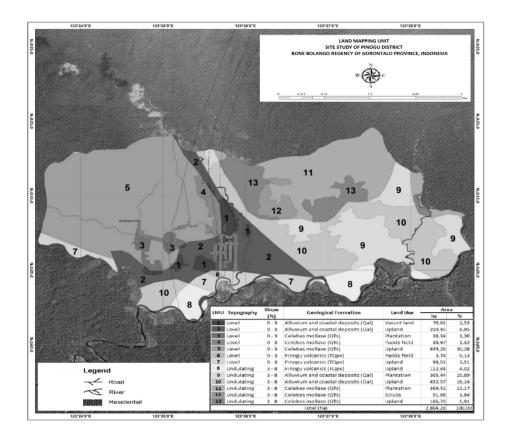
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# 31 Land Mapping Unit

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 Figure 2. Land Mapping Unit

# 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.

# 11 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 Eviyati & Sulaeman (2009). Soil reaction parameters (pH H<sub>2</sub>O) 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<sub>4</sub>OAc 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.

# 19 Land Suitability Assessment

- 20 Land suitability assessment was carried out using the selected land characteristics for both methods.
- 21 For the limiting factor method, the land evaluation framework was adopted (FAO, 1976), and the

- 1 land characteristics and qualities were compared according to the criteria (Table 1) selected from the
- 2 Indonesian Directorate General of Plantations (2014) to choose the actual land suitability class and
- 3 limiting factors for land use. Optimization was further performed on the limiting factor of the actual
- 4 land suitability class to obtain a potential land suitability class.
- 5 **Table 1**. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/	Symbo	Unit -		Land suita	bility class	
land characteristics	I.	Unit	S1	S2	S3	Ν
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 (H₂O Extraction)			5.5–6.0	6.1-7.0	7.1-8.0	>8.0
C-organic (Walkley & Black)	1	%	2–5	1–2; 5–10	0.5–1.0; 10–15	<0.5; >15
Cation exchange capacity (NH4.OAc pH 7 Extraction)	nr	cmol kg <sup>-1</sup>	>15	10–15	5–10	<5
Base saturation (NH4.OAc pH 7 Extraction)		%	>35	20–35	<20	-
Nutrient availability: P availability ( <i>Olsen</i> )	na	ppm	>16	10–15	<10	-

6 Source: (Indonesian Directorate General of Plantations, 2014), modified.

Remark: S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable. m asl = mean above sea
 level, ppm = part per million.

9 For the parametric method, the productivity (Y) of coffee was estimated using the following 10 equations (Simbolon, 2018):

-		
11	Y = -2.672 + 0.026 Elevation(1)	
12	Y = 17,190 – 0.090 Slope	
13	Y = 3.055 + 0.005 pH H <sub>2</sub> O(3)	
14	Y = 4.050 – 0.019 C-organic(4)	
15	Y = -28.796 + 0.621 P Olsen(5)	
16	Y = 32.450 – 0.109 Cation exchange capacity(6)	
17	Y = 0.457 – 0.002 Base saturation(7)	
18	where Y = estimated production (ton $ha^{-1}$ ). The optimal productivity of liberica coffee was 0.75 to	n
19	ha <sup>-1</sup> (Martono, 2018). The accuracy of the estimated liberica coffee productivity was analyzed using	g

20 the root mean square error (RMSE) with the following equation:

- 21
- 22  $RMSE = \sqrt{\frac{\sum_{t=1}^{n} (At Ft)^2}{n}}$  .....(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:

27

28  $LI = LC_{min} \sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}}$  .....(9)

29 where LI = land index; LC = land characteristic; LC<sub>min</sub> = minimum LC rating; A, B, C, ..., N = other LC in

1 beside the minimum LC.

2 LI was calculated from all LC values affecting the liberica coffee productivity and scored using the

3 following LI criteria (Sys et al., 1991): S1 class (very suitable) with a value of 75–100, S2 class

4 (moderately suitable) with a value of 50–75, S3 class (marginally suitable) with a value of 25–50, and

5 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

9 with suitability of N class. All data and information obtained were described and presented in tabular

10 form, and their spatial distribution was presented in map form.

11

#### 12 **RESULTS**

#### 13 Land Suitability Class Based on Limiting Factor Method

14 The results of matching the land suitability criteria with the land characteristics in the actual land

15 suitability class for liberica coffee in Pinogu Plateau are shown in Table 2 and Figure 3. The actual

16 land suitability class was moderately suitable (S2), which dominated a total area of 2,149.64 ha or

17 76.66%. By comparison, the marginally suitable class (S3) accounted for 654.64 ha or only 23.34%.

18 Very suitable class (S1) and not suitable (N) were not obtained from this assessment. The most

- 19 dominant limiting factors in almost all LMUs for liberica coffee land use in Pinogu Plateau were
- 20 nutrient retention (C-organic, base saturation, and soil pH) and nutrient availability (P availability). In
- 21 addition, an elevation limiting factor was identified in LMUs 1 and 7.

	Eleva	tion	Slo	pe	pl	Н	C-Or	ganic	CE	С	B	S	Ava	a-P		Are	а
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual 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

22 **Table 2**. Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

Remark: LMU = land mapping unit, LC = land characteristic, LSC = land suitability class, CEC = cation exchange capacity, BS =
 base saturation, Ava-P = P availability, m sl = mean sea level, ppm = part per million.

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

27 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

29 elevation limiting factor (Table 3, Figure 3). The limiting factors for nutrient retention, namely, pH, C-

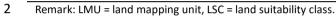
30 organic, and low base saturation, were improved with the addition of organic matter. Meanwhile, the

31 limiting factor for available nutrient, that is, low P availability, was enhanced with the addition of P

32 fertilizer.

1 Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

1 8 4 1 1	Actual	Limiting Factors	Efforts	Potential	Area	a
LMU	LSC	Limiting Factors	Efforts	LSC	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)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S2	36,34	1.30
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	<ul> <li>Addition of organic matter</li> </ul>	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



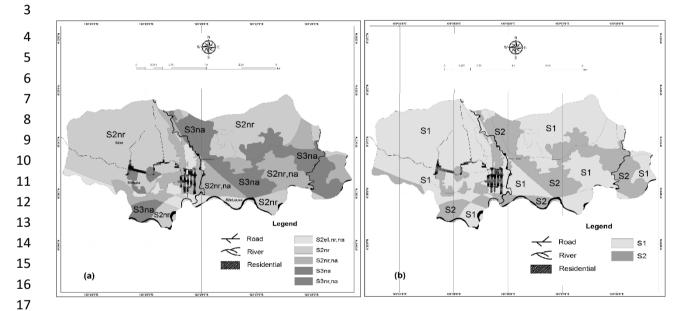




Table 4 shows the highest liberica coffee productivity for slope characteristics with an average of 1.69 ton ha<sup>-1</sup> and the lowest for P availability with an average of 0.20 ton ha<sup>-1</sup>. The remaining land characteristics had an average productivity 0.30. RMSE values on the alleged productivity 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

- 1 characteristic index value affects the LI. Hence, LMUs 3 and 13 obtained the highest Lis at 76 and 80,
- 2 respectively. Meanwhile, LMU 8 had the lowest LI of 50. The remaining LMUs achieved a LI ranging
- 3 from 50 to 71. The variation in LI greatly affects the land suitability class for liberica coffee.

	Eleva	ation	Slo	pe	pH H	120	C-Org	anic	CE	C	B	5	Ava	I-P	- v		
LMU	Value (m sl)	Y (ton ha <sup>-1</sup> )	Value (%)	Y (ton ha⁻¹)	Value	Y (ton ha⁻¹)	Value (%)	Y (ton ha⁻¹)	Value (cmol)	Y (ton ha⁻¹)	Value (%)	Y (ton ha⁻¹)	Value (ppm)	Y (ton ha⁻¹)	(ton ha <sup>-1</sup> )	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

4 **Table 4**. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

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

8 On the basis of Lis, the land suitability class for liberica coffee was dominated by S2 covering 88.77%

9 of total area (Table 5). Meanwhile, S1 and S3 classes accounted for 7.21% and 4.02%, respectively.

10 Not suitable class (N) was not detected.

	Elev	ation	Slo	ре	pН	H2O	C-Or	ganic	C	EC	E	3S	Av	a-P		_	Area	
LMU	Y		Y		Y		Y		Y		Y		Y			LCS		
LINIO	(ton ha⁻¹)	LC	(ton ha⁻¹)	LC	(ton ha <sup>-1</sup> )	LC	(ton ha⁻¹)	LC	(ton ha <sup>-1</sup> )	LC	(ton ha⁻¹)	LC	(ton ha <sup>-1</sup> )	LC	2.	200	ha	%
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

11 **Table 5**. Value of Land Characteristic Rating, Land Index, and Land Suitability Class for Liberica Coffee

Remark: 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.

#### 15 Comparison of Land Suitability Classes and their Recommendations on Land Management

16 Comparison in Table 6 shows that the two methods exhibit similarity in the land suitability class

17 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

19 class S2:S1 at 7.21% (LMUs 3 and 13) and the lowest was class S1:S3 at 4.02% (LMU 8).

20 On the basis of the land suitability class from the limiting factor method, the land that was included

21 in recommendation I (S1) accounted for 70.62% of the total area, and that in recommendation II (S2)

22 comprised 29.38%. No land recommendations III (S3) and IV (N) were noted. For the parametric

<sup>14</sup> 

- 1 method, the land included in recommendation I (S1) accounted for 7.21% of the total area, that in
- 2 recommendation II (S2) comprised 88.77%, and that in recommendation III (S3) constituted 4.20%.
- 3 Land recommendation IV (N) was not detected.

Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for
 Liberica Coffee in Pinogu Plateau

	Land Suit	tability Class	Land S	uitability Class	Area	a
LMU	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%
1, 7, 10	S2	II	S2	Ш	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	I	S2	Ш	1,867.46	66.59
3, 13	S2	II	S1	I	202.07	7.21
8	S1	Ι	S3	111	112.84	4.02
		Total (ha)			2,804.28	100.00

#### 6 Remark: LMU = land mapping unit.

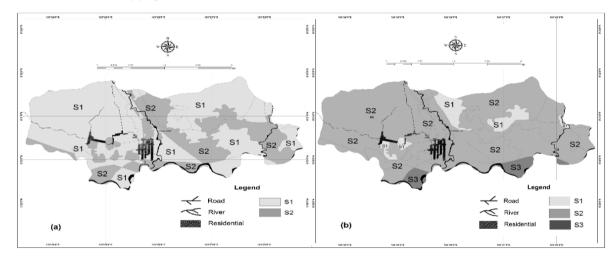


Figure 3. Comparison of Land Suitability Classes for Liberica Coffee in Pinogu Plateau obtained using
 Limiting Factor (a) and Parametric (b) Methods

#### 10 DISCUSSION

7

The land suitability for liberica coffee vary between the two methods in terms of class and areas. The dominant class was very 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 1 with the square root of LI uses a minimum rating to assess LSCs (Juita et al., 2020). Mathewos et al.

2 (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).

5 In the land suitability assessment for liberica coffee, the number of limiting factors was higher in the 6 limiting factor method than in the parametric method. The only minimum rating value in the 7 parametric method was the low P availability. A low land suitability index should be improved to 8 ensure that the plant grows optimally (Isramiranti et al., 2020). A land with S3 suitability class can be 9 enhanced through various land improvement efforts to become class S2 or even S1 (Refitri et al., 10 2016). Low nutrient availability can be ameliorated through fertilization on liberica coffee plants by 11 maximizing nutrient absorption by coffee roots and minimizing nutrient loss from the coffee root 12 zone (Saidi & Suryani, 2021). According to Mahapatra et al. (2019), land management can be 13 accomplished by adding organic matter and fertilizing according to the recommended fertilizer dose. 14 The addition of organic matter can increase soil pH and C-organic content (Afandi et al., 2015; Siregar et al., 2017), and base saturation (Sembiring et al., 2015). 15

16 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 17 swamps that are often inundated, were classified as very suitable (S1) for liberica coffee. In the 18 19 limiting factor method, the most limiting factor has a dominant role; hence, the other factors can be 20 ignored (Nugroho & Istianto, 2013) and the results of the land suitability assessment do not have 21 further specifications (Abbasi et al., 2019). With the parametric method, LMUs 4 and 6 were included 22 in the moderately suitable class (S2), which is in accordance with the conditions of land use. In 23 principle, the parametric method assigns values at different limiting levels to land properties on a 24 normal scale from a maximum of 100 to a minimum of 0 (Juita et al., 2020). In this case, the effect of 25 the most limiting factor is reduced because it is covered by the cumulative value of all factors 26 (Nugroho & Istianto, 2013).

27 The results of the land suitability assessment for liberica coffee in Pinogu Plateau with the parametric 28 method followed the class pattern S2 > S1 > S3. In addition to calculating LSCs based on soil 29 properties, this technique calculates all factors and places them in one land suitability map (Marbun 30 et al., 2019). The land index obtained by the parametric method was close to the actual field 31 conditions; the average liberica coffee productivity in the Pinogu Plateau ranges from 0.51 ton ha<sup>-1</sup> to 32 0.61 ton ha<sup>-1</sup>, and that of Pinogu coffee currently reaches 0.75 ton ha<sup>-1</sup> (Martono, 2018). Ghazanchaii 33 and Fariabi (2014) stated a significant relationship between land index and production, that is, the 34 yield based on the range of LSCs increases with the land index. Diagnostic criteria were assessed 35 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., 36 37 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 1 upstream Bone watershed must implement conservation agriculture. Coffee-based agroforestry can

- 2 be applied because it affects growth and production, land and water conservation, and adds
- 3 nutrients (Supriadi & Pranowo, 2015). The distribution of LSCs and the land recommendations for
- 4 liberica coffee in Plato Pinogu are important for its development. According to Saidi & Suryani (2021),
- 5 land suitability maps provide information on the suitability of various agricultural commodities and
- 6 the distribution of limiting factors in an area.
- 7

#### 8 CONCLUSION

9 The actual land suitability for liberica coffee using the limiting factor method consists of moderately 10 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 11 12 upgrade it to 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 13 14 recommendations I and II according to the limiting factor method but is composed of 15 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 16 17 productivity than the limiting factor method.

18

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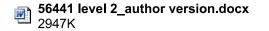
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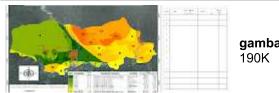
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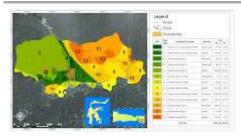
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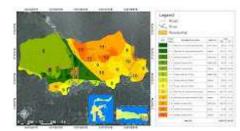
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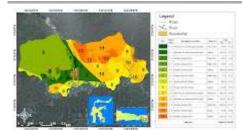
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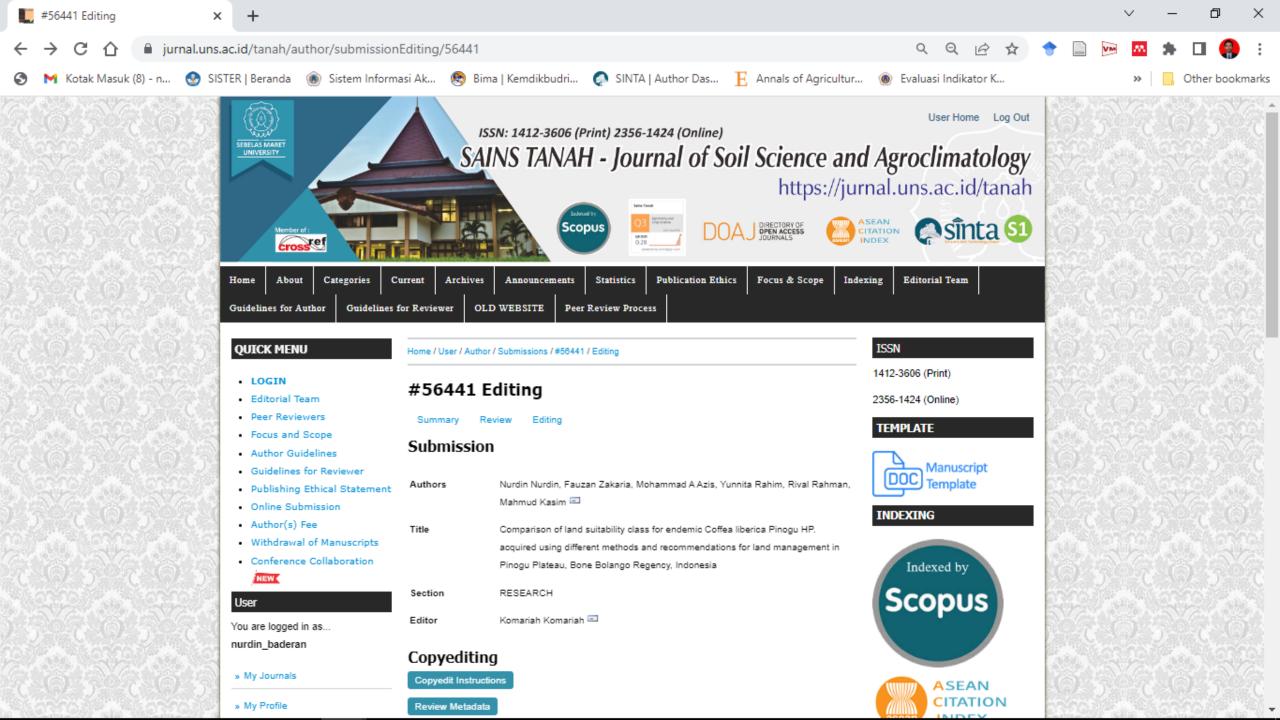
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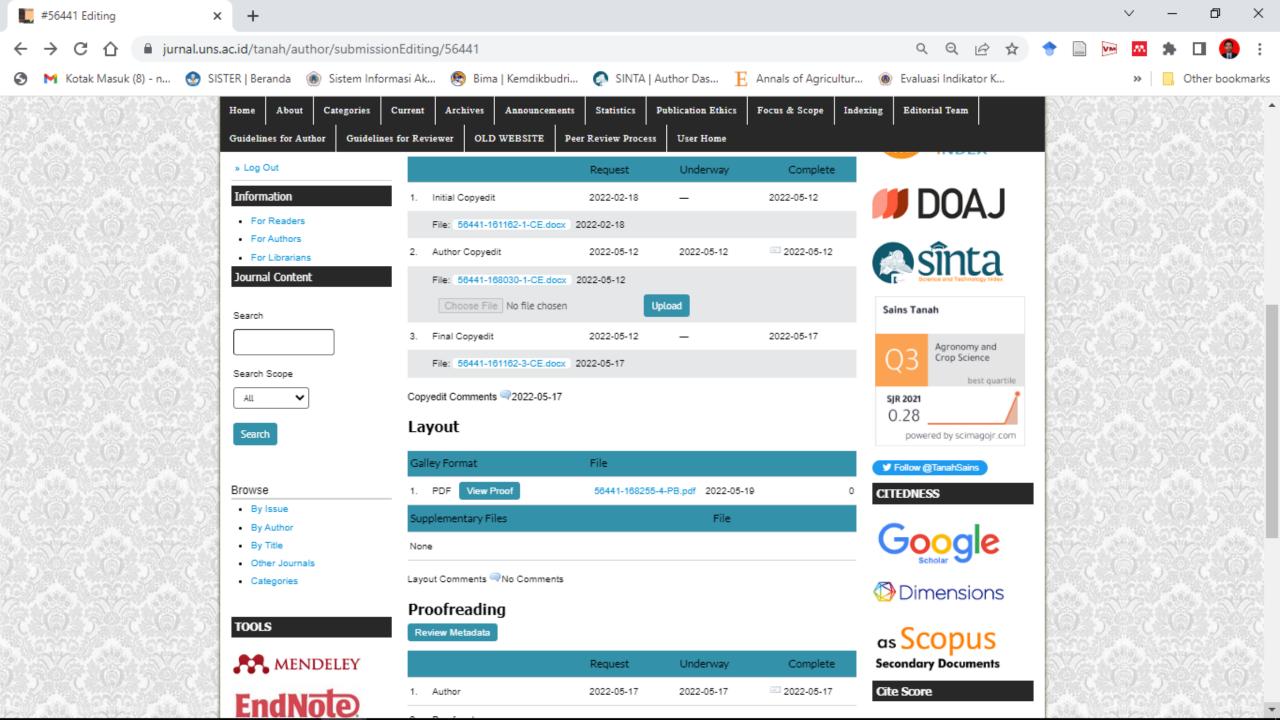


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# Comparison of land suitability class for endemic *Coffea liberica Pinogu* HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia

#### Nurdin, Fauzan Zakaria, Mohammad A Azis, Yunnita Rahim, Rival Rahman, Mahmud Kasim

Department of Agrotechnology, Faculty of Agriculture, State University of Gorontalo, Gorontalo, Indonesia

ARTICLE INFO	ABSTRACT
Keywords:	Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange,
Land suitability	but its productivity remains low due to cultivation on low potential land. This study aimed
Coffee	to determine the land suitability of endemic liberica coffee using two different methods
Liberica	and formulate recommendations for land management in Pinogu Plateau. Thirteen land
Endemic	units were surveyed, and soil samples were collected and analyzed in the laboratory to
Pinogu	identify the land characteristics. Land suitability classes (LSCs) were compared by limiting factor and parametric methods. Determination of land management recommendations
Article history	consists of I that it was without limiting factors, II was a little limiting factor, III was a lot of
Submitted: 2021-11-12	limiting factors but can still be improved, while recommendation IV was a lot of limiting
Accepted: 2022-02-18	factors and cannot be improved for the liberica coffee development. Analysis using the
Available online: <mark>2022-03-</mark> xx	limiting factor method showed that the actual LSC for liberica coffee consisted of
Published regularly: June 2022	moderately suitable (S2) and marginally suitable (S3) classes. Efforts for improvement could increase the potential of LSC to became highly suitable (S1) and S2 classes.
* Corresponding Author	Meanwhile, the assessment with the parametric method indicated that the LSC consisted
Email address: nurdin@ung.ac.id	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 turned out to be more dominant with the recommendation of adding P and organic fertilizer.

**How to Cite**: Nurdin, Zakaria, F., Azis, M.A., Rahim, Y., Rahman, R., Kasim, M. (2022). 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. Sains Tanah Journal of Soil Science and Agroclimatology, 19(1): 40-49. https://dx.doi.org/10.20961/stjssa.v19i1.56441

#### **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<sup>2</sup>) 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<sup>-1</sup> year<sup>-1</sup>. By comparison, the productivity of liberica coffee can reach 1.69-1.98 ton ha<sup>-1</sup> (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 a 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 their 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. 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.

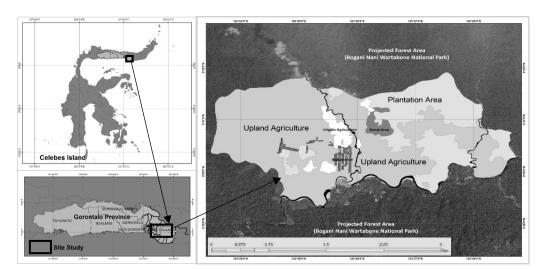


Figure 1. Research Location Map

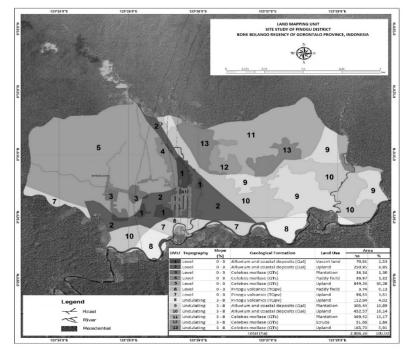


Figure 2. Land Mapping Unit

#### 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<sub>2</sub>O) 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<sub>4</sub>OAc 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.

Land use requirements/	Cumbol	l Unit		Land suita	ability class	
land characteristics	Symbol	Unit	S1	S2	S3	Ν
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 <sub>2</sub> O 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 (NH4.OAc pH 7 Extraction)	nr	cmol kg⁻¹	>15	10–15	5–10	<5
Base saturation (NH4.OAc pH 7 Extraction)		%	>35	20–35	<20	-
Nutrient availability: P availability ( <i>Olsen</i> )	na	ppm	>16	10–15	<10	-

Source: (Indonesian Directorate General of Plantations, 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 <sub>2</sub> O	[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]

Y = 0.457 - 0.002 Base saturation [7] where Y = estimated production (ton ha<sup>-1</sup>). The optimal productivity of liberica coffee was 0.75 ton ha<sup>-1</sup> (Martono, 2018). The accuracy of the estimated liberica coffee productivity was analyzed using the root mean square error (RMSE) with the following equation:

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

where RMSE = root mean square error, At = actual productivity (ton ha<sup>-1</sup>), Ft = estimated productivity (ton ha<sup>-1</sup>), 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:

$$LI = LC_{min} \sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}}$$
[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 Figure 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, Figure 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 Liberica Coffee in Pinogu Plateau

	Eleva	tion	Slo	ре	р	Н	C-Or	ganic	CEO	С	B	S	Ava	I-P	_	Are	а
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual 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= P availability, m sl= meters sea level, ppm = part per million.

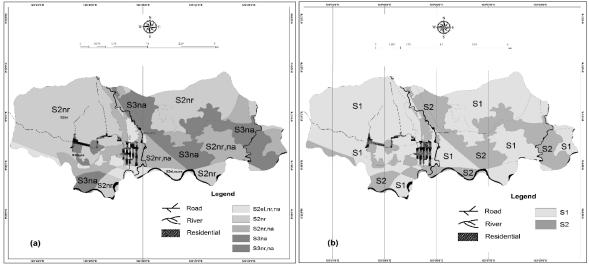


Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Table 3. Potential Land Suitability Classes	for Liberica	ı Coffee in Pinogu F	lateau
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	AstualISC	Linciting Exchange	Efforts	Potential	Area	
LMU	Actual LSC	Limiting Factors	Efforts	LSC	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)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	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.

#### 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<sup>-1</sup> and the lowest for P availability with an average of 0.20 ton ha<sup>-1</sup>. 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 their Recommendations on Land Management

Comparison in Table 6 and Figure 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 accounted for 70.62% of the total area, and that in recommendation II comprised 29.38%. No land recommendations III and IV were noted. For the parametric method, the land included in recommendation I accounted for 7.21% of the total area, that in recommendation II comprised 88.77%, and that in recommendation III constituted 4.20%. Land recommendation IV was not detected.

#### Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

	Eleva	ation	Slo	ре	рН Н	120	C-Org	ganic	CE	С	B	S	Ava	I-P	v		
LMU	Value (m sl)	Y (ton ha <sup>-1</sup> )	Value (%)	Y (ton ha <sup>-1</sup> )	Value	Y (ton ha <sup>-1</sup> )	Value (%)	Y (ton ha⁻¹)	Value (cmol)	Y (ton ha⁻¹)	Value (%)	Y (ton ha⁻¹)	Value (ppm)	Y (ton ha⁻¹)	(ton ha <sup>-1</sup> )	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, 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 Liberica Coffee

	Elev	ation	Slo	pe	pН	H2O	C-Or	ganic	C	EC	E	3S	Av	a-P			Area	
LMU	Y (ton	LC	Y (ton	LC	Y (ton	LC	Y (ton	LC	Y (ton	LC	Y (ton	LC	Y (ton	LC	LI	LCS	ha	%
	ha <sup>-1</sup> )	LC	ha <sup>-1</sup> )	LC	ha <sup>-1</sup> )	LC	ha <sup>-1</sup> )	LC	ha <sup>-1</sup> )	LC	ha <sup>−1</sup> )	LC	ha⁻¹)	LC			IIa	70
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
							Т	otal (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 Corganic content (Afandi et al., 2017; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

	Land Suitabi	lity Class	Land S	uitability Class	Area		
LMU	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%	
1, 7, 10	S2	11	S2		621.91	22.18	
2, 4, 5, 6, 9, 11, 12	S1	I	S2	П	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	

 Table 6. Comparison of Land Suitability Classes with Limiting Factors and Parametric Methods for Liberica Coffee in Pinogu

 Plateau

Remark: LMU = land mapping unit.

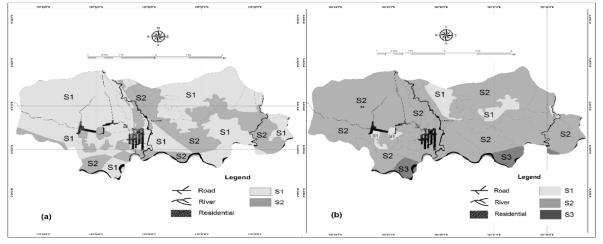


Figure 4. Comparison of Land Suitability Classes for Liberica Coffee in Pinogu Plateau obtained using Limiting Factor (a) and Parametric Methods (b)

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<sup>-1</sup> to 0.61 ton ha<sup>-1</sup>, and that of Pinogu coffee currently reaches 0.75 ton ha<sup>-1</sup> (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.

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#### 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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# 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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ARTICLE INFO	ABSTRACT
Keywords:	Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange,
Land suitability	but its productivity remains low due to cultivation on low potential land. This study aimed
Coffee	to determine the land suitability of endemic liberica coffee using two different methods
Liberica	and formulate recommendations for land management in Pinogu Plateau. Thirteen land
Endemic	units were surveyed, and soil samples were collected and analyzed in the laboratory to
Pinogu	identify the land characteristics. Land suitability classes (LSCs) were compared by limiting
	factor and parametric methods. Land managements were classified as follows:
Article history	recommendation I or highly suitable (S1), II or moderately suitable (S2), III or marginally
Submitted: 2021-11-12	suitable (S3), and IV or not suitable (N). Determination of land management
Accepted: 2022-02-18	recommendations consists of I that it was without limiting factors, II was a little limiting
Available online: <mark>2022-03-</mark> xx	factor, III was a lot of limiting factors but can still be improved, while recommendation IV
Published regularly: June 2022	was a lot of limiting factors and cannot be improved for the liberica coffee development.
	Analysis using the limiting factor method showed that the actual LSC for liberica coffee
* Corresponding Author	consisted of S2 and S3 classes. Efforts for improvement could increase the potential of LSC
Email address:	to became S1 and S2 classes. Meanwhile, the assessment with the parametric method
nurdin@ung.ac.id	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 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<sup>2</sup>) 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

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**Commented [h1]:** This classification is improper. Highly suitable (S1), S2, etc. are not "land management classification". If land management classification, please specifically mention the recommendation, not only recommendation I, II or III. But mention the managements in detail briefly.

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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<sup>-1</sup> year<sup>-1</sup>. By comparison, the productivity of liberica coffee can reach 1.69-1.98 ton ha<sup>-1</sup> (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 a 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 their 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. 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.

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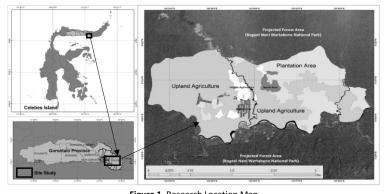


Figure 1. Research Location Map

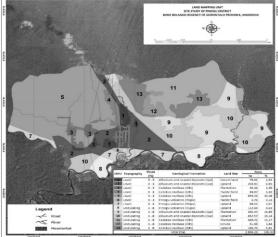


Figure 2. Land Mapping Unit

#### 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<sub>4</sub>OAc 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.

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 Table 1. Selected Land Suitability Criteria for Liberica Coffee

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Land use requirements/	C	11		Land suita	ability class	
land characteristics	Symbol	Unit	S1	S2	S3	Ν
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 <sub>2</sub> O 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 (NH4.OAc pH 7 Extraction)	nr	cmol kg <sup>-1</sup>	>15	10–15	5–10	<5
Base saturation (NH4.OAc pH 7 Extraction)		%	>35	20–35	<20	-
Nutrient availability: P availability ( <i>Olsen</i> )	na	ppm	>16	10–15	<10	-

Source: (Indonesian Directorate General of Plantations, 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 <sub>2</sub> O	[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<sup>-1</sup>). The optimal productivity of liberica coffee was 0.75 ton ha<sup>-1</sup> (Martono, 2018). The accuracy of the estimated liberica coffee productivity was analyzed using the root mean square error (RMSE) with the following equation:

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

where  $RMSE^{2}$  = root mean square error, At = actual productivity (ton ha<sup>-1</sup>), Ft = estimated productivity (ton ha<sup>-1</sup>), 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:

$$LI = LC_{min} \sqrt{\frac{A}{100} \ x \ \frac{B}{100} \ x \ \frac{C}{100} \ x \dots x \ \frac{N}{100}}$$

where LI= land index; LC= land characteristic; LC<sub>min</sub>= 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 51 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 Figure 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, Figure 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 Liberica Coffee in Pinogu Plateau

[8]

[9]

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	Eleva	tion	Slo	ре	р	н	C-Or	ganic	CEO	-	B	S	Ava	I-P		Area	а
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual 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	ı)							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= P availability, m sl= meters sea level, ppm = part per million.

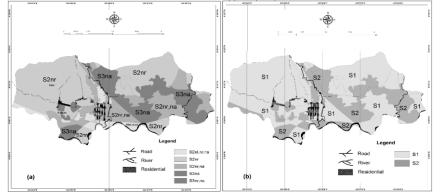


Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

	Actual LSC	Limiting Festers	Efforts	Potential	Area	
LMU	ACTUALLSC	Limiting Factors	ETIONS	LSC	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	2.5
2, 4, 9	S2nr,na	Nutrient retention (C-organic, base saturation, pH), nutrient availability (available of P)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S1	593,36	8.9
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S2	36,34	1.3
5, 6, 8, 11, 12	S2nr	Nutrient retention (C-organic, base saturation)	- Addition of organic matter	S1	1.386,94	30.2
10, 13	S3na	Nutrient availability (available of P)	- Addition of P fertilizer	S2	618,30	16.1
		Total (Ha)			2.804,28	10

**Remarks**: LMU = land mapping unit, LSC = land suitability class.

lowest for P availability with an average of 0.20 ton ha<sup>-1</sup>. 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).

**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<sup>-1</sup> and the

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

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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 their **Recommendations on Land Management**

Slope

Elevation

Table 4. Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

рН Н2О

Comparison in Table 6 and Figure 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 accounted for 70.62% of the total area, and that in recommendation II comprised 29.38%. No land recommendations III and IV were noted. For the parametric method, the land included in recommendation I accounted for 7.21% of the total area, that in recommendation II comprised 88.77%, and that in recommendation III constituted 4.20%. Land recommendation IV was not detected.

Ava-P

BS

Ŷ LMU Value Value Value Value (ton Stdev RMSE Value Value (ton (ton Valu (ton (ton (ton (ton (ton (%) (%) (%) . ha⁻¹' (m sl) (cmol) (ppm) ha-1) ha-1 ha-1 ha-1) ha-1) ha-1 ha-1 5.82 0.31 1.59 0.40 19.24 32.75 0.39 13.87 0.60 0.49 0.52 293 0.49 0.30 1.69 0.20 2 307 0.53 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 0.51 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 1.69 0.40 0.40 0.52 5.64 0.31 1.21 22.77 0.30 24.67 0.41 12.22 0.21 0.60 0.49 0.52 4 5 6 7 8 302 0.52 0.54 5.78 0.30 29.25 17.04 311 3 1.69 0.31 1.46 26.39 0.40 0.18 0.60 0.49 305 0.53 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 0.52 290 0.49 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 3 0.40 20.35 0.53 288 0.48 1.69 5.89 0.31 1.92 23.22 0.30 36.67 0.38 0.16 0.59 0.49 9 338 0.61 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 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 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 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 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

CEC

C-Organic

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

LMU	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P				Area	
	Y	-	Y		Y (ton	LC	Y (ton	LC	Y (ton L		Y LC (ton	LC	Y	Y (ton LC	LI	LCS	ha	%
	(ton	LC	(ton	LC						LC			(ton					
	ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)					
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
-							1	otal (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).

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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 Corganic 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 Liberica Coffee in Pinogu

Fiat	cau					
	Land Suitabi	lity Class	Land S	uitability Class	Area	3
LMU	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%
1, 7, 10	S2	11	S2	11	621.91	22.18
2, 4, 5, 6, 9, 11, 12	S1	I	S2	П	1,867.46	66.59
3, 13	S2	Ш	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.

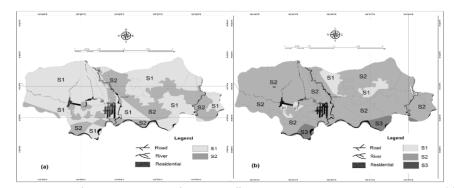


Figure 4. Comparison of Land Suitability Classes for Liberica Coffee in Pinogu Plateau obtained using Limiting Factor (a) and Parametric (b) Methods

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

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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<sup>-1</sup> to 0.61 ton ha<sup>-1</sup>, and that of Pinogu coffee currently reaches 0.75 ton ha<sup>-1</sup> (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 Survani (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 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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Zakarya, Y. M., Metwaly, M. M., AbdelRahman, M. A. E., Metwalli, M. R., & Koubouris, G. (2021). Optimized Land Use through Integrated Land Suitability and GIS Approach in West El-Minia Governorate, Upper Egypt.Sustainability,13(21),12236.https://doi.org/10.3390/su132112236



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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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ARTICLE INFO	ABSTRACT
Keywords:	Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange,
Land suitability	but its productivity remains low due to cultivation on low potential land. This study aimed
Coffee	to determine the land suitability of endemic liberica coffee using two different methods
Liberica	and formulate recommendations for land management in Pinogu Plateau. Thirteen land
Endemic	units were surveyed, and soil samples were collected and analyzed in the laboratory to
Pinogu	identify the land characteristics. Land suitability classes (LSCs) were compared by limiting
	factor and parametric methods. Determination of land management recommendations
Article history	consists of I that it was without limiting factors, II was a little limiting factor, III was a lot of
Submitted: 2021-11-12	limiting factors but can still be improved, while recommendation IV was a lot of limiting
Accepted: 2022-02-18	factors and cannot be improved for the liberica coffee development. Analysis using the
Available online: <mark>2022-03-</mark> xx	limiting factor method showed that the actual LSCs for liberica coffee consisted of S2 and
Published regularly: June 2022	S3 classes. Efforts for improvement could increase the potential of LSC to became S1 and
	S2 classes. Meanwhile, the assessment with the parametric method indicated that the LSC
* Corresponding Author	consisted of S1, S2, and S3 classes. These results revealed that the parametric method
Email address:	provides more realistic land characteristics than the limiting factor method. Land
nurdin@ung.ac.id	management II 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<sup>2</sup>) 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).

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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<sup>-1</sup> year<sup>-1</sup>. 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 coffiee; 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 a 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., 2016), and efficient agriculture 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 their 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. 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.

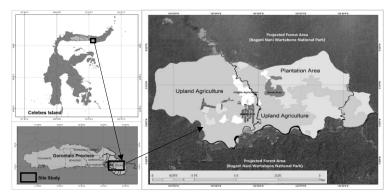


Figure 1. Research Location Map

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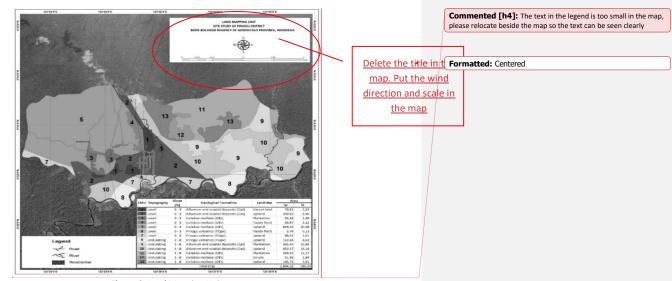


Figure 2. Land Mapping Unit

# 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

# Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/	Symbol	Unit -		Land suita	ability class	
land characteristics	Symbol	Unit	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 <sub>2</sub> O 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 (NH4.OAc pH 7 Extraction)	nr	cmol kg <sup>-1</sup>	>15	10–15	5–10	<5
Base saturation (NH4.OAc pH 7 Extraction)		%	>35	20–35	<20	-
Nutrient availability: P availability ( <i>Olsen</i> )	na	ppm	>16	10–15	<10	-

ce: (Indonesian Directorate General of Plantations, 2014), modifie

carried out to determine land characteristics, such as elevation and slope. Approximately 1 kg of soil samples were taken for laboratory analysis.

properties on 13 land units (Fig.2). Field observations were

## 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  $\ensuremath{\text{H}_2\text{O}}\xspace$ ) 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<sub>4</sub>OAc 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.

**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 <sub>2</sub> O	[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]
X 0 457 0 000 0 1 1	(m)

Y = 0.457 - 0.002 Base saturation [7] where Y = estimated production (ton ha<sup>-1</sup>). The optimal productivity of liberica coffee was 0.75 ton ha<sup>-1</sup> (Martono, 2018). The accuracy of the estimated liberica coffee productivity was analyzed using the root mean square error (RMSE) with the following equation:

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

where RMSE = root mean square error, At = actual productivity (ton ha<sup>-1</sup>), Ft = estimated productivity (ton ha<sup>-1</sup>), 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:

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

where LI= land index; LC= land characteristic; LC<sub>min</sub>= 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

## Table 2. Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

	Eleva	tion	Slo	ре	р	н	C-Or	ganic	CEO	2	B	S	Ava	I-P	-	Are	а
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual 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	ı)							2,804.28	100

## (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 51 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 Figure 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, Figure 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.

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Remarks: LMU= land mapping unit, LC= land characteristic, LSC= land suitability class, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, m sI= meters sea level, ppm = part per million.

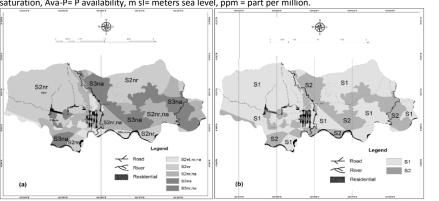


Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

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	Actual LSC	Linsibian Factors	Efforts	Potential	Area	
LMU	Actual LSC	Limiting Factors	Efforts	LSC	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)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	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

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Remarks: LMU = land mapping unit, LSC = land suitability class.

# 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<sup>-1</sup> and the lowest for P availability with an average of 0.20 ton ha<sup>-1</sup>. 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 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 their Recommendations on Land Management

Comparison in Table 6 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

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(S1) accounted for 7.21% of the total area, that in recommendation III (S3) constituted 4.20%. Land recommendation II (S2) comprised 88.77%, and that in recommendation IV (N) was not detected. **Table 4.** Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

	Eleva	ition	Slo	ре	pH F	120	C-Org	ganic	CE	C	B	5	Ava	I-P	v		
LMU	Value (m sl)	Y (ton ha <sup>-1</sup> )	Value (%)	Y (ton ha <sup>-1</sup> )	Value	Y (ton ha <sup>-1</sup> )	Value (%)	Y (ton ha <sup>-1</sup> )	Value (cmol)	Y (ton ha⁻¹)	Value (%)	Y (ton ha⁻¹)	Value (ppm)	Y (ton ha <sup>-1</sup> )	(ton ha <sup>-1</sup> )	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, m asl= meters above sea level, ppm= part per million, Stdev= standard deviation, RMSE= root mean square error.

	Elev	ation	Slo	pe	pH	H2O	C-Or	ganic	C	EC	E	S	Av	a-P			Area	
LMU	Y		Y		Y		Y		Y		Y		Y		ш	LCS		
LIVIU	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	LI	LCS	ha	%
	ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)					
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
							1	'otal (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.

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The addition of organic matter can increase soil pH and Corganic 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 Liberica Coffee in Pinogu Plateau

	Land Suitabi	lity Class	Land S	uitability Class	Area	
LMU	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	П	1,867.46	66.59
3, 13	S2	Ш	S1	1	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.

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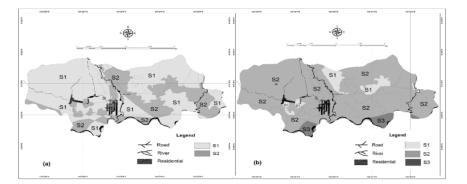


Figure 3. Comparison of Land Suitability Classes for Liberica Coffee in Pinogu Plateau obtained using Limiting Factor (a) and Parametric (b) Methods

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<sup>-1</sup> to 0.61 ton ha<sup>-1</sup>, and that of Pinogu coffee currently reaches 0.75 ton ha<sup>-1</sup> (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).

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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 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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# 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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ARTICLE INFO	ABSTRACT
Keywords:	Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange,
Land suitability	but its productivity remains low due to cultivation on low potential land. This study aimed
Coffee	to determine the land suitability of endemic liberica coffee using two different methods
Liberica	and formulate recommendations for land management in Pinogu Plateau. Thirteen land
Endemic	units were surveyed, and soil samples were collected and analyzed in the laboratory to
Pinogu	identify the land characteristics. Land suitability classes (LSCs) were compared by limiting
-	factor and parametric methods. Determination of land management recommendations
Article history	consists of I that it was without limiting factors, II was a little limiting factor, III was a lot of
Submitted: 2021-11-12	limiting factors but can still be improved, while recommendation IV was a lot of limiting
Accepted: 2022-02-18	factors and cannot be improved for the liberica coffee development. Analysis using the
Available online: <mark>2022-03-</mark> xx	limiting factor method showed that the actual LSCs for liberica coffee consisted of
Published regularly: June 2022	moderately suitable (S2) and marginally suitable (S3) classes. Efforts for improvement
	could increase the potential of LSC to became very suitable (S1) and S2 classes. Meanwhile,
* Corresponding Author	the assessment with the parametric method indicated that the LSC consisted of S1, S2, and
Email address:	S3 classes. These results revealed that the parametric method provides more realistic land
nurdin@ung.ac.id	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<sup>2</sup>) 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

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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<sup>-1</sup> year<sup>-1</sup>. By comparison, the productivity of liberica coffee can reach 1.69-1.98 ton ha<sup>-1</sup> (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 coffiee; land potential varies for every plant according to growth conditions based on land characteristics (Sukarman et al., 2018).

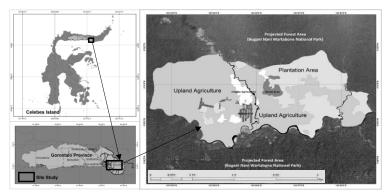
Land management requires land suitability assessment to ensure that a land can be used productively and sustainably (Mustafa et al., 2014). Land evaluation based on land suitability is important in agricultural land use planning (AbdelRahman et al., 2018), appropriate land use (AbdelRahman et al., 2016), and efficient agriculture land use (Zakarya et al., 2021). Information on land use potential is presented as the output of land evaluation, including their 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. 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.



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Figure 1. Research Location Map

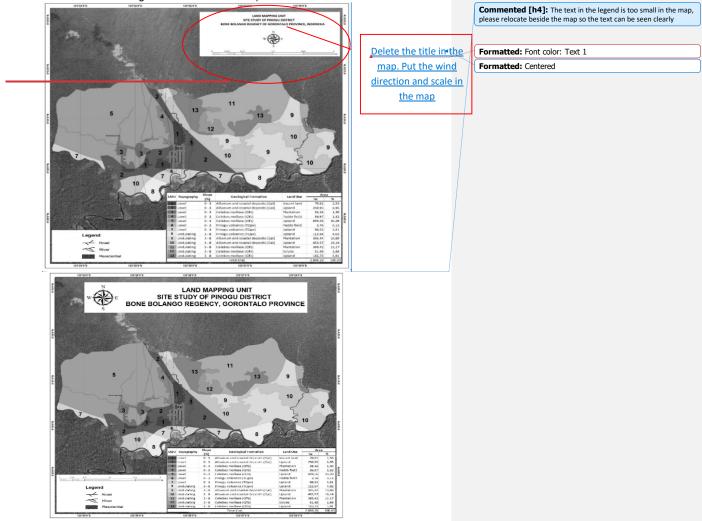


Figure 2. Land Mapping Unit

# 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.

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 $_4$ OAc 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

# 2.4. Soil Laboratory Analysis

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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

Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/	Symbol	Unit -	Land suitability class								
land characteristics	Symbol		S1	S2	S3	Ν					
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 (H₂O 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	nr	cmol kg <sup>-1</sup>	>15	10-15	5-10	<5					
(NH4.OAc pH 7 Extraction)		CITIOI Kg									
Base saturation		%	>35	20-35	<20	-					
(NH4.OAc pH 7 Extraction)		/0									
Nutrient availability:											
P availability (Olsen)	na	ppm	>16	10-15	<10	-					
Source: (Indonesian Directorate General of Plantations, 2014), modified.											

spreadsheet.

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 <sub>2</sub> O	[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 <sup>-1</sup> ). The	optimal

productivity of liberica coffee was 0.75 ton ha<sup>-1</sup> (Martono, 2018). The accuracy of the estimated liberica coffee productivity was analyzed using the root mean square error (RMSE) with the following equation:

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

where RMSE = root mean square error, At = actual productivity (ton ha<sup>-1</sup>), Ft = estimated productivity (ton ha<sup>-1</sup>), 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:

$$LI = LC_{min} \sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}}$$
[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 Figure 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)

[8]

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and nutrient availability (P availability). In addition, an elevation limiting factor was identified in LMUs 1 and 7.

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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, Figure 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.

|--|

	Eleva	tion	Slo	ре	р	H	C-Or	ganic	CE	С	B	S	Ava	a-P		Are	а
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual 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	<u></u>							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 51 = highly suitable, 52 =

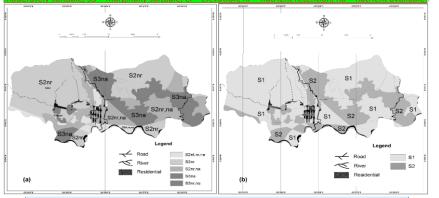


Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

# Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Limiting Festers	Efforts	Potential	Area	
LIVIO ACLUAILISC		Limiting Factors	ETIONS	LSC	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)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	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	10

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Commented [h6]: Specify in remarks what are: S1. S2, S3, el, nr, na

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

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Table 4 shows the highest liberica coffee productivity for slope characteristics with an average of 1.69 ton ha<sup>-1</sup> and the lowest for P availability with an average of 0.20 ton ha<sup>-1</sup>. 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.

Slope

(ton

ha-1

1 69

1.69

1 69

1.69

1.69

1.69 6.12

1.69

1.69 5.89

1.69

1.65 5.92

1.69

1.65 5.95 0.31

1.69 6.00 0.31

Value

(%)

2

З

RMSE= root mean square error.

pH H2O

ha-1

0 31

0.31

0.31

0.31

0.31

0.31

0.31

0.31

0.31

Value (ton

5.82

5.88

6.22 0 31

5.64

5.78

6.28 0.31

6.25

5.96

C-Organic

(ton

ha⁻¹)

0 40

0.40

0.40

0.40

0.40

0.40

0.40

Value

(%)

1 5 9

1.30

0.78 0 40

1.21 0.40

1.46 0.40

1.02

1.43

1.92

1.79

1.38 0.40

1.15 0.40

1.07

1.35 0.40 CEC

(ton

ha-1)

0.30

0.30

0 29

0.30

0.30

0.29

0.29

0.30 36.67

0.29

0.30

0.29

0.30

0.29

Value

(cmol)

19 24

23.77

27.60

22.77

26.39

29.68

27.92

23.22

27.10

23.67

27.69

25.03

32.67

Elevation

(m sl)

293 0 49

307

313

302

311

305

290

288

338

300 0.51

334 0.60

306 0.53

310 0.54

(ton

ha-1)

0.53

0 55

0.52

0.54

0.53

0 4 9

0.48

0.61

LMU Value

2

11

12

13

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 their **Recommendations on Land Management**

Comparison in Table 6 and Figure 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 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 Liberica Coffee Productivity in Pinogu Plateau

Ava-P

(ton

ha-1

0.20 0.60 0.49

0.19

0 23 0.61 0 4 9

0.21

0.18 0.60 0.49

0.17 0.60 0.49

0.20 0.60 0 49

0.16 0.59

0.19 0.61

0.23 0.60 0.48

0.18 0.61

0.19 0.59

0.24

Value

(ppm)

13 87

15.85

9.77

12.22

17.04

18.52

14 53

20.35

14.98

9.98

17.12

16.41

7.78

Ŷ

(ton

ha-1)

0.60 0.49

0.60

0.61 0.49

Stdev

0.49

0.49

0.49

0.49

0.48

RMSE

0.52

0.52

0 51

0.52

0.52

0.52

0 52

0.53

0.52

0.51

0.52

0.51

0.51

BS

(ton

ha-1

0.39

0 40

0.41

0 40

0.38

0.38

0.39

0.41

Value

(%)

32 75 0.39

33.75

28.00

24.67

29.25

29.68 0.40

39.75

37.00 0.38

42.33 0.37

33.00

39.50 0.38

23.67

# Formatted: Highlight Commented [h7]: Specify in remarks what are: S1. S2, S3, el, nr, n Formatted: Highlight

Remarks: LMU= land mapping unit, C-Org= C-organic, Exc= exchangeable, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, <u>Y = productivity</u>, m asl= meters above sea level, ppm= part per million, Stdev= standard deviation, Formatted: Highlight

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#### Table 5. Value of Land Characteristic Rating, Land Index, and Land Suitability Class for Liberica Coffee

	Elev	ation	Slo	pe	pН	H2O	C-Or	ganic	C	EC	E	3S	Av	a-P			Area	
LMU	Y		Y		Y		Y		Y		Y		Y			LCS		
LIVIO	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	LI	LCS	ha	%
	ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)		ha-1)		ha⁻¹)					
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

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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 **Table 6**. Comparison of Land Suitability Classes with Limiting

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 Corganic 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 Liberica Coffee in Pinogu

Plat	eau	-				-	
	Land Suitabi	lity Class	Land S	uitability Class	Area		
LMU	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	П	1,867.46	66.59	
3, 13	S2	Ш	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.

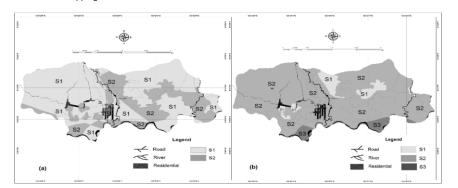


Figure 34. Comparison of Land Suitability Classes for Liberica Coffee in Pinogu Plateau obtained using Limiting Factor (a) and Parametric (b) Methods Formatted: Font color: Text 1

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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<sup>-1</sup> to 0.61 ton ha<sup>-1</sup>, and that of Pinogu coffee currently reaches 0.75 ton ha<sup>-1</sup> (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 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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# 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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ARTICLE INFO	ABSTRACT
Keywords:	Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange,
Land suitability	but its productivity remains low due to cultivation on low potential land. This study aimed
Coffee	to determine the land suitability of endemic liberica coffee using two different methods
Liberica	and formulate recommendations for land management in Pinogu Plateau. Thirteen land
Endemic	units were surveyed, and soil samples were collected and analyzed in the laboratory to
Pinogu	identify the land characteristics. Land suitability classes (LSCs) were compared by limiting
	factor and parametric methods. Determination of land management recommendations
Article history	consists of I that it was without limiting factors, II was a little limiting factor, III was a lot of
Submitted: 2021-11-12	limiting factors but can still be improved, while recommendation IV was a lot of limiting
Accepted: 2022-02-18	factors and cannot be improved for the liberica coffee development. Analysis using the
Available online: <mark>2022-03-</mark> xx	limiting factor method showed that the actual LSCs for liberica coffee consisted of S2 and
Published regularly: June 2022	S3 classes. Efforts for improvement could increase the potential of LSC to became S1 and
	S2 classes. Meanwhile, the assessment with the parametric method indicated that the LSC
* Corresponding Author	consisted of S1, S2, and S3 classes. These results revealed that the parametric method
Email address:	provides more realistic land characteristics than the limiting factor method. Land
nurdin@ung.ac.id	management II 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<sup>2</sup>) 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).

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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<sup>-1</sup> year<sup>-1</sup>. 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 coffiee; 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 a 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., 2016), and efficient agriculture 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 their 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. 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.

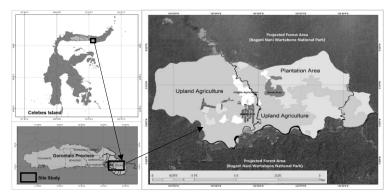


Figure 1. Research Location Map

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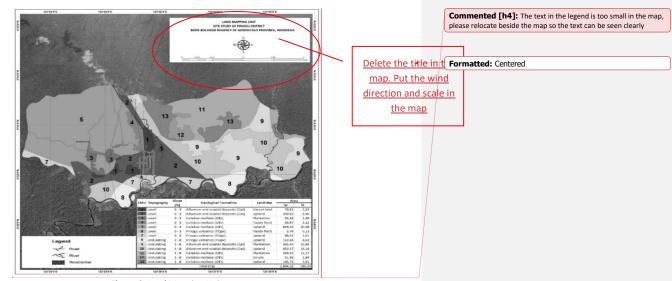


Figure 2. Land Mapping Unit

# 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

# Table 1. Selected Land Suitability Criteria for Liberica Coffee

Land use requirements/	Symbol	Unit -		Land suitability class								
land characteristics	Symbol	Unit	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 <sub>2</sub> O 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 (NH4.OAc pH 7 Extraction)	nr	cmol kg <sup>-1</sup>	>15	10–15	5–10	<5						
Base saturation (NH4.OAc pH 7 Extraction)		%	>35	20–35	<20	-						
Nutrient availability: P availability ( <i>Olsen</i> )	na	ppm	>16	10–15	<10	-						

ce: (Indonesian Directorate General of Plantations, 2014), modifie

carried out to determine land characteristics, such as elevation and slope. Approximately 1 kg of soil samples were taken for laboratory analysis.

properties on 13 land units (Fig.2). Field observations were

## 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  $\ensuremath{\text{H}_2\text{O}}\xspace$ ) 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<sub>4</sub>OAc 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.

**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 <sub>2</sub> O	[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]
X 0 457 0 000 0 1 1	(m)

Y = 0.457 - 0.002 Base saturation [7] where Y = estimated production (ton ha<sup>-1</sup>). The optimal productivity of liberica coffee was 0.75 ton ha<sup>-1</sup> (Martono, 2018). The accuracy of the estimated liberica coffee productivity was analyzed using the root mean square error (RMSE) with the following equation:

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

where RMSE = root mean square error, At = actual productivity (ton ha<sup>-1</sup>), Ft = estimated productivity (ton ha<sup>-1</sup>), 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:

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

where LI= land index; LC= land characteristic; LC<sub>min</sub>= 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

## Table 2. Actual Land Suitability Class for Liberica Coffee in Pinogu Plateau

	Elevation		Slope		рН		C-Organic		CEC		BS		Ava-P			Are	а
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual 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				

## (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 51 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 Figure 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, Figure 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.

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Remarks: LMU= land mapping unit, LC= land characteristic, LSC= land suitability class, CEC= cation exchange capacity, BS= base saturation, Ava-P= P availability, m sI= meters sea level, ppm = part per million.

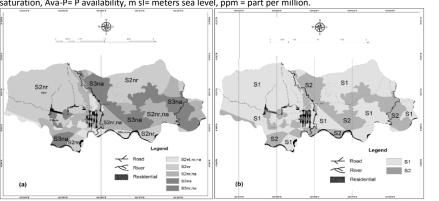


Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

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	Actual LSC	Linsibian Factors	Efforts	Potential	Area		
LMU	ACTUALLSC	Limiting Factors	Ellorts	LSC	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)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S1	593,36	8.95	
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	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	

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Remarks: LMU = land mapping unit, LSC = land suitability class.

# 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<sup>-1</sup> and the lowest for P availability with an average of 0.20 ton ha<sup>-1</sup>. 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 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 their Recommendations on Land Management

Comparison in Table 6 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

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(S1) accounted for 7.21% of the total area, that in recommendation III (S3) constituted 4.20%. Land recommendation II (S2) comprised 88.77%, and that in recommendation IV (N) was not detected. **Table 4.** Estimated Value of Liberica Coffee Productivity in Pinogu Plateau

	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P		v		
LMU	Value (m sl)	Y (ton ha <sup>-1</sup> )	Value (%)	Y (ton ha <sup>-1</sup> )	Value	Y (ton ha <sup>-1</sup> )	Value (%)	Y (ton ha <sup>-1</sup> )	Value (cmol)	Y (ton ha⁻¹)	Value (%)	Y (ton ha <sup>-1</sup> )	Value (ppm)	Y (ton ha <sup>-1</sup> )	(ton ha <sup>-1</sup> )	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, m asl= meters above sea level, ppm= part per million, Stdev= standard deviation, RMSE= root mean square error.

	Elevation		Slope		pH H2O		C-Organic		CEC		BS		Ava-P				Area	
LMU	Y		Y		Y		Y		Y		Y		Y		Ш	LCS		
LIVIU	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	LI	LUS	ha	%
	ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)					
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
							1	'otal (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.

## Commented [h8]: Specify in remarks what is Y

The addition of organic matter can increase soil pH and Corganic 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 Liberica Coffee in Pinogu Plateau

	Land Suitabi	lity Class	Land S	uitability Class	Area		
LMU	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	П	1,867.46	66.59	
3, 13	S2	Ш	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.

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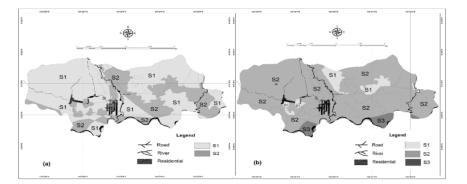


Figure 3. Comparison of Land Suitability Classes for Liberica Coffee in Pinogu Plateau obtained using Limiting Factor (a) and Parametric (b) Methods

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<sup>-1</sup> to 0.61 ton ha<sup>-1</sup>, and that of Pinogu coffee currently reaches 0.75 ton ha<sup>-1</sup> (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).

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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 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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## 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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ARTICLE INFO	ABSTRACT	
Keywords:	Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange,	
Land suitability	but its productivity remains low due to cultivation on low potential land. This study aimed	
Coffee	to determine the land suitability of endemic liberica coffee using two different methods	
Liberica	and formulate recommendations for land management in Pinogu Plateau. Thirteen land	
Endemic	units were surveyed, and soil samples were collected and analyzed in the laboratory to	
Pinogu	identify the land characteristics. Land suitability classes (LSCs) were compared by limiting	
-	factor and parametric methods. Determination of land management recommendations	
Article history	consists of I that it was without limiting factors, II was a little limiting factor, III was a lot of	
Submitted: 2021-11-12	limiting factors but can still be improved, while recommendation IV was a lot of limiting	
Accepted: 2022-02-18	factors and cannot be improved for the liberica coffee development. Analysis using the	
Available online: <mark>2022-03-</mark> xx	limiting factor method showed that the actual LSCs for liberica coffee consisted of	
Published regularly: June 2022	recleated schedule S2 and received schedule S3 classes. Efforts for improvement	-
	could increase the potential of LSC to became <b>service of S1</b> and S2 classes. Meanwhile,	$\sim$
* Corresponding Author	the assessment with the parametric method indicated that the LSC consisted of S1, S2, and	$\langle \rangle \rangle > \langle \rangle$
Email address:	S3 classes. These results revealed that the parametric method provides more realistic land	$\mathbb{A}$
nurdin@ung.ac.id	characteristics than the limiting factor method.	J / //
	the finiting factor turned out to be more dominant with the recommendation of adding	
	R and organic fertilizer Land management II humed out to be more dominant with the	
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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<sup>2</sup>) 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: Sancavaningsih 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

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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<sup>-1</sup> year<sup>-1</sup>. By comparison, the productivity of liberica coffee can reach 1.69-1.98 ton ha<sup>-1</sup> (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 a 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 their 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. 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.

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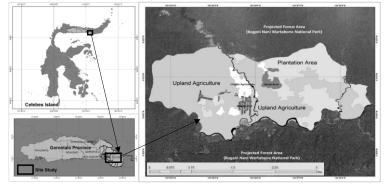


Figure 1. Research Location Map



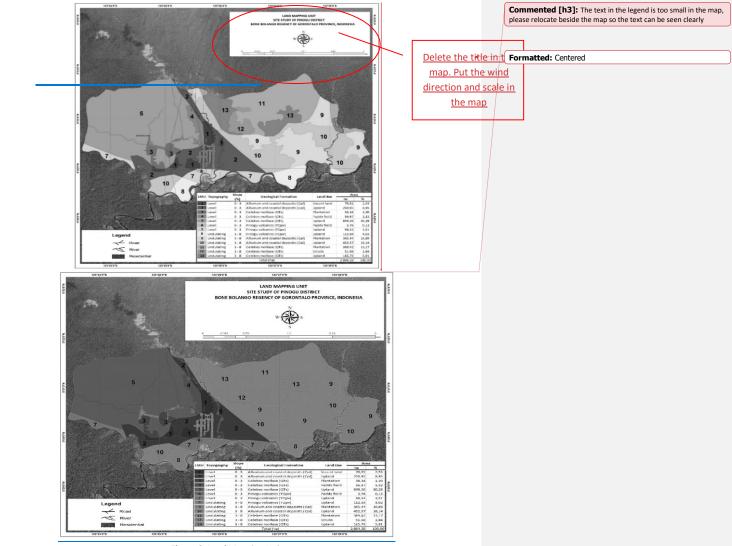


Figure 2. Land Mapping Unit

#### 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. 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.

#### 2.3. Soil Survey and Land Observation

#### 2.4. Soil Laboratory Analysis

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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 NH4OAc 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 Liberica Coffee

Land use requirements/	Cumbol	1 11	Land suitability class							
land characteristics	Symbol	Unit -	S1	S2	S3	N >1,000				
Elevation	el	m asl	300-500	600-800; 0-300	800-1.000					
Slopes	sl	%	0-8	8–25	25-45	>45				
Nutrient retention:										
Soil pH (H₂O 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 (NH4.OAc pH 7 Extraction)	nr	cmol kg <sup>-1</sup>	>15	10–15	5–10	<5				
(NH4.OAc pH 7 Extraction) (NH4.OAc pH 7 Extraction)		%	>35	20–35	<20	-				
Nutrient availability: P availability ( <i>Olsen</i> )	na	ppm	>16	10–15	<10	-				

Source: (Indonesian Directorate General of Plantations, 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 <sub>2</sub> O	[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]
· · · · · · · · · · · · · · · · · · ·	The second second

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:

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

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:

$$LI = LC_{min} \sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}}$$
[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 Figure 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)

[8]

and nutrient availability (P availability). In addition, an elevation limiting factor was identified in LMUs 1 and 7.

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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, Figure 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 Liberica Coffee in Pinogu Plateau

	Eleva	tion	Slo	ре	р	Н	C-Or	ganic	CE	0	B	S	Ava	I-P		Are	а
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual 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	u)							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= P availability, m sl= meters sea level, ppm = part per million.

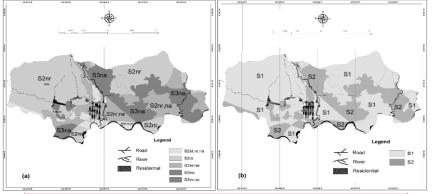


Figure 3. Actual (a) and Potential (b) of Land Suitability Class for Liberica Coffee in Pinogu Plateau

#### Table 3. Potential Land Suitability Classes for Liberica Coffee in Pinogu Plateau

LMU	Actual LSC	Lingiting To store	Efforts	Potential	Area	
LIVIU	ACTUALLSC	Limiting Factors	Ellorts	LSC	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)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	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.

Commented [h4]: Specify in remarks what are: S1. S2, S3, el, nr, na

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S1. S2, S3, el, nr, na

#### 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<sup>-1</sup> and the lowest for P availability with an average of 0.20 ton ha<sup>-1</sup>. 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 their **Recommendations on Land Management**

Comparison in Table 6 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 Liberica Coffee Productivity in Pinogu Plateau

	Eleva	ation	Slo	pe	рН Н	120	C-Org	ganic	CE	с	B	S	Ava	I-P	v		
LMU	Value (m sl)	Y (ton ha⁻¹)	Value (%)	Y (ton ha <sup>-1</sup> )	Value	Y (ton ha <sup>-1</sup> )	Value (%)	Y (ton ha <sup>-1</sup> )	Value (cmol)	Y (ton ha <sup>-1</sup> )	Value (%)	Y (ton ha <sup>-1</sup> )	Value (ppm)	Y (ton ha⁻¹)	(ton ha <sup>-1</sup> )	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, 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 Liberica Coffee

	Elev	ation	Slo	pe	pH	H2O	C-Or	ganic	C	EC	E	3S	Av	a-P			Area	
LMU	Y		Y		Y		Y		Y		Y		Y		Ц	LCS		
LIVIO	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	(ton	LC	LI	LUS	ha	%
	ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)		ha⁻¹)					
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
							1	otal (ha)									2.804,28	100

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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 Corganic 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 Liberica Coffee in Pinogu

	Land Suitabi	lity Class	Land S	uitability Class	Area		
LMU	Limiting Factor Method	Recommendation	Parametric Method	Recommendation	ha	%	
1, 7, 10	S2	11	S2	11	621.91	22.18	
2, 4, 5, 6, 9, 11, 12	S1	I	S2	II	1,867.46	66.59	
3, 13	S2	Ш	S1	1	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.

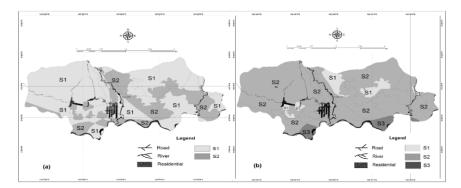


Figure 34. Comparison of Land Suitability Classes for Liberica Coffee in Pinogu Plateau obtained using Limiting Factor (a) and Parametric (b) Methods

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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<sup>-1</sup> to 0.61 ton ha<sup>-1</sup>, and that of Pinogu coffee currently reaches 0.75 ton ha<sup>-1</sup> (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 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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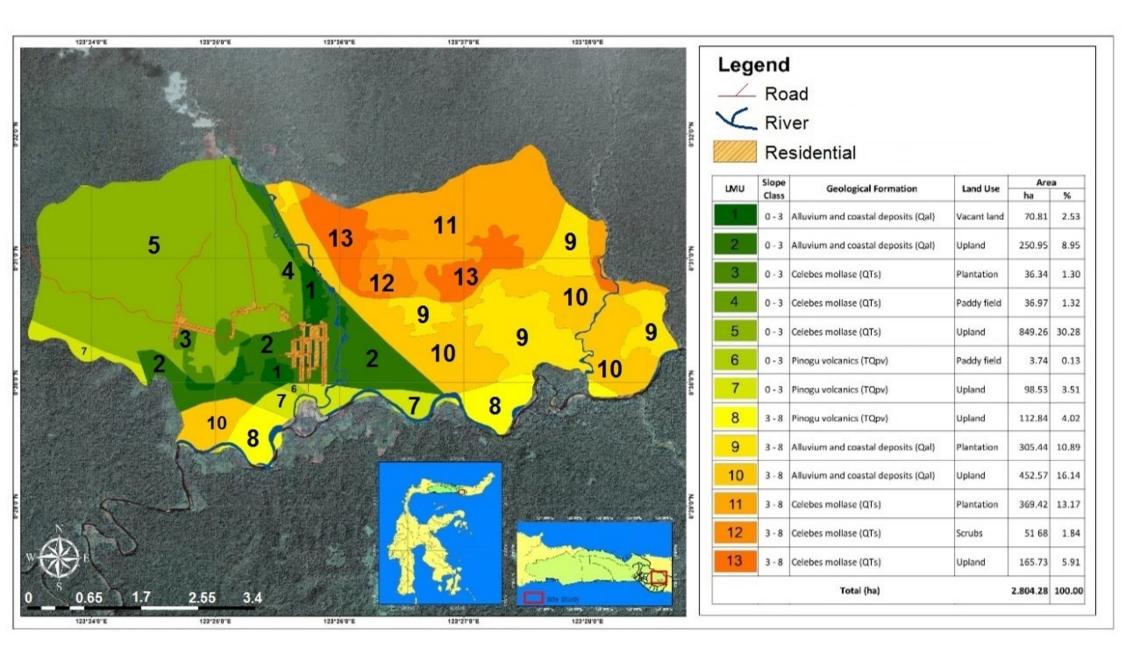
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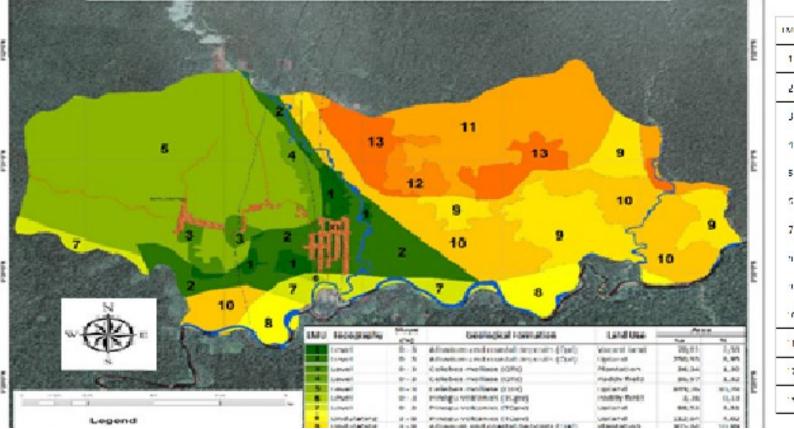
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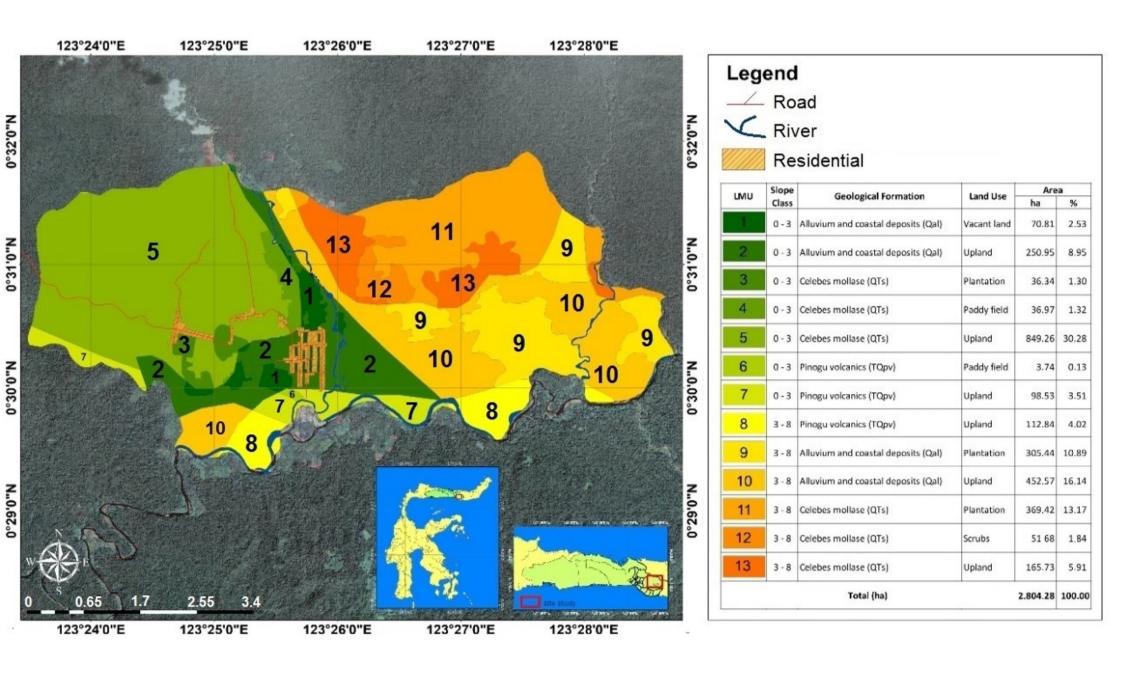
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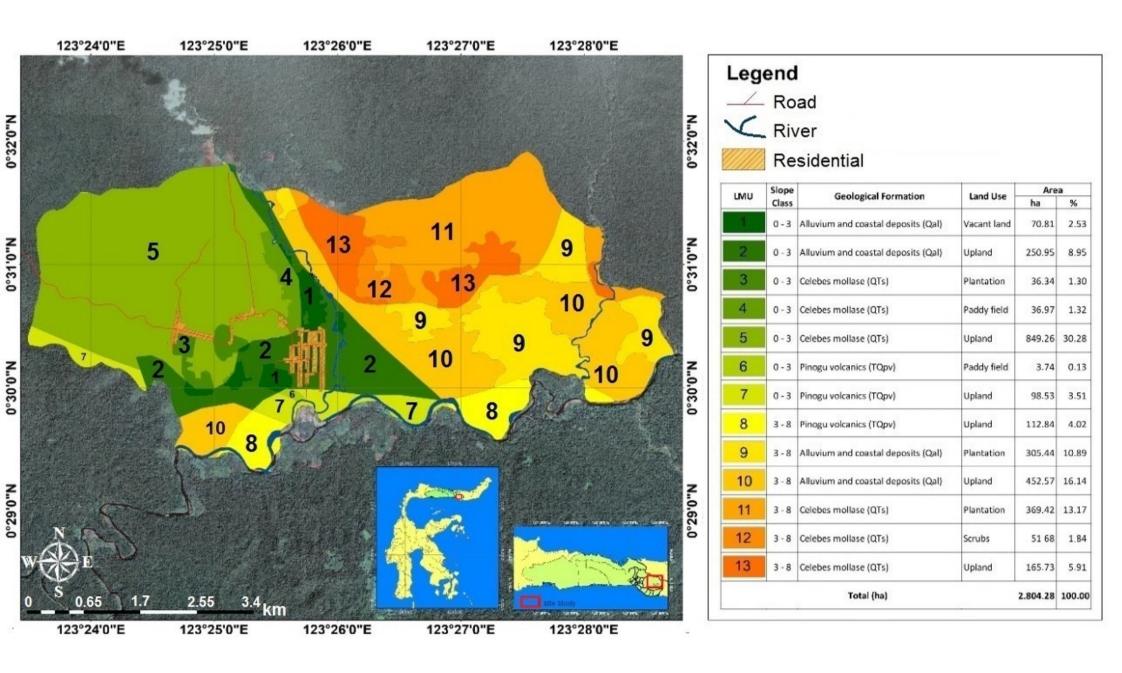
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Dear STJJSA Editor

After carefully reading our pre-published article with the title "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", we humbly I beg if you can correct some incorrect bibliography (bibliography attached), namely:

Written:

Gusfarina, D. S. (2014). Mengenal Kopi Liberika Tungkal Komposit (Libtukom). In: Balai Pengkajian eknologi Pertanian (BPTP) Jambi. Should:

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Hartati, T. M., Sunarminto, B. H., & Nurudin, M. (2018). Evaluasi Kesesuaian Lahan untuk Tanaman Perkebunan di Wilayah Galela, Kabupaten Halmahera Utara, Propinsi Maluku Utara., 33(1), 10. https://doi.org/10.20961/carakatani.v33i1.19298

Should:

Hartati, T. M., Sunarminto, B. H., & Nurudin, M. (2018). Evaluasi Kesesuaian Lahan untuk Tanaman Perkebunan di Wilayah Galela, Kabupaten Halmahera Utara, Provinsi Maluku Utara . Caraka Tani: Journal of Sustainable Agriculture, 33(1), 68-77 . https://doi.org/10.20961/carakatani.v33i1.19298 Written:

Sancayaningsih, R. P., Suryanto, E., Reza, A., & Wiryawan, I. F. (2016). Community Empowerment Program in Pinogu Subdistrict, Bone Bolango Regency, Gorontalo Province, Indonesia: Concerning The Unique Local Biodiversity Conservation. 2016, 1(2), 193 -193. https://doi.org/10.22146/jpkm.10604 Should:

Sancayaningsih, R. P., Suryanto, E., Reza, A., & Wiryawan, I. F. (2016). Community Empowerment Program in Pinogu Subdistrict, Bone Bolango Regency, Gorontalo Province, Indonesia: Concerning The Unique Local Biodiversity Conservation. Indonesian Journal of Community Engagement, 1(2), 183 -193. https://doi.org/10.22146/jpkm.10604

Nurdin <nurdin@ung.ac.id>

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Susilo, B., Fibrianto, K., Sunaryo, S., Ciptadi, G., Arwani, M., & Salsabila, A. N. (2021). Upaya Pengembangan Agroindustri Kopi Pinogu Melalui Introduksi Alat Pengolahan Kopi. 2021, 7(1), 1184-1192. Should: Susilo, B., Fibrianto, K., Sunaryo, S., Ciptadi, G., Arwani, M., & Salsabila, A. N. (2021). Upaya Pengembangan Agroindustri Kopi Pinogu Melalui Introduksi Alat Pengolahan Kopi. Journal Of Innovation And Applied Technology, 7(1), 1184-1192.

So, hopefully this fix can be completed Regards Nurdin-UNG [Kutipan teks disembunyikan]

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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

## Nurdin, Fauzan Zakaria, Mohammad A Azis, Yunnita Rahim, Rival Rahman, Mahmud Kasim

Department of Agrotechnology, Faculty of Agriculture, State University of Gorontalo, Gorontalo, Indonesia

ARTICLE INFO	ABSTRACT
Keywords:	Coffee is a national strategic commodity that contributes to Indonesia's foreign exchange,
Land suitability	but its productivity remains low due to cultivation on low potential land. This study aimed
Coffee	to determine the land suitability of endemic liberica coffee using two different methods
Liberica	and formulate recommendations for land management in Pinogu Plateau. Thirteen land
Endemic	units were surveyed, and soil samples were collected and analyzed in the laboratory to
Pinogu	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
Article history	actual LSCs for liberica coffee consisted of moderately suitable (S2) and marginally suitable
Submitted: 2021-11-12	(S3) classes. Efforts for improvement could increase the potential of LSC to become very
Accepted: 2022-02-18	suitable (S1) and S2 classes. Meanwhile, the assessment with the parametric method
Available online: 2022-05-20	indicated that the LSC consisted of S1, S2, and S3 classes. These results revealed that the
Published regularly: June 2022	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
* Corresponding Author Email address: nurdin@ung.ac.id	more dominant with the recommendation of adding P and organic fertilizer.

**How to Cite**: Nurdin, Zakaria, F., Azis, M.A., Rahim, Y., Rahman, R., Kasim, M. (2022). 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. Sains Tanah Journal of Soil Science and Agroclimatology, 19(1): 42-51. https://dx.doi.org/10.20961/stjssa.v19i1.56441

## **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<sup>2</sup>) 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<sup>-1</sup> year<sup>-1</sup>. By comparison, the productivity of liberica coffee can reach 1.69-1.98 ton ha<sup>-1</sup> (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.

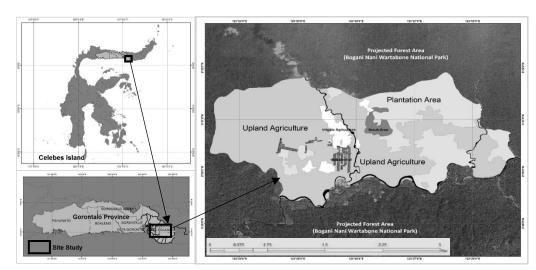


Figure 1. Research location map

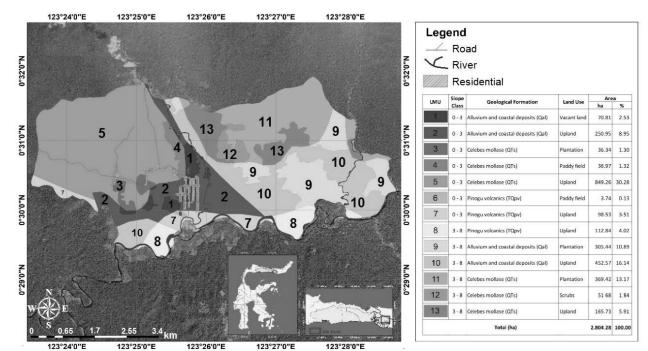


Figure 2. Land mapping unit

## 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<sub>2</sub>O) 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<sub>4</sub>OAc 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.

Land use requirements/	Currente e l	11	Land suitability class								
land characteristics	Symbol	Unit	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 <sub>2</sub> O 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	nr	cmol kg <sup>−1</sup>	>15	10–15	5–10	<5					
(NH₄.OAc pH 7 Extraction) Base saturation		U	>35	20–35	<20	-					
(NH <sub>4</sub> .OAc pH 7 Extraction)		%		20 00	-20						
Nutrient availability:	<b>n</b> 2										
P availability ( <i>Olsen</i> )	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 <sub>2</sub> O	[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:

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

where RMSE = root mean square error, At = actual productivity (ton ha<sup>-1</sup>), Ft = estimated productivity (ton ha<sup>-1</sup>), 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:

$$LI = LC_{min} \sqrt{\frac{A}{100} x \frac{B}{100} x \frac{C}{100} x \dots x \frac{N}{100}}$$
[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

	Eleva	Elevation		Slope		рН		ganic	CEO	0	B	S	Ava	a-P		Are	а
LMU	LC (m sl)	LSC	LC (%)	LSC	LC	LSC	LC (%)	LSC	LC (cmol)	LSC	LC (%)	LSC	LC (ppm)	LSC	Actual 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

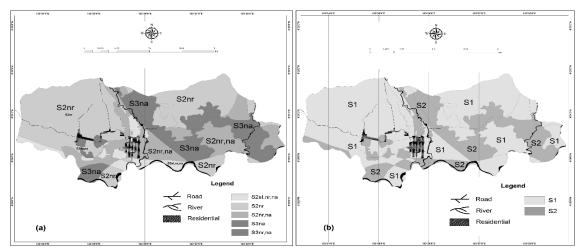


Figure 3. Actual (a) and potential (b) of land suitability class of *Coffea liberica* in Pinogu Plateau (Remarks: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, el = elevation, nr = nutrient retention, na = nutrient availability)

LMU	Actual LSC	Limiting Factors	Efforts	Potential	Area	
LIVIO	ACLUAI LSC	Limiting Factors	Ellorts	LSC	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)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	S1	593,36	8.95
3	S3nr,na	Nutrient retention (C-organic), nutrient availability (available of P)	<ul> <li>Addition of organic matter</li> <li>Addition of P fertilizer</li> </ul>	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

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

**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<sup>-1</sup> and the lowest for P availability with an average of 0.20 ton ha<sup>-1</sup>. 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 Ll. Hence, LMUs 3 and 13 obtained the highest Lis at 76 and 80, respectively. Meanwhile, LMU 8 had the lowest Ll 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. Esti	imated value of	of Coffea liberi	a productivit	y in Pinogu Plateau
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	Elevation		Slope		pH H2O		C-Organic		CE	С	BS		Ava-P		v		
LMU	Value (m sl)	Y (ton ha⁻¹)	Value (%)	Y (ton ha <sup>-1</sup> )	Value	Y (ton ha⁻¹)	Value (%)	Y (ton ha <sup>-1</sup> )	Value (cmol)	Y (ton ha⁻¹)	Value (%)	Y (ton ha⁻¹)	Value (ppm)	Y (ton ha⁻¹)	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

	Eleva	ation	Slo	pe	pН	H2O	C-Or	ganic	C	EC	E	3S	Av	a-P			Area	
LMU	Y		Y		Y		Y		Y		Y		Y		LI	LCS		
	(ton ha⁻¹)	LC	(ton ha⁻¹)	LC	(ton ha <sup>-1</sup> )	LC	(ton ha <sup>-1</sup> )	LC	(ton ha⁻¹)	LC	(ton ha⁻¹)	LC	(ton ha⁻¹)	LC			ha	%
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
							T	otal (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 Corganic content (Afandi et al., 2017; Siregar et al., 2017), and base saturation (Sembiring et al., 2015).

Table 6. Com	<b>Table 6</b> . Comparison of land suitability classes with limiting factors and parametric methods for <i>Coffea liberica</i> in Pinogu Plateau										
	Land Suitabi	lity Class	Land S	uitability Class	Area						
LMU	Limiting Factor Method	Recommendation	Parametric	Recommendation	ha	0/					

LMU		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	1	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

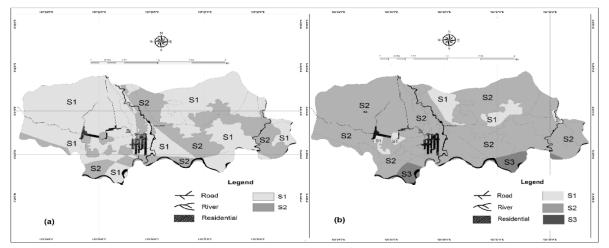


Figure 4. Comparison of land suitability classes for *Coffea liberica* in Pinogu Plateau obtained using limiting factor (a) and parametric methods (b) (Remarks: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable)

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<sup>-1</sup> to 0.61 ton ha<sup>-1</sup>, and that of Pinogu coffee currently reaches 0.75 ton ha<sup>-1</sup> (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 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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