SUBMISSION



22 Oktober 2022 pukul 23.50

Manuscript submitted to Applied and Environmental Soil Science

1 pesan

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Congratulations, the manuscript titled "Determination of Maize Hybrid Land Suitability Criteria Based on Optimum Yield and Selected Land Quality" has been successfully submitted to Applied and Environmental Soil Science.

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Cover Letter

22 October 2022

Dear Editor in Chief of Applied and Environmental Soil Science

We wish to submit an original research article entitled "Determination of Maize Hybrid Land Suitability Criteria Based on Optimum Yield and Selected Land Quality" for consideration by Applied and Environmental Soil Science.

We confirm that neither the manuscript nor any parts of its content are currently under consideration or published in another journal. All authors have approved the manuscript and agree with its submission to Applied and Environmental Soil Science.

In this paper, we report that land qualities that define the optimum yield of hybrid maize included root conditions, nutrient retention, nutrient availability, erosion hazard, and land preparation. Meanwhile, for land characteristics covered coarse material, effective soil depth, soil organic C, total N, exchangeable K, slopes, soil erosion, rock outcrops, and surface rocks. Combining PLS SEM and boundary line analysis was a better approach to developing new land suitability criteria for hybrid maize. This is significant because the land suitability criteria for existing maize fields are still general and there are no specific criteria for hybrid maize varieties. In addition, the selection of land quality and characteristics of the land used can use PLS SEM and the determination of range limits can use the boundary line method. Availability of land suitability criteria for specific varieties-based maize plants is urgently needed at this time as a basis for soil management and strategic efforts to increase maize productivity, so that food availability is maintained properly.

We believe that this manuscript is appropriate for publication by Applied and Environmental Soil Science because this manuscript is relevant to the aim and scope of the journal.

We have no conflicts of interest to disclose.

Please address all correspondence concerning this manuscript to me at <u>nurdin@ung.ac.id</u>.

Thank you for your consideration of this manuscript.

Sincerely,

Dr. Nurdin

1 Determination of Maize Hybrid Land Suitability Criteria Based

2 on Optimum Yield and Selected Land Quality

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12 Abstract

13 The significant effect of land quality on maize production has not been fully considered in the existing land suitability criteria. Therefore, this study aims to determine the hybrid maize land 14 15 suitability criteria based on the optimum yield and land quality. It was carried out in Boalemo 16 Regency, Indonesia, where a total of 67 land units were surveyed to obtain land characteristics data. A partial least square of structural equation model (PLS-SEM) with SmartPLS 8.0 was 17 18 used to select a robust land quality controlling hybrid maize yield, while the boundary line 19 method was used to determine optimum yield and differentiating of land suitability criteria. 20 The result showed that land qualities that define the optimum yield of hybrid maize were root 21 conditions, nutrient retention and availability, erosion hazard, and land preparation. The soil 22 characteristics were coarse material, effective depth, organic C, total N, exchangeable K, 23 slopes, erosion, rock outcrops, and surface rocks. Furthermore, the highest optimum yield of 24 8.35 ton/ha was achieved by the effective depth and organic C content for a very suitable class 25 (S1), while the lowest of 5.47 ton/ha was obtained by exchangeable K for class S1. This showed 26 that the combination of PLS-SEM and boundary line analysis was a better approach to 27 developing new land suitability criteria for hybrid maize.

28 **1. Introduction**

- Food security and farmer prosperity are global concerns, this makes every country increase crop production as well as farmers' income. An important issue for countries with developing economies is ensuring food security, where the agricultural sector plays a strategic role in increasing food availability [1]. Although the global food system has placed maize (*Zea mays* L.) as the leading cereal crop [2], its productivity is being disrupted by land degradation, water
- 34 scarcity, and climate change [3].
- In Indonesia, the wet tropical climate with rainfall and high temperatures tends to reduce the quality of land and agricultural products [4]. This country ranked 8th among the maizeproducing nations with a contribution of 2.19% and 2.42% of the world's total harvested area [5]. However, the main problem is the relatively low level of yield in several regions because the achievement of maize production has not been followed by an increase in yield per unit area [6]. This is indicated by the average yield in 2020, which was up to 5.57 ton/ha [5].

- 41 According to a previous investigation, maize production in Indonesia can reach between 10-12
- 42 ton/ha [7], [8] thereby making the country the 21st leading importer in the world.

43 Maize is usually grown on land with low yield potential [9] and soil fertility, thereby causing low productivity [10]. Moreover, land productivity is determined by quality and characteristics 44 [11], [12], while land quality has a close relationship with maize yields [13]. The land quality 45 46 affecting the optimum yield of maize needs to be determined [14] and increased by using hybrid 47 varieties that have high yields. This makes it necessary to evaluate the suitability of the hybrid 48 maize in a region to ensure optimal production. The land suitability criteria for hybrid maize 49 are not yet available because the current criterion is the general suitability of maize plants without distinguishing between hybrids and inbreds. Therefore, there is a need to make land 50 51 suitability criteria for hybrid maize plants.

52 A previous study has shown that land quality has a significant effect on suitability for certain 53 uses [15]. Meanwhile, land suitability is also important due to the continuous increase in the 54 demand for agricultural land [16]. The land suitability criteria for existing maize fields are still 55 general [17] and there are no specific criteria for hybrid maize varieties. The class assessment 56 outcomes obtained using the existing criteria are relatively many and are not in line with the 57 actual field results [18]. The current criteria consist of 3 components, namely, land quality, characteristics, and ranges of land characteristic values to determine its suitability. Therefore, 58 59 the problem in developing criteria is choosing land quality, characteristics, and determining the 60 range of land characteristic values associated with suitability classes, namely suitable, 61 somewhat suitable, marginally suitable, and not suitable.

62 The selection of land quality and characteristics can be carried out through the partial least 63 square of the structural equation model (PLS-SEM), while the range limits is being determined 64 by the boundary line method. Land qualities and characteristics in the current criteria can be 65 used temporarily since structural equation model analysis with partial least squares produces better indicators and models than other multivariate analyses [19]-[23]. This is because the 66 67 variant-based PLS-SEM has a higher level of flexibility and the size of the sample used is relatively small ranging from 30 to 100 [24]-[27]. The use of PLS-SEM to determine land 68 69 characteristics and qualities that control maize crop yields is still relatively rare, except for Syaf 70 [28] on older cocoa plants, maize composite [29], and on local varieties [6]. The boundary line 71 method can help determine nutrient adequacy concentrations and the optimum yield range of 72 a plant that affects nutrients, as well as other land characteristics [30], [31]. Currently, the land 73 suitability criteria for maize plants have not been determined using the boundary line method, 74 except by Ridayanti et al. [32], although the investigation was not specific to hybrid maize.

After obtaining the quality and characteristics of land affecting maize yields with PLS-SEM, the boundary line method can be used to determine the optimum yield as well as land suitability criteria simultaneously. This is carried out by drawing the intersection of the boundary line at the yield and projecting with the land characteristics [17]. Therefore, this study aims to determine land suitability criteria for hybrid maize based on the optimum yield and land quality.

81 **2. Materials and Methods**

82 2.1 Study area

- The study area extends from 0°28'5.6" 0°57'30.02" N to 122°08'34.25" 122°43'10.41"E 83
- (Figure 1), which is located in the agricultural land of Boalemo Regency, Gorontalo Province, 84 Indonesia. The maximum air temperature was 28.19°C and the minimum was 26.79°C with an 85
- average of 28.01°C. Meanwhile, the maximum rainfall was 1,849 mm and the minimum was
- 86 1,246 mm with an average of 1,478 mm. The wet and dry seasons last for 3 months and 5 87
- months respectively. The soil mapping carried out by Ritung et al. [33], consists of 35 soil 88
- 89 units, where each unit has information on land characteristics, namely effective depth,
- 90 drainage, texture, pH, cation exchange capacity, base saturation, landform, parent material,
- 91 relief, and land unit area.

l	Slopes (%)	Land Use	Relief	Soil Types	Elevation (m asl)	Area (Ha)
1	8 - 15	Plantation	Hilly	Typic Haplustalfs	0 - 100	5615.40
2	> 45	Scrub	Mountainous	Fluventic Ustropepts	0 - 100	286.81
3	> 45	Scrub	Mountainous	Typic Haplustalfs	250 - 500	943.88
4	>45	Upland	Mountainous	Fluventic Ustropepts	250 - 500	354.01
5	0-3	Plantation	Flat	Pluventic Haplustepts		4024.22
6	0-3	Upland	Flat	Pluventic Haplustepts		3052.60
7	0-3	Upland	Flat	Typic Argiustolls	0 - 100	1073.14
8	0-3	Upland	Flat	Typic Tropaquepts	100 - 250	65.04
9	15-30	Plantation	Hilly	Fluventic Ustropepts	250 - 500	575.02
10	15-30	Scrub	Hilly	Typic Argiustolls	100 - 250	1813.67
11	15-30	Scrub	Hilly	Typic Haplustalfs	0-100	605.20
12	15-30	Upland	Hilly	Fluventic Ustropepts	100 - 250	804.83
12	15 - 30				250 - 500	705.51
		Upland	Hilly	Pluventic Haplustepts		2530.37
14 15	15-30	Upland	Hilly Hilly	Typic Argiustolls	250 - 500	423.49
15	15 - 30	Upland		Typic Haplustalfs	0 - 100	
	15 - 30	Upland	Hilly	Typic Haplustalfs	250 - 500	5118.25
17	15 - 30	Upland	Hilly	Typic Haplusteps	100 - 250	28.16
18	15 - 30	Upland	Hilly	Typic Tropaquepts	0 - 100	89.21
19	3-8	Plantation	Wavy	Pluventic Haplustepts		6060.03
20	3-8	Plantation	Wavy	Typic Argiustolls	100 - 250	151.63
21	3-8	Scrub	Wavy	Typic Haplustalfs	250 - 500	1266.07
22	3-8	Upland	Wavy	Pluventic Haplustepts		4863.96
23	3-8	Upland	Wavy	Typic Argiustolls	0 - 100	3530.19
24	3-8	Upland	Wavy	Typic Dystrudepts	0 - 100	403.97
25	3-8	Upland	Wavy	Typic Haplustalfs	250 - 500	413.33
26	30 - 45	Plantation	Mountainous	Typic Haplustalfs	100 - 250	60.16
27	30 - 45	Scrub	Mountainous	Typic Haplustalfs	100 - 250	690.28
28	30 - 45	Upland	Mountainous	Typic Haplustalfs	0 - 100	282.93
29	30 - 45	Upland	Mountainous	Typic Haplustalfs	100 - 250	4773.13
30	8 - 15	Upland	Hilly	Typic Argiustolls	0 - 100	9581.79
31	8-15	Upland	Hilly	Typic Haplustalfs	250 - 500	254.52
32	8-15	Upland	Hilly	Typic Haplusteps	250 - 500	79.96
01	0 40	opraria	Total	Typie naprasteps	200 000	60520.76
Signa	I mapping unit	A.			523	1
			Sala Salar and	and and		

92 93

Figure 1: Study area.

94 2.2 Dataset collection for land quality and land characteristics

95 The framework of this study is presented in Figure 2. The previous soil map [33] was used as a working map, where information on land characteristics, namely soil, climate, and terrain, 96 97 was extracted. It was updated by taking 32 pedons, thereby becoming 67 pedons representing 98 soil diversity in each location. For each observation location, the climatic data of land and 99 terrain characteristics were observed and the previous data were updated. The soil samples according to horizon boundaries were taken for analysis in the laboratory. 100



$\begin{array}{c} 101 \\ 102 \end{array}$

Figure 2: Research framework.

103 Soil samples were dried for 3 days and sieved through a 2 mesh sieve. The method of laboratory 104 analysis was carried out according to the procedures by Eviyati and Sulaeman [34]. The soil pH was determined with a pH meter in a 1:2.5 soil and water solution, while the organic C 105 content was assessed using the Walkley and Black method. The available P content was 106 107 measured using the Olsen method, while the cation exchange capacity (CEC) was extracted 108 with 1N NH4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, and the base 109 saturation was determined by calculation. Subsequently, the data from the chemical analysis were averaged to a depth of 0-30 cm using the weighted averaging technique. 110

111 **2.3 Dataset collection for hybrid maize yield**

112 The areas currently planted with hybrid maize were identified and blocks with a size of 2.5 m

113 x 2.5 m were made in each map unit. Maize plants in each block passed through standardized

114 management according to farmers' technology. After harvesting, weighting was carried out to

obtain hybrid maize yield data from the results of tiles on each land unit. Subsequently, the results were calculated using the formula as expressed below:

116 results were calculated using the formula, as expressed below:
117
$$Y(t) = H x \frac{A}{6.25 m^2}$$
(1)

118 Meanwhile, productivity is calculated using the formula below:

119
$$Y(t ha^{-1}) = \frac{H x \, 1.64 \, x \, 56.73}{100}$$
 (2)

120 where Y = hybrid maize yield, H = tile yield (kg), A = maize area 1 per hectare (ha), 1.64 121 and 56.73 = constant.

122 **2.4 Selection of land quality and land characteristics**

The quality and characteristics of the land in the suitability criteria were used as presented in 123 Tables 1 and 2, which show brief statistics. Generally, most data are relatively homogenous, 124 except for coarse material, available P, slopes, soil erosion, height and inundation, as well as 125 126 rock outcrops and surface rocks. The selection used the partial least squares of the structural equation model (PLS-SEM) with tools SmartPLS, where land quality and characteristics were 127 128 selected as the latent and manifest variables, respectively. The analysis in PLS-SEM has 2 main 129 steps, namely (1) the measurement model (outer model) and (2) the structural model test (inner 130 model).

]	Latent variables		Indicators
Notation	Land quality	Notation	Land characteristics
X1	Temperature (t)	X1.1	Temperature
X2	Water availability (wa)	X2.1	Rainfall
	• 、 •	X2.2	Wet month
		X2.3	Dry month
		X2.4	Long growth period (LGP)
X3	Oxygen availability (oa)	X3.1	Drainage
X4	Rooting condition (rc)	X4.1	Texture
		X4.1.1	Sand fraction
		X4.1.2	Silt fraction
		X4.1.3	Clay
		X4.2	Coarse material
		X4.3	Effective depth
X5	Nutrient retention (nr)	X5.1	pH H ₂ O
		X5.2	pH KCl
		X5.3	Organic C
		X5.4	Cation exchange capacity (CEC)
		X5.5	Base saturation
X6	Nutrient availability (na)	X6.1	Total N
		X6.2	P availability
		X6.3	K exchangeable
X7	Sodicity (xn)	X7.1	Exchangeable sodium percentage
			(ESP)
X8	Erosion hazard (eh)	X8.1	Slopes
		X8.2	Soil erosion
X9	Flooding hazard (fh)	X9.1	Inundation height
		X9.2	Inundation period
X10	Land preparation (lp)	X10.1	Rock outcrops
		X10.2	Surface rock
Y	Hybrid maize yield	Y.1	Hybrid maize yield

131

Table 1: Latent variables and indicators used in this study

132

(3)

(4)

Step 1 consists of validity and reliability tests, wherein the validity test is conducted with convergent and discriminant validity. The convergent validity is in form of outer loadings (loading factor) and average variance extracted (AVE), while discriminant validity is in form of cross-loading and the Fornell-Larcker criterion. Meanwhile, the reliability test uses composite reliability and Cronbach's alpha.

139 Convergent validity was observed from the magnitude of the outer loading and the AVE

140 value of each indicator on the latent variable. The validity was calculated according to the 141 equation:

142
$$x_i = \lambda x_i \xi_I + \delta_i$$

143
$$y_i = \lambda y_i \eta_1 + \varepsilon_i$$

144 where x and y = exogenous (ξ) and endogenous (η) latent variable indicator, λx and $\lambda y =$ 145 loading factors, δ and ε = residual/measurement errors or noise.

Table 2: Brief statistics of land quality and characteristics.

Latent variables / Indicators	Unit	n	Min	Median	Mean	Max	SD
X1 (Temperature)							
X1.1 (Temperature)	°C	67	26.79	27.80	28.01	28.19	0.6
X2 (Water availability)							
X2.1 (Rainfall)	mm	67	1,246.00	1,533.42	1,478.00	1,849.00	232.6
X2.2 (Wet month)	month	67	0.00	1.03	1.00	3.00	0.8
X2.3 (Dry month)	month	67	2.00	3.39	4.00	5.00	1.0
X2.4 (LGP)	day	67	211.00	246.00	214.00	304.00	44.5
X3 (Oxygen availability)	-						
X3.1 (Drainage)	class	67	0.00	3.76	4.00	6.00	1.8
X4 (Rooting conditions)							
X4.1 (texture)	class	67	1.00	2.21	2.00	5.00	0.9
X4.1.1 (Sand fraction)	%	67	5.00	41.58	43.00	81.33	18.5
X4.1.2 (Silt fraction)	%	67	7.33	27.31	24.50	51.50	11.5
X4.1.3 (Clay)	%	67	11.33	31.90	30.00	56.33	12.7
X4.2 (Coarse material)	%	67	5.00	17.27	10.00	70.00	16.5
X4.3 (Effective depth)	cm	67	10.00	74.55	74.00	160.00	36.4
X5 (Nutrient retention)							
X5.1 (pH H ₂ O)		67	5.00	5.92	5.90	7.15	0.5
X5.2 (pH KCl)		67	4.35	5.24	5.17	6.60	0.5
X5.3 (Organic C)	%	67	0.41	0.85	0.77	2.35	0.3
X5.4 (CEC)	cmol(+)/kg	67	8.94	24.89	22.43	59.57	11.4
X5.5 (Base saturation)	%	67	45.03	56.22	52.85	81.89	9.7
X6 (Nutrient availability)							
X6.1 (Total N)	%	67	0.04	0.09	0.08	0.27	0.0
X6.2 (P availability)	mg/kg	67	0.73	8.62	3.77	58.67	12.6
X6.3 (K exchangeable)	cmol(+)/kg	67	0.07	0.39	0.24	1.92	0.4
X7 (Sodicity)	_						
X7.1 (ESP)	%	67	0.76	7.06	6.20	24.17	5.6
X8 (Erosion hazard)							
X8.1 (Slopes)	%	67	1.00	9.58	6.00	25.00	7.2
X8.2 (Soil erosion)	ton/ha/year	67	3.66	334.51	110.27	1772.43	439.0

X9 (Flooding hazard)							
X9.1 (Inundation height)	cm	67	0.00	7.58	0.00	50.00	17.10
X9.2 (Inundation period)	day	67	0.00	0.64	0.00	5.00	1.52
X10 (Land preparation)							
X10.1 (Rock outcrops)	%	67	0.00	6.64	0.00	45.00	11.56
X10.2 (Surface rock)	%	67	0.00	6.58	0.00	45.00	11.59
Y (Hybrid maize yield)	ton/ha	67	2.85	4.95	4.68	8.07	1.15

147

n = the number of the land unit, min = minimum, max is maximum, SD = standard deviations, LGP = long growth 148 periods, CEC = cation exchange capacity, and ESP = exchangeable sodium percentage.

149 Meanwhile, the average variance extracted (AVE) value was calculated using the equation:

150
$$AVE = \frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i \, var(\varepsilon_i)}$$
 (5)

Where λ_i^2 = the loading factor, var = the variance, and ε_i = the error variance. 151

152 The loading factor of an indicator with the highest value is the strongest or most important 153 measure in reflecting the latent variable. In this study, the loading factor value is > 0.70 for selecting best land characteristics, but values ranging from 0.50-0.60 can still be tolerated with 154 155 a t-statistic > 1.96 or a small p-value of 0.05 [25], [35]. Meanwhile, the AVE value used was more than 0.50, showing that the convergent validity on the latent variable has been reached. 156

157 The discriminant validity test used the cross-loading value and the Fornell-Larker criterion to 158 test discriminantly valid indicators in explaining or reflecting latent variables. When the correlation between the latent variables and the core measurement of each indicator is high, the 159 160 latent variable can predict the indicator better and is considered valid. The discriminant validity 161 is measured by the square root of the average variance extracted, which will be compared with 162 the correlation value between variables. The value calculated based on the square root of AVE must be higher than the correlation between constructs [36]. The equation is expressed below 163

164 Square Root of AVE =
$$\sqrt{\frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i \, var(\varepsilon_i)}}$$
 (6)

165 where λ^2_i = the loading factor, var = the variance, and ε_i = the error variance.

Furthermore, the composite reliability and Cronbach's alpha were used to test the reliability 166 value between indicators of the latent variables. They are considered good and accepted when 167 the value is > 0.70 and has a minimum value of 0.60 [25]. The composite reliability value is 168 calculated using the equation: 169

170
$$\rho c = \frac{(\Sigma \lambda_i)^2}{(\Sigma \lambda_i)^2 + \Sigma i \, var(\varepsilon_i)}$$
(7)

171 where λ_i = the loading factor, var = the variance, and ε_i = the error variance.

Meanwhile, the value of Cronbach's Alpha is calculated according to the equation: 172

173
$$\alpha = \left(\frac{\sum p \neq p'^{cor(X_{pq}, X_{p'q})}}{p_{q+\sum p \neq p'}^{cor(X_{pq}, X_{p'q})}}\right) \left(\frac{p_q}{p_{q-1}}\right)$$
(8)

174 where P_q = the number of indicators or manifest variables, and q = the indicator block.

For step 2, the structural model testing (inner model) was carried out after the relationship model was built in line with the observed data and the overall suitability, namely goodness of fit. The structural equation (inner model) is as follows:

178
$$H_j = \gamma_j \xi_1 + \gamma_j \xi_2 + \dots + \gamma_j \xi_n + \zeta_j$$
(9)

179 where η_j = endogenous variable vector (dependent), $\gamma_j \xi_1 + \gamma_j \xi_2 + \dots + \gamma_j \xi_n$ = exogenous latent 180 variable vector, and ς_j = residual vector (error).

181 Meanwhile, the determinant coefficient and goodness of fit (Q^2) were calculated using the 182 equation:

183
$$Q^2$$
 (Predictive relevance) = 1 - (1 - R_1^2) (1 - R_2^2) ... (1 - R_p^2) (10)

184 where R_1^2 , R_2^2 , ... $R_p^2 = R$ square of endogenous variables in the equation model.

185 The quantity of Q^2 has a value with a range of 0 < Q2 < 1, the closer the value to 1, the better 186 the model [25]. It is also equivalent to the coefficient of total determination in path analysis. 187 Furthermore, the effect and significance were tested based on the estimated value of the path 188 coefficient and the critical point value (t-statistics or p-value) at = 0.05. The relationship model 189 between variables was measured by testing the direct correlation coefficient between variables. 190 The results of testing the relationship between X and Y variables were indicated by the 191 correlation coefficient as well as t-statistics, and are also presented in the path diagram.

192 **2.5 Class assignment**

To determine the class-required data for optimum results, class limits were calculated from the percentage of optimum results. After knowing the highest and lowest yields, the values were connected with the range of land characteristics values. The land suitability class and yield used referred to FAO [37], namely class S1 (very suitable) when the values reach 80-100%, S2 was moderately suitable 60-80%, S3 marginally suitable 40-60%, and N not suitable <40% of the optimum capacity.

199 The optimum yield was determined using the boundary line method. This method is carried 200 out by drawing a boundary line on the graph of the relationship between yield and land 201 characteristics to obtain optimum results. In the boundary line method according to 202 Widiatmaka et al. [38], each land characteristic is plotted on the X-axis, while hybrid maize 203 yields are plotted on the Y-axis. Bhat and Sujatha [30] stated that the preparation of the hybrid 204 maize yield boundary line includes the preparation of a scatter diagram between the X and the 205 Y variable, (2) division of the X-axis into several classes of intervals, (3) determination of the highest data points in each class interval, (4) preparation of boundary lines based on the highest 206 data points from each class interval, (5) draw a line parallel to the X-axis according to the 207 208 percentage of the result class.

209 Furthermore, with the Microsoft Excel application tools, the boundary between classes S1 to

- 210 S2, S2 to S3, and S3 to N were determined by the Data menu \rightarrow What-if-Analysis \rightarrow Goal
- 211 Seek \rightarrow Set the cell at the location containing the regression equation \rightarrow to value fill with the 212 result limit values S1 to S2, S2 to S3, and S3 to N \rightarrow By changing cell \rightarrow the location where

- 213 the value of the characteristics of the land will be sought \rightarrow Ok. On location "By changing
- cell", the number being searched will appear, and at the location "set cell" will be equal to the
- 215 limit value of the result.

216 **3. Results and Discussion**

217 **3.1 Land quality and characteristics controlling hybrid maize yield**

218 *3.1.1 Validity test result*

233

219 Table 3 shows the loading factor of the variables, where most indicators were more than the 220 critical limit of 0.70 with a 95% confidence level (P > 1.960). Therefore, these variables are 221 highly recommended and the indicators are considered convergently valid. In the soil texture 222 indicator for the latent variable of root conditions as well as the cation exchange capacity (CEC) 223 and base saturation (BS) indicators for nutrient retention, the loading factor was below the 224 tolerance value of 0.50 at the 95% confidence level (P < 1.960), hence, it was not used. This 225 implies that the indicators have not been established or explained properly because the standard 226 value of the loading factor must be greater than or equal to 0.50 [26].

The average variance extracted (AVE) value of almost all variables was greater than 0.50, therefore, it was considered convergently valid [36]. The AVE value of the available nutrient variable was not valid due to the smaller value of the loading factor for the CEC and BS indicators of 0.50, leading to the removal of both indicators. A similar result was discovered in the root condition variable, although the AVE value was greater than 0.50, while the soil texture indicator was not used because the loading factor value is only 0.013.

Indicators)	Latent Variables	Loading	t-Stat	Status	AVE	
(land characteristic		(land quality)	Factors				
X1.1 (Temperature)	\rightarrow	X1 (Temperature)	1.000**	11.192	Valid	1.000	
X2.1 (Rainfall)	\rightarrow		0.838	0.085	Valid		
X2.2 (Wet month)	\rightarrow	V2 (Watan availability)	0.989	0.999	Valid	0.006	
X2.3 (Dry month)	\rightarrow	X2 (Water availability)	0.850	0.428	Valid	0.906	
X2.4 (LGP)	\rightarrow		0.993*	1.431	Valid		
X3.1 (Drainage)	\rightarrow	X3 (Oxygen availability)	1.000	0.000	Valid	1.000	
X4.1 (Texture)	\rightarrow		0.013	0.066	Invalid		
X4.2 (Coarse material)	\rightarrow	X4 (Rooting condition)	0.921	1.086	Valid	0.573	
X4.3 (Effective depth)	\rightarrow		-0.899	1.047	Valid		
X5.1 (pH H ₂ O)	\rightarrow		0.647	0.857	Valid		
X5.2 (pH KCl)	\rightarrow		0.570**	1.973	Valid		
X5.3 (Organic C)	\rightarrow	V5 (Nutriant notantian)	0.831**	3.135	Valid	0.360	
X5.4 (CEC)	\rightarrow	X5 (Nutrient retention)	0.436*	1.381	Invalid	(invalid)	
X5.5 (Base saturation)	\rightarrow		0.365	0.845	Invalid		
X6.1 (Total N)	\rightarrow		0.760**	3.226	Valid	0.585	

Table 3: Outer loading (loading factor) and the average variance extracted from study variables.

X6.2 (P availability)	\rightarrow	X6 (Nutrient	0.587*	1.385	Valid	
X6.3 (K exchangeable)	\rightarrow	availability)	0.897**	6.907	Valid	
X7.1 (ESP)	\rightarrow	X7 (Sodicity)	1.000	0.000	Valid	1.000
X8.1 (Slopes)	\rightarrow	VQ (Encion harond)	0.954**	21.438	Valid	0.932
X8.2 (Soil erosion)	\rightarrow	X8 (Erosion hazard)	0.941**	18.308	Valid	0.932
X9.1 (Inundation	\rightarrow		0.984**	4.213	Valid	
height)		X9 (Flooding hazard)	0.964	4.215	vanu	0.984
X9.2 (Inundation period)	\rightarrow	X9 (Probuling hazard)	0.985**	3.918	Valid	0.964
X10.1 (Rock outcrops)	\rightarrow	X10 (Land	0.998**	189.133	Valid	0.995
X10.2 (Surface rock)	\rightarrow	preparation)	0.998**	320.273	Valid	

AVE = average variance extracted, LGP = long growth periods, CEC = cation exchange capacity, and ESP =
 exchangeable sodium percentage.

The measurement of the Fornell-Larcker criterion and cross-loading was used as the basis for assessing the discriminant validity of the model. The calculation results on the Fornell-Larcker criterion in Table 4 show that the average of the tested variables has a higher square root of AVE than the correlation value, hence, the latent variable was considered discriminantly valid. The square root value of the AVE must be greater than its correlation value with other constructs to meet the discriminant validity requirements [39]. The average loading factor value for the latent variable indicator was above that of others as shown in Table 5.

243 *3.1.2 Reliability test result*

The variables are considered reliable because composite reliability and Cronbach's alpha coefficient on average were more than 0.7 as shown in Table 6 [36], [40]. However, certain indicators still had values less than 0.6, namely soil texture but the indicators used are reliable and adequate in forming the latent variables.

The highest composite reliability and cronbach's alpha coefficients were obtained for the variables of temperature, oxygen availability, and toxicity of 1 for the variables to be very reliable. The lowest coefficient was obtained on the root condition variable, therefore, the variable was not reliable. According to Bagozzi and Yi [41] and Hair et al. [40], variables are considered good and accepted when the value is > 0.70.

The remaining variables are water availability, nutrient retention, available nutrients, erosion hazard, and land preparation variables. The coefficient of composite reliability and cronbach's alpha > 0.6, there, the variable is considered reliable. The minimum value of composite reliability and cronbach's alpha coefficients was 0.60 [36], [40], [41].

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Table 4: Fornell-Larker criterion test

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Y		
X1	1.000												
X2	0.940	0.952											
X3	0.059	0.149	1.000										
X4	0.082	0.030	-0.162	0.757									
X5	-0.360	-0.239	-0.103	-0.368	0.600								
X6	-0.069	0.021	0.012	-0.518	0.694	0.765							
X7	0.382	0.429	0.084	0.228	-0.030	-0.217	1.000						
X8	0.019	-0.082	-0.501	0.285	-0.317	-0.370	-0.009	0.966					
X9	-0.104	-0.033	0.237	-0.204	0.073	0.090	0.202	-0.250	0.992				
X10	0.198	0.093	-0.223	0.873	-0.303	-0.538	0.362	0.304	-0.126	0.998			
Y	0.018	0.152	0.169	-0.578	0.387	0.456	-0.016	-0.517	0.164	-0.568	1.000		

X1 = temperature, X2 = water availability, X3 = oxygen availability, X4 = rooting condition, X5 = nutrient retention, X6 = nutrient availability, X7 = sodicity, X8 = erosion hazard, X9 = flooding hazard, X10 = land preparation, Y = maize hybrid yield.

	Table 5: Cross-Loading of latent variables to indicators											
Indicators					Lat	ent Variab	les					
Indicators	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Y	
X1.1	1	0.8300	0.0312	0.0240	-0.2959	-0.0592	0.3270	0.0195	-0.0837	0.1680	-0.0204	
X2.1	0.9783	0.8379	-0.0035	-0.0063	-0.2488	-0.0320	0.3555	-0.0017	-0.0539	0.1552	0.0155	
X2.2	0.8534	0.9887	0.1938	-0.0557	-0.1257	0.0988	0.4025	-0.1435	-0.0279	-0.0178	0.1748	
X2.3	0.5223	0.8497	0.1523	0.2464	-0.2505	-0.1161	0.4641	-0.1494	0.0144	0.2154	0.0592	
X2.4	0.8293	0.9928	0.1721	-0.0334	-0.1524	0.0833	0.4440	-0.1713	-0.0383	-0.0031	0.1331	
X3.1	0.0312	0.1785	1	-0.1541	-0.1091	-0.0375	0.0843	-0.4964	0.2530	-0.2229	0.2156	
X4.1	-0.0058	-0.0006	-0.1696	0.0126	0.2127	0.1013	0.2173	0.1761	0.0055	-0.0225	0.0050	
X4.2	-0.0728	-0.1082	-0.0829	0.9212	-0.2754	-0.5494	0.1845	0.2891	-0.2674	0.7910	-0.5276	
X4.3	-0.1289	-0.1240	0.2071	-0.8990	0.2046	0.3209	-0.2633	-0.1587	0.0730	-0.7693	0.4666	
X5.1	-0.2975	-0.4140	-0.3824	-0.3027	0.6470	0.3024	-0.1283	0.1730	-0.0342	-0.1190	0.0718	
X5.2	-0.2033	-0.2939	-0.4480	-0.2791	0.5701	0.3176	-0.0273	0.1935	0.0801	-0.1829	0.1445	
X5.3	-0.2440	-0.0158	0.1276	-0.1134	0.8308	0.5651	0.0728	-0.5076	0.0545	-0.1147	0.3501	
X5.4	0.0537	0.1002	0.0033	0.0110	0.4360	0.4081	0.3732	-0.0504	0.1426	-0.0137	0.1395	
X5.5	-0.2717	-0.2512	-0.1053	-0.4382	0.3650	0.4343	-0.6008	-0.0619	-0.1498	-0.4876	0.0825	
X6.1	-0.0256	0.1778	0.0335	-0.1950	0.7028	0.7604	0.0453	-0.3878	-0.0809	-0.2162	0.2623	
X6.2	-0.1201	-0.2238	-0.4256	-0.2590	0.4149	0.5865	-0.2829	-0.0389	-0.0267	-0.2860	0.1025	
X6.3	-0.0437	0.0283	0.0310	-0.5607	0.5145	0.8974	-0.3341	-0.2613	0.2133	-0.6520	0.3892	
X7.1	0.3270	0.4411	0.0843	0.2420	0.0290	-0.2417	1	-0.0286	0.2142	0.3621	0.0487	
X8.1	-0.0226	-0.2234	-0.5132	0.2998	-0.2625	-0.3475	-0.0481	0.9537	-0.3383	0.3031	-0.5274	
X8.2	0.0649	-0.0590	-0.4223	0.1646	-0.2942	-0.2950	-0.0035	0.9409	-0.0988	0.2516	-0.4682	
X9.1	-0.0996	-0.0225	0.2254	-0.1949	0.1126	0.1483	0.1939	-0.2440	0.9835	-0.1342	0.2278	
X9.2	-0.0658	-0.0305	0.2717	-0.1860	0.0271	0.0449	0.2271	-0.2252	0.9849	-0.0901	0.2380	
X10.1	0.1848	0.0403	-0.2340	0.8480	-0.2309	-0.5544	0.3760	0.3058	-0.1188	0.9977	-0.5424	
X10.2	0.1503	0.0225	-0.2107	0.8629	-0.2274	-0.5592	0.3464	0.2812	-0.1076	0.9976	-0.5365	
											and the second	

Table 5. Cross-Loading of latent variables to indicators

269

Y.1

-0.0204

0.1413

0.2156

X1 = temperature, X2 = water availability, X3 = oxygen availability, X4 = rooting condition, X5 = nutrient retention, X6 = nutrient availability, X7 = sodicity, X8 = erosion

0.3790

0.0487

-0.5271

0.2367

-0.5408

270 hazard, X9 = flooding hazard, X10 = land preparation, Y = hybrid maize yield, X1.1 = temperature, X2.1 = rainfall, X2.2 = the wet month, X2.3 = the dry month, X2.3 = long growth period, X3.1 = drainage, X4.1 = texture, X4.2 = coarse material, X4.3 = effective depth, X5.1 = organic C, X5.2 = cation exchanges capacity, X5.3 = base

0.3425

271 272 saturation, X6.1 = total N, X6.2 = P availability, X6.3 = K exchangeable, X7.1 = the exchange sodium percentage, X8.1 = slopes, X8.2 = soil erosion, X9.1 = inundation

273 height, X9.2 = inundation period, X10.1 = rock outcrops, X10.2 = surface rock, Y.1 = hybrid maize yield.

-0.5479

12

Indicators (land characteristics)	Cronbach's Alpha	Composite Reliability
X1.1 (Temperature)	1.000	1.000
X2.1 (Rainfall)		
X2.2 (Wet month)	0.975	0.965
X2.3 (Dry month)	0.975	0.905
X2.4 (Long growth periods)		
X3.1 (Drainage)	1.000	1.000
X4.1 (Texture)		
X4.2 (Coarse material)	0.002^{nor}	-1.055 ^{nor}
X4.3 (Effective depth)		
X5.1 (pH H ₂ O)		
X5.2 (pH KCl)		
X5.3 (Organic C)	0.718	0.628
X5.4 (Cation exchange capacity)		
X5.5 (Base saturation)		
X6.1 (Total N)		
X6.2 (P availability)	0.805	0.681
X6.3 (K exchangeable)		
X7.1 (Exchangeable sodium percentage)	1.000	1.000
X8.1 (Slopes)	0.965	0.928
X8.2 (Soil erosion)	0.705	0.728
X9.1 (Inundation height)	0.992	0.984
X9.2 (Inundation period)	0.772	0.704
X10.1 (Rock outcrops)	0.998	0.995
X10.2 (Surface rock)	0.770	0.775

275 nor = not reliable.

276 3.1.3 Structural model test (inner models)

277 Land characteristics that have a significant correlation with hybrid maize yields show a high level of contribution to land quality in influencing hybrid maize yields as indicated in Figure 278 279 3. The figure shows a structural model of the relationship between indicator variables, namely 280 24 land characteristics, rectangular yellow, and latent variables, including 10 land qualities maize yield, and oval blue. It also shows a model for the relationship between latent variables 281 282 such as land qualities and maize yield as well as loading figures. The factor for each indicator 283 and path coefficient for land qualities has a direct effect on the value of maize yields.

284 For example, X8 (erosion hazard) significantly determines the hybrid maize yield with a path coefficient of -0.392. The negative sign indicates that the erosion hazard is negatively related 285 286 to maize yield, where the higher the erosion hazard, the lower the maize yield. Furthermore, nutrient retention (X5) contributes to the diversity of hybrid maize yields with a path coefficient 287 of 0.252. A positive sign indicates that nutrient retention is positively related to maize yield, 288 where the higher the value of nutrient retention were followed by the maize yield. 289



²⁹⁰

291

Figure 3: Path Coefficient of land quality on hybrid maize yield.

292 The results of this path analysis indicated that the land quality that can be a predictor of maize 293 yield diversity were oxygen availability (X3), nutrient retention (X5), nutrient availability 294 (X6), erosion hazard (X8), and land preparation (X 10). Figure 2 indicates that only 8 of the 24 295 indicators explain latent variance at the 5% real test level. The 8 indicators were coarse material and effective soil depth as an indicator of rooting condition, organic carbon content as nutrient 296 297 retention, exchangeable K as nutrient availability, soil erosion and slope as erosion hazard, as well as rock outcrop and surface rock as an indicator of land preparation. It was also indicated 298 299 that the drainage loading factor was unable to explain the diversity of oxygen availability. Therefore, oxygen availability cannot be used as a land quality because there are no indicators 300 that can represent it. Only the land qualities of nutrient retention (X5), nutrient availability 301 302 (x6), erosion hazard (x8), and land preparation (X10) were used next.

The indicators of land characteristics for effective depth, organic C, total N, and exchangeable K have a fairly strong positive relationship and a very significant effect on hybrid maize yields. In this relationship, an increase in these parameters by 1%, will be followed by a rise in hybrid maize yields of 39% to 57.7%. According to [4], effective depth affects root growth and development, making plants grow and develop properly. Moreover, the levels of organic C, total N, and CEC are influenced by soil organic matter [42], while potassium plays a role in the growth and development of maize [43].

- 310 Indicators of rough soil characteristics, slopes, soil erosion, as well as surface and rock outcrops
- 311 have a strong negative relationship with a very significant effect on hybrid maize yields. In this
- 312 relationship, a 1% decrease in coarse material, slope, soil erosion, as well as surface and rock
- 313 outcrop is followed by an increase in hybrid maize yields by 39% to 57.7%.

314 3.2. Optimum hybrid maize yield by the land quality and land characteristics

315 Table 7 shows the mathematical equations for each land characteristic and also the optimum 316 hybrid maize yield for the land equation. Figure 4 shows the diagram of the relationship between land characteristics as an independent variable (X) and maize yield as an independent 317 variable Y. Model fitting indicates that the quadratic equation is sufficient to describe the 318 319 condition of data distribution.

Land Quality/Land Characteristics	Optimum Yield (ton/ha)	Yield Equation	R
Rooting condition (rc)			
Coarse material	8.06	$Y = 0.0024800x^2 - 0.2457487x + 10.9082465$	0.9
Effective depth	8.35	$\begin{array}{l} Y = -0.0007242 x^2 + 0.1890458 x - \\ 1.2946385 \end{array}$	0.9
Nutrient retention (nr)			
Organic carbon	8.35	$Y = -24.3891969x^2 + 46.8464078X \\ - 8.8894056$	0.8
Nutrient availability (na)			
Total N	8.43	$Y = -304.4463543X^2 + 144.7590906X - 2.6328530$	1.(
K Exchangeable	5.74	$Y = -10.5596308X^2 + 17.4129832X + 2.2069179$	0.9
Erosion hazard (eh)			
Slopes	8.43	$Y = 0.0172X^2 - 0.8448X + 13.907$	0.9
Soil erosion	8.06	$y = 0.0000173X^2 - 0.0187536X + 9.0426459$	0.8
Land preparation (lp)			
Rock outcrops	7.30	$Y = 0.0046385X^2 - 0.2934756X + 8.5159674$	0.9
Surface rock	7.30	$\begin{split} Y &= 0.0046385 X^2 - 0.2934756 X + \\ 8.5159674 \end{split}$	0.9

321

320

The optimum of hybrid maize yield ranged from 5.74 to 8.43 ton/ha, where the highest yield 322 was obtained from total N and slopes of 8.43 ton/ha with an R^2 value of 100% and 91%. 323 324 Sutardjo et al (2012) showed that hybrid maize yields ranged from 7.43 to 9.2 ton/ha. This 325 indicated that the optimum yield achieved is still within the range of hybrid maize yields that 326 have been previously reported. Nitrogen is directly involved in the formation of amino acids, proteins, nucleic acids, enzymes, nucleoproteins, and alkaloids, which are needed in the plant 327 growth process [44], [45]. An extremely high amount of N causes excessive vegetative growth, 328 329 thereby making plants fall easily and increasing susceptibility to disease [46]. Meanwhile, the 330 lack of N nutrients can limit cell division, enlargement [47], and the formation of chlorophyll, 331 leading to stunted growth as well as yellowing of leaves [46].

The lowest optimum yield was obtained from exchangeable K, which was only 5.74 ton/ha 332 333 with an \mathbb{R}^2 value of 94%. This was presumably because the K content in the soil is very low,

334 thereby affecting the hybrid maize yield. Potassium (K) is required by plants for physiological

functions, including carbohydrate metabolism, enzyme activity, osmotic regulation, efficient 335

water use, N uptake, protein synthesis, and assimilate translocation [48]–[51]. It also plays a
role in improving the quality of crop yields (McKenzie, 2013, Subandi, 2013).

The optimum hybrid maize yield of the remaining is relatively diverse. This includes effective 338 depth and organic carbon, which were both 8.35 ton/ha with an R² value of 87%. Furthermore, 339 coarse material and soil erosion were 8.06 ton/ha with an R² value of 95% and 88%, while rock 340 341 outcrops and surface rock were 7.30 ton/ha with an R2 value of 91%. The absence of coarse 342 material > 2 mm in diameter indicated that plant roots can grow freely on the surface or deeper 343 parts of the soil [54], because the deeper the roots of the maize, the greater the maize yield 344 [55], [56]. The addition of organic matter will increase maize yield [57]–[59] and organic C content [60] because soil organic matter is a strong positive predictor of yield [61]. Kane et al. 345 346 [61] also stated that the addition of more organic matter will improve water retention, thereby 347 reducing maize yield losses due to drought. The slope has a significant effect on soil 348 degradation [62]. According to a previous study, erosion and maize yield are negatively correlated, hence, increased erosion will reduce maize productivity [63]. Soil erosion on flat 349 350 land is slower surface runoff [64]. It was also reported that surface rocks and outcrops are the limiting factors in the suitability of maize plantations [65]. Therefore, a high percentage of rock 351 352 outcrops will complicate land cultivation and plant root growth.

353 **3.3. Land suitability criteria for hybrid maize crops**

354 Table 8 shows the yield limit for each class from the calculation of the optimum yield, where the class range for each land characteristic is derived. Based on the optimum yield of the highest 355 356 hybrid maize, there were 2 indicators, namely the total N content and the slope. The total N indicator with a very suitable class (S1) was achieved when the value in the soil was greater 357 358 than 0.10%, while in the moderately suitable class (S2), it was achieved when the total N in 359 the soil ranges from 0.07-0.09%. In the marginally appropriate class (S3), the total N indicator 360 was achieved when the total N in the soil ranges from 0.05-0.06%, while the not suitable class (N) was achieved when the content was less than 0.05%. On the slope indicator with class S1, 361 it was obtained when the slope class ranges from 0-7.69%%, while class S2 was achieved when 362 the slope class ranges from 7.70-11.83%. Furthermore, in classes S3 and N, it was obtained 363 364 when the slope class ranged from 11.84-18.24% and greater than 18.24%, respectively.

Based on the optimum yield of the lowest hybrid maize, only the exchangeable K was the 365 indicator. In classes S1 and S2, it was achieved when the exchangeable K content in the soil 366 367 was greater than 0.24 cmol(+)/kg and ranges from 0.13-0.23 cmol(+)/kg, respectively. 368 Furthermore, class S3 was achieved when the exchangeable K content in the soil ranges from 0.04-0.12 cmol(+)/kg, while in class N, it was obtained when the exchangeable K content in 369 370 the soil was less than 0.04 cmol(+)/kg. The remaining variables and indicators were relatively 371 varied according to the optimum yield of hybrid maize and the range of land suitability classes 372 obtained as presented in Table 8.



373



Figure 4: Scatter diagram relationship among maize yield and land characteristics

Value of Land Suitability Criterion Yield Limits (ton/ha) Obtained Land Quality/Land **S1 - S2** S2 - S3S3 - NCharacteristics (80% x (60% x (40% x **S1 S2 S3** Ν Yoptim) Yoptim) Yoptim) Rooting condition (rc) 0 – 13.41 -27.38 -> Coarse material (%) 8.06 6.04 4.03 13.40 27.37 52.39 52.39 49.25 -33.18 -<Effective depth (cm) 8.35 6.26 4.18 ≥ 69.55 69.54 49.24 33.18 Nutrient retention (nr) 6.26 0.41 - 0.49Organic carbon (%) 8.35 4.18 ≥ 0.50 0.34 - 0.40< 0.34 Nutrient availability (na) Total N (%) 8.43 6.32 4.22 ≥ 0.10 0.07 - 0.090.05 - 0.06< 0.05 K Exchangeable 0.04 - 0.125.74 4.31 2.87 ≥ 0.24 0.13 - 0.23< 0.04(cmol(+)/kg)Erosion hazard (eh) 7.70 -0 – 11.84 -> Slopes (%) 8.43 6.32 4.22 18.24 7.69 11.83 18.24 Soil erosion > 8.06 6.04 4.03 ≤ 55.21 195.29 605.56 (ton/ha/year) 605.56 Land preparation (lp) 0 -4.46 -13.10 -> Rock outcrops (%) 3.85 7.30 5.47 4.45 13.09 31.78 31.78 0 – 4.46 -13.10 ->Surface rock (%) 7.30 5.47 3.85 4.45 13.09 31.78 31.78

 Table 8: Yield limits of hybrid maize and values obtained in each land suitability class interval by land quality and characteristics.

377 S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, and N = not suitable.

Based on the relationship between the quality and characteristics of the selected land with optimum results, the criteria for hybrid maize land suitability were obtained as shown in Table 8. These criteria described the actual state of achieving optimum, moderate, and minimum yields of hybrid maize in the field with values of 80%, 60%, and 40%, respectively. According to Sukarman et al. [66], the parameters used in the land suitability assessment must describe the actual conditions. This is due to the significant positive correlation between maize yield and land suitability class [67].

385 The land suitability criteria for the new hybrid maize are fewer and have referred to the optimum yield. Meanwhile, the land quality and characteristics in this new criterion are less 386 because it only consists of root conditions with characteristics of coarse material and effective 387 depth, nutrient retention with organic C, and nutrient availability with total N and K 388 exchangeable. It also consists of erosion hazards with characteristics of slopes and soil erosion, 389 390 as well as land preparation with surface rocks and rock outcrops only. The land qualities 391 selected and maize yields consistent with the land potential are the basis for developing suitability criteria. This will reduce the land characteristics and make the evaluation process 392 393 faster, cheaper, and easier with accurate results [14]. Some characteristics and land quality 394 criteria were not made because they did not significantly affect the yield of hybrid maize. The 395 number and distribution of the data were still limited and the diversity of values was small or 396 not measurable in the field [38].

397 Compared to Wahyunto et al. [68], the new land suitability criteria for hybrid maize plants in 398 Table 9 is more realistic in value with the conditions in the field and is based on the 399 achievement of optimum yields. The current land suitability criteria are still general and not 400 specific to maize yields [14], although the agronomic and yield potential of each maize variety 401 differ, based on the diversity of characteristics and land quality in the field.

Land Quality/Land Characteristics	Nev		bility Criterio d Maize	on of		l Suitabili General N	•	
Characteristics	S1	S2	S3	Ν	S1	S2	S3	Ν
Rooting condition (rc)								
Coarse material (%)	0 – 13.40	13.41 – 27.37	27.38 – 52.39	> 52.39	< 15	15 – 35	35 – 55	>55
Effective depth (cm)	≥ 69.55	49.25 – 69.54	33.18 – 49.24	< 33.18	> 60	$\frac{60}{40}$	40 – 25	< 25
Nutrient retention (nr)								
Organic carbon (%)	≥ 0.50	0.41 - 0.49	0.34 - 0.40	< 0.34	> 1.20	0.8 – 1.2	< 0.8	-
Nutrient availability (na)								
Total N (%)	≥ 0.10	0.07 - 0.09	0.05 - 0.06	< 0.05	Mo	Lo	VLo	-
K Exchangeable (cmol(+)/kg)	≥ 0.24	0.13 - 0.23	0.04 - 0.12	< 0.04	Mo- Hi	Lo	VLo	-
Erosion hazard (eh)								
Slopes (%)	0 – 7.69	7.70 – 11.83	11.84 – 18.24	> 18.24	< 8	8 – 15	15 – 25	> 25
Soil erosion (ton/ha/year)	≤ 55.21	195.29	605.56	> 605.56	-	VLi	Li- Mo	He- VHe
Land preparation (lp)								
Rock outcrops (%)	0 – 4.45	4.46 – 13.09	13.10 – 31.78	> 31.78	< 5	5 – 15	15 - 40	> 4(
Surface rock (%)	0 – 4.45	4.46 – 13.09	13.10 – 31.78	> 31.78	< 5	5 – 15	15 – 40	>4(

Table 9: Comparison of new and general land suitability criteria with land quality and characteristics.

403 S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable, Hi = high, Mo =

404 moderate, Lo = low, VLo = very low, He = heavy, Li = light, VLi = very light, VHe = very heavy.

405 **Conclusions**

402

406 Land suitability criteria for the new hybrid maize are determined by land qualities, namely root conditions, nutrient retention, available nutrients, erosion hazard, as well as land preparation, 407 408 and land characteristics, including coarse material, effective depth, organic C, total N, exchangeable K, slopes, soil erosion, rock outcrops, and surface rocks. The highest optimum 409 yield of 8.35 ton/ha was achieved by the effective depth and organic C content for a very 410 suitable class (S1), while the lowest value of 5.47 ton/ha was attained by exchangeable K for 411 class S1. These results showed that the combination of the PLS-SEM and boundary line 412 analysis can be an alternative approach to establishing new land suitability criteria for crops 413 414 based on optimum yields and selected land quality.

415 Data Availability

416 All data can be obtained from the corresponding author upon request.

417 **Conflicts of Interest**

418 The authors declared that there is no conflict of interest regarding the publication of this paper.

419 **Funding Statement**

This study was funded by the Directorate of Research, Technology and Community Service,
Directorate General of Higher Education, Research and Technology, Ministry of Education,
Culture, Research and Technology of the Republic of Indonesia, grant number
B/105/UN47.D1/PT.01.03/2022.

424 Acknowledgments

- 425 The authors are grateful to the Ministry of Education, Culture, Research and Technology of
- 426 the Republic of Indonesia, and the Institute Research and Community Service of Universitas
- 427 Negeri Gorontalo for their financial and administrative support.

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← BACK DASHBOARD / ARTICLE DETAILS Updated on 2022-10-22 Version 1 🗸 Determination of Maize Hybrid Land Suitability Criteria Based on Optimum Yield and VIEWING AN OLDER VERSION Selected Land Quality ID 3800877 Nurdin, Nurdin SA CA¹, Asda Rauf¹, Yunnita Rahim¹, Echan Adam¹, Nikmah Musa¹, Fitriah Suryani Jamin¹, Rival Rahman¹, Suyono Dude¹, Hidayat Arismunandar Katili² + Show Affiliations Article Type Research Article Journal Applied and Environmental Soil Science Academic Editor Turiaman Maman Submitted on 2022-10-22 (2 months ago) > Abstract > Author Declaration > Files 2 Editorial Comments Recommendation Maman Turjaman AE 12.12.2022 Maior Revision Requested Message for Author Major Revision - Reviewer Reports 1 submitted Report Reviewer 1 21.11.2022 Summary The topic presented by the authors is very interesting, relevant to efforts to increase food production in Indonesia, and in accordance with the scope of the journal. However, this manuscript must be corrected to be suitable for subsequent processes, especially in the introduction and method sections. The scope of activities to develop Land Suitability Criteria is only focused on Boalemo Regency, so there should be more background and discussion at that location. Citations are still very minimal, especially in the method section. Major Issues Introduction The author, of course, knows that Indonesia's maize production centres are not only in Gorontalo Province, so hybrid maize does not only grow optimally in the Boalemo region. However, in this study, the authors only limited their area to Boalemo Regency, so the result of land suitability criteria was limited to the Boalemo area and its surroundings. In the introduction section, there should be a justification for why Boalemo was chosen as the research location. How is corn production there, what are the differences between local and hybrid corn production at a glance, and why has the determination of maize hybrid land suitability criteria for the Boalemo Regency become necessary? Method - Line 85-87: add citations/references. - Please write down the scale of the soil map. Line 88 stated that there are 35 soil units, but in the legend of Figure 1, there are 32 SMUs. Is there a connection between the soil mapping carried out by Ritung et al. and the map in Figure 1? Why is the soil mapping unit in Figure 1 not explained in paragraph lines 83-91? - Line 95-110: It is advisable that at the beginning of the paragraph, each component/variable of land characteristics is described in advance. In the next section, each variable is explained on how to obtain the data. - Line 97-99: Give reasons why it is necessary to update the available land characteristics and justify the determination of 32 additional points. Add sampling points (32 pedons) to a map. Explain the method for taking climatic data and where the equipment/stations are placed. - Line 112-113: the results of this identification should be displayed on a map and indicate the points where the 2.5 x 2.5m blocks were placed. - Line 117, 119, 142, 143, etc.: each formula should be equipped with a reference. - Line 127-145, 175-184; please add citations - Line 131: Table 1 should be equipped with a column showing secondary data sources for each land characteristic or data acquisition method in the field (as a summary from updated lines 95-110). - Line 397-401: It must be conveyed that the results of this study are of limited use for the development of hybrid maize in Boalemo, because the arrangement is based only on the land characteristics and optimum yield in Boalemo Regency (not representing the national scale).
1 Determination of Maize Hybrid Land Suitability Criteria Based

2 on Optimum Yield and Selected Land Quality

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12 Abstract

13 The significant effect of land quality on maize production has not been fully considered in the existing land suitability criteria. Therefore, this study aims to determine the hybrid maize land 14 15 suitability criteria based on the optimum yield and land quality. It was carried out in Boalemo 16 Regency, Indonesia, where a total of 67 land units were surveyed to obtain land characteristics data. A partial least square of structural equation model (PLS-SEM) with SmartPLS 8.0 was 17 18 used to select a robust land quality controlling hybrid maize yield, while the boundary line 19 method was used to determine optimum yield and differentiating of land suitability criteria. 20 The result showed that land qualities that define the optimum yield of hybrid maize were root 21 conditions, nutrient retention and availability, erosion hazard, and land preparation. The soil 22 characteristics were coarse material, effective depth, organic C, total N, exchangeable K, 23 slopes, erosion, rock outcrops, and surface rocks. Furthermore, the highest optimum yield of 24 8.35 ton/ha was achieved by the effective depth and organic C content for a very suitable class 25 (S1), while the lowest of 5.47 ton/ha was obtained by exchangeable K for class S1. This showed 26 that the combination of PLS-SEM and boundary line analysis was a better approach to 27 developing new land suitability criteria for hybrid maize.

28 **1. Introduction**

- Food security and farmer prosperity are global concerns, this makes every country increase crop production as well as farmers' income. An important issue for countries with developing economies is ensuring food security, where the agricultural sector plays a strategic role in increasing food availability [1]. Although the global food system has placed maize (*Zea mays* L.) as the leading cereal crop [2], its productivity is being disrupted by land degradation, water
- 34 scarcity, and climate change [3].
- In Indonesia, the wet tropical climate with rainfall and high temperatures tends to reduce the quality of land and agricultural products [4]. This country ranked 8th among the maizeproducing nations with a contribution of 2.19% and 2.42% of the world's total harvested area [5]. However, the main problem is the relatively low level of yield in several regions because the achievement of maize production has not been followed by an increase in yield per unit area [6]. This is indicated by the average yield in 2020, which was up to 5.57 ton/ha [5].

- 41 According to a previous investigation, maize production in Indonesia can reach between 10-12
- 42 ton/ha [7], [8] thereby making the country the 21st leading importer in the world.

43 Maize is usually grown on land with low yield potential [9] and soil fertility, thereby causing low productivity [10]. Moreover, land productivity is determined by quality and characteristics 44 [11], [12], while land quality has a close relationship with maize yields [13]. The land quality 45 46 affecting the optimum yield of maize needs to be determined [14] and increased by using hybrid 47 varieties that have high yields. This makes it necessary to evaluate the suitability of the hybrid 48 maize in a region to ensure optimal production. The land suitability criteria for hybrid maize 49 are not yet available because the current criterion is the general suitability of maize plants without distinguishing between hybrids and inbreds. Therefore, there is a need to make land 50 51 suitability criteria for hybrid maize plants.

52 A previous study has shown that land quality has a significant effect on suitability for certain 53 uses [15]. Meanwhile, land suitability is also important due to the continuous increase in the 54 demand for agricultural land [16]. The land suitability criteria for existing maize fields are still 55 general [17] and there are no specific criteria for hybrid maize varieties. The class assessment 56 outcomes obtained using the existing criteria are relatively many and are not in line with the 57 actual field results [18]. The current criteria consist of 3 components, namely, land quality, characteristics, and ranges of land characteristic values to determine its suitability. Therefore, 58 59 the problem in developing criteria is choosing land quality, characteristics, and determining the 60 range of land characteristic values associated with suitability classes, namely suitable, 61 somewhat suitable, marginally suitable, and not suitable.

62 The selection of land quality and characteristics can be carried out through the partial least 63 square of the structural equation model (PLS-SEM), while the range limits is being determined 64 by the boundary line method. Land qualities and characteristics in the current criteria can be 65 used temporarily since structural equation model analysis with partial least squares produces better indicators and models than other multivariate analyses [19]-[23]. This is because the 66 67 variant-based PLS-SEM has a higher level of flexibility and the size of the sample used is relatively small ranging from 30 to 100 [24]-[27]. The use of PLS-SEM to determine land 68 69 characteristics and qualities that control maize crop yields is still relatively rare, except for Syaf 70 [28] on older cocoa plants, maize composite [29], and on local varieties [6]. The boundary line 71 method can help determine nutrient adequacy concentrations and the optimum yield range of 72 a plant that affects nutrients, as well as other land characteristics [30], [31]. Currently, the land 73 suitability criteria for maize plants have not been determined using the boundary line method, 74 except by Ridayanti et al. [32], although the investigation was not specific to hybrid maize.

After obtaining the quality and characteristics of land affecting maize yields with PLS-SEM, the boundary line method can be used to determine the optimum yield as well as land suitability criteria simultaneously. This is carried out by drawing the intersection of the boundary line at the yield and projecting with the land characteristics [17]. Therefore, this study aims to determine land suitability criteria for hybrid maize based on the optimum yield and land quality.

81 **2. Materials and Methods**

82 2.1 Study area

- 83 The study area extends from $0^{\circ}28'5.6" 0^{\circ}57'30.02"$ N to $122^{\circ0}8'34.25" 122^{\circ}43'10.41"E$
- 84 (Figure 1), which is located in the agricultural land of Boalemo Regency, Gorontalo Province,
- ⁸⁵ Indonesia. The maximum air temperature was 28.19°C and the minimum was 26.79°C with an
- average of 28.01°C. Meanwhile, the maximum rainfall was 1,849 mm and the minimum was
 1,246 mm with an average of 1,478 mm. The wet and dry seasons last for 3 months and 5
- months respectively. The soil mapping carried out by Ritung et al. [33], consists of 35 soil
- 89 units, where each unit has information on land characteristics, namely effective depth,
- 90 drainage, texture, pH, cation exchange capacity, base saturation, landform, parent material,
- 91 relief, and land unit area.

1	Slopes (%)	Land Use	Relief	Soil Types	Elevation (m asl)	
1	8 - 15	Plantation	Hilly	Typic Haplustalfs	0 - 100	5615.40
2	> 45	Scrub	Mountainous	Fluventic Ustropepts		286.81
3	> 45	Scrub	Mountainous	Typic Haplustalfs	250 - 500	943.88
4	> 45	Upland	Mountainous	Fluventic Ustropepts	250 - 500	354.01
5	0-3	Plantation	Flat	Pluventic Haplustepts		4024.22
6	0-3	Upland	Flat	Pluventic Haplustepts	0 - 100	3052.60
7	0-3	Upland	Flat	Typic Argiustolls	0 - 100	1073.14
8	0-3	Upland	Flat	Typic Tropaquepts	100 - 250	65.04
9	15 - 30	Plantation	Hilly	Fluventic Ustropepts	250 - 500	575.02
10	15 - 30	Scrub	Hilly	Typic Argiustolls	100 - 250	1813.67
11	15 - 30	Scrub	Hilly	Typic Haplustalfs	0 - 100	605.20
12	15 - 30	Upland	Hilly	Fluventic Ustropepts	100 - 250	804.83
13	15 - 30	Upland	Hilly	Pluventic Haplustepts	250 - 500	705.51
14	15 - 30	Upland	Hilly	Typic Argiustolls	250 - 500	2530.37
15	15 - 30	Upland	Hilly	Typic Haplustalfs	0 - 100	423.49
16	15 - 30	Upland	Hilly	Typic Haplustalfs	250 - 500	5118.25
17	15 - 30	Upland	Hilly	Typic Haplusteps	100 - 250	28.16
18	15 - 30	Upland	Hilly	Typic Tropaquepts	0 - 100	89.21
19	3-8	Plantation	Wavy	Pluventic Haplustepts		6060.03
20	3-8	Plantation	Wavy	Typic Argiustolls	100 - 250	151.63
21	3-8	Scrub	Wavy	Typic Haplustalfs	250 - 500	1266.07
22	3-8	Upland	Wavy	Pluventic Haplustepts		4863.96
23	3-8	Upland	Wavy	Typic Argiustolls	0 - 100	3530.19
24	3-8	Upland	Wavy	Typic Dystrudepts	0 - 100	403.97
25	3-8	Upland	Wavy	Typic Haplustalfs	250 - 500	413.33
26	30-45	Plantation	Mountainous	Typic Haplustalfs	100 - 250	60.16
27	30-45	Scrub	Mountainous	Typic Haplustalfs	100 - 250	690.28
28	30-45	Upland	Mountainous	Typic Haplustalfs	0-100	282.93
29	30-45	Upland	Mountainous	Typic Haplustalfs	100 - 250	4773.13
30	8-15	Upland	Hilly	Typic Argiustolls	0-100	9581.79
30	8-15	Upland				254.52
31			Hilly	Typic Haplustalfs	250 - 500	
32	8 - 15	Upland	Hilly	Typic Haplusteps	250 - 500	79.96
	I mapping unit		Total			60520.76
Low	And and a second				363	1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-

Figure 1: Study area.

94 **2.2 Dataset collection for land quality and land characteristics**

The framework of this study is presented in Figure 2. The previous soil map [33] was used as a working map, where information on land characteristics, namely soil, climate, and terrain, was extracted. It was updated by taking 32 pedons, thereby becoming 67 pedons representing soil diversity in each location. For each observation location, the climatic data of land and terrain characteristics were observed and the previous data were updated. The soil samples according to horizon boundaries were taken for analysis in the laboratory.



$\begin{array}{c} 101 \\ 102 \end{array}$

Soil samples were dried for 3 days and sieved through a 2 mesh sieve. The method of laboratory analysis was carried out according to the procedures by Eviyati and Sulaeman [34]. The soil pH was determined with a pH meter in a 1:2.5 soil and water solution, while the organic C content was assessed using the Walkley and Black method. The available P content was measured using the Olsen method, while the cation exchange capacity (CEC) was extracted with 1N NH4OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C, and the base saturation was determined by calculation. Subsequently, the data from the chemical analysis

110 were averaged to a depth of 0-30 cm using the weighted averaging technique.

111 **2.3 Dataset collection for hybrid maize yield**

112 The areas currently planted with hybrid maize were identified and blocks with a size of 2.5 m

113 x 2.5 m were made in each map unit. Maize plants in each block passed through standardized

114 management according to farmers' technology. After harvesting, weighting was carried out to

obtain hybrid maize yield data from the results of tiles on each land unit. Subsequently, the

results were calculated using the formula, as expressed below:

117	$Y(t) = H x \frac{A}{6.25 m^2}$	(1)
110	Meanwhile, and destinity is calculated using the formula halory	

118 Meanwhile, productivity is calculated using the formula below:

(2)

- 119 $Y(t ha^{-1}) = \frac{H \times 1.64 \times 56.73}{100}$
- 120 where Y = hybrid maize yield, H = tile yield (kg), A = maize area 1 per hectare (ha), 1.64
- 121 and 56.73 = constant.

122 **2.4 Selection of land quality and land characteristics**

123 The quality and characteristics of the land in the suitability criteria were used as presented in Tables 1 and 2, which show brief statistics. Generally, most data are relatively homogenous, 124 except for coarse material, available P, slopes, soil erosion, height and inundation, as well as 125 rock outcrops and surface rocks. The selection used the partial least squares of the structural 126 127 equation model (PLS-SEM) with tools SmartPLS, where land quality and characteristics were 128 selected as the latent and manifest variables, respectively. The analysis in PLS-SEM has 2 main steps, namely (1) the measurement model (outer model) and (2) the structural model test (inner 129 130 model).

131 Table 1: Latent variables and indicators used in this study Latent variables **Indicators Notation** Land quality **Notation** Land characteristics **T**emperature X1Temperature (t) X1.1 <mark>X2</mark> Water availability (wa) X2.1 Rainfall X2.2 Wet month X2.3 Dry month X2.4 Long growth period (LGP) Oxygen availability (oa) Drainage **X3** X3.1 $\mathbf{X4}$ Rooting condition (rc) X4.1 Texture X4.1.1 Sand fraction X4.1.2 Silt fraction X4.1.3 **Clay** X4.2 Coarse material X4.3 Effective depth X5.1 X5 pHH₂O Nutrient retention (nr) X5.2 pH KCl X5.3 Organic C X5.4 Cation exchange capacity (CEC) X5.5 **Base saturation** <mark>X6</mark> Nutrient availability (na) X6.1 Total N X6.2 P availability K exchangeable X6.3 Exchangeable sodium percentage X7 Sodicity (xn) X7.1 (ESP) Erosion hazard (eh) X8.1 Slopes $\mathbf{X8}$ Soil erosion X8.2 <mark>X9</mark> Flooding hazard (fh) X9.1 **Inundation** height X9.2 Inundation period Land preparation (lp) X10.1 Rock outcrops X10 X10.2 Surface rock Hybrid maize yield Y Hybrid maize yield **Y.1**

132

Step 1 consists of validity and reliability tests, wherein the validity test is conducted with convergent and discriminant validity. The convergent validity is in form of outer loadings (loading factor) and average variance extracted (AVE), while discriminant validity is in form of cross-loading and the Fornell-Larcker criterion. Meanwhile, the reliability test uses

- 138 composite reliability and Cronbach's alpha.
- 139 Convergent validity was observed from the magnitude of the outer loading and the AVE
- 140 value of each indicator on the latent variable. The validity was calculated according to the
- 141 equation:
- 142 $x_i = \lambda x_i \xi_l + \delta_i$
- 143 $y_i = \lambda y_i \eta_1 + \varepsilon_i$

(4)

(3)

- 144 where x and y = exogenous (ξ) and endogenous (η) latent variable indicator, λx and $\lambda y =$ 145 loading factors, δ and ε = residual/measurement errors or noise.
- 146

Table 2: Brief statistics of land quality and characteristics.

Latent variables / Indicators	Unit	n	Min	Median	Mean	Max	SD
X1 (Temperature)							
X1.1 (Temperature)	°C	67	26.79	27.80	28.01	28.19	0.63
X2 (Water availability)							
X2.1 (Rainfall)	mm	67	1,246.00	1,533.42	1,478.00	1,849.00	232.69
X2.2 (Wet month)	month	67	0.00	1.03	1.00	3.00	0.85
X2.3 (Dry month)	month	67	2.00	3.39	4.00	5.00	1.00
X2.4 (LGP)	day	67	211.00	246.00	214.00	304.00	44.54
X3 (Oxygen availability)							
X3.1 (Drainage)	class	67	0.00	3.76	4.00	6.00	1.82
X4 (Rooting conditions)							
X4.1 (texture)	class	67	1.00	2.21	2.00	5.00	0.9
X4.1.1 (Sand fraction)	%	67	5.00	41.58	43.00	81.33	18.5
X4.1.2 (Silt fraction)	%	67	7.33	27.31	24.50	51.50	11.5
X4.1.3 (Clay)	%	67	11.33	31.90	30.00	56.33	12.7
X4.2 (Coarse material)	%	67	5.00	17.27	10.00	70.00	16.5
X4.3 (Effective depth)	cm	67	10.00	74.55	74.00	160.00	36.4
X5 (Nutrient retention)							
X5.1 (pH H ₂ O)		67	5.00	5.92	5.90	7.15	0.5
X5.2 (pH KCl)		67	4.35	5.24	5.17	6.60	0.5
X5.3 (Organic C)	%	67	0.41	0.85	0.77	2.35	0.3
X5.4 (CEC)	cmol(+)/kg	67	8.94	24.89	22.43	59.57	11.4
X5.5 (Base saturation)	%	67	45.03	56.22	52.85	81.89	9.7
X6 (Nutrient availability)							
X6.1 (Total N)	%	67	0.04	0.09	0.08	0.27	0.04
X6.2 (P availability)	mg/kg	67	0.73	8.62	3.77	58.67	12.6
X6.3 (K exchangeable)	cmol(+)/kg	67	0.07	0.39	0.24	1.92	0.42
X7 (Sodicity)							
X7.1 (ESP)	%	67	0.76	7.06	6.20	24.17	5.62
X8 (Erosion hazard)							
X8.1 (Slopes)	%	67	1.00	9.58	6.00	25.00	7.2
X8.2 (Soil erosion)	ton/ha/year	67	3.66	334.51	110.27	1772.43	439.0

X9 (Flooding hazard)							
X9.1 (Inundation height)	cm	67	0.00	7.58	0.00	50.00	17.10
X9.2 (Inundation period)	day	67	0.00	0.64	0.00	5.00	1.52
X10 (Land preparation)							
X10.1 (Rock outcrops)	%	67	0.00	6.64	0.00	45.00	11.56
X10.2 (Surface rock)	%	67	0.00	6.58	0.00	45.00	11.59
Y (Hybrid maize yield)	ton/ha	67	2.85	4.95	4.68	8.07	1.15

n = the number of the land unit, min = minimum, max is maximum, SD = standard deviations, LGP = long growth 148 periods, CEC = cation exchange capacity, and ESP = exchangeable sodium percentage.

149 Meanwhile, the average variance extracted (AVE) value was calculated using the equation:

150
$$AVE = \frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i \, var(\varepsilon_i)}$$
 (5)

Where λ_i^2 = the loading factor, var = the variance, and ε_i = the error variance. 151

152 The loading factor of an indicator with the highest value is the strongest or most important 153 measure in reflecting the latent variable. In this study, the loading factor value is > 0.70 for selecting best land characteristics, but values ranging from 0.50-0.60 can still be tolerated with 154 155 a t-statistic > 1.96 or a small p-value of 0.05 [25], [35]. Meanwhile, the AVE value used was more than 0.50, showing that the convergent validity on the latent variable has been reached. 156

157 The discriminant validity test used the cross-loading value and the Fornell-Larker criterion to 158 test discriminantly valid indicators in explaining or reflecting latent variables. When the correlation between the latent variables and the core measurement of each indicator is high, the 159 160 latent variable can predict the indicator better and is considered valid. The discriminant validity 161 is measured by the square root of the average variance extracted, which will be compared with 162 the correlation value between variables. The value calculated based on the square root of AVE must be higher than the correlation between constructs [36]. The equation is expressed below 163

164 Square Root of AVE =
$$\sqrt{\frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i \, var(\varepsilon_i)}}$$
 (6)

165 where λ^2_i = the loading factor, var = the variance, and ε_i = the error variance.

Furthermore, the composite reliability and Cronbach's alpha were used to test the reliability 166 value between indicators of the latent variables. They are considered good and accepted when 167 the value is > 0.70 and has a minimum value of 0.60 [25]. The composite reliability value is 168 calculated using the equation: 169

170
$$\rho c = \frac{(\Sigma \lambda_i)^2}{(\Sigma \lambda_i)^2 + \Sigma i \, var(\varepsilon_i)}$$
(7)

171 where λ_i = the loading factor, var = the variance, and ε_i = the error variance.

Meanwhile, the value of Cronbach's Alpha is calculated according to the equation: 172

173
$$\alpha = \left(\frac{\sum p \neq p'^{cor(X_{pq}, X_{p'q})}}{p_{q+\sum p \neq p'}^{cor(X_{pq}, X_{p'q})}}\right) \left(\frac{p_q}{p_{q-1}}\right)$$
(8)

174 where P_q = the number of indicators or manifest variables, and q = the indicator block.

- 175 For step 2, the structural model testing (inner model) was carried out after the relationship
- 176 model was built in line with the observed data and the overall suitability, namely goodness of
- 177 fit. The structural equation (inner model) is as follows:

178
$$H_j = \gamma_j \xi_1 + \gamma_j \xi_2 + \dots + \gamma_j \xi_n + \zeta_j$$
(9)

- 179 where η_j = endogenous variable vector (dependent), $\gamma_j \xi_1 + \gamma_j \xi_2 + \dots + \gamma_j \xi_n$ = exogenous latent 180 variable vector, and ς_j = residual vector (error).
- 181 Meanwhile, the determinant coefficient and goodness of fit (Q^2) were calculated using the 182 equation:
- 183 Q^2 (Predictive relevance) = 1 (1 R_1^2) (1 R_2^2) ... (1 R_p^2) (10)
- 184 where R_1^2 , R_2^2 , ... $R_p^2 = R$ square of endogenous variables in the equation model.

The quantity of Q^2 has a value with a range of 0 < Q2 < 1, the closer the value to 1, the better the model [25]. It is also equivalent to the coefficient of total determination in path analysis. Furthermore, the effect and significance were tested based on the estimated value of the path coefficient and the critical point value (t-statistics or p-value) at = 0.05. The relationship model between variables was measured by testing the direct correlation coefficient between variables. The results of testing the relationship between *X* and *Y* variables were indicated by the correlation coefficient as well as t-statistics, and are also presented in the path diagram.

192 **2.5 Class assignment**

To determine the class-required data for optimum results, class limits were calculated from the percentage of optimum results. After knowing the highest and lowest yields, the values were connected with the range of land characteristics values. The land suitability class and yield used referred to FAO [37], namely class S1 (very suitable) when the values reach 80-100%, S2 was moderately suitable 60-80%, S3 marginally suitable 40-60%, and N not suitable <40% of the optimum capacity.

199 The optimum yield was determined using the boundary line method. This method is carried 200 out by drawing a boundary line on the graph of the relationship between yield and land characteristics to obtain optimum results. In the boundary line method according to 201 Widiatmaka et al. [38], each land characteristic is plotted on the X-axis, while hybrid maize 202 203 yields are plotted on the Y-axis. Bhat and Sujatha [30] stated that the preparation of the hybrid 204 maize yield boundary line includes the preparation of a scatter diagram between the X and the 205 Y variable, (2) division of the X-axis into several classes of intervals, (3) determination of the highest data points in each class interval, (4) preparation of boundary lines based on the highest 206 data points from each class interval, (5) draw a line parallel to the X-axis according to the 207 208 percentage of the result class.

209 Furthermore, with the Microsoft Excel application tools, the boundary between classes S1 to

- 210 S2, S2 to S3, and S3 to N were determined by the Data menu \rightarrow What-if-Analysis \rightarrow Goal
- 211 Seek \rightarrow Set the cell at the location containing the regression equation \rightarrow to value fill with the 212 result limit values S1 to S2 S2 to S3 and S3 to N \rightarrow By changing cell \rightarrow the location where

- 213 the value of the characteristics of the land will be sought \rightarrow Ok. On location "By changing
- cell", the number being searched will appear, and at the location "set cell" will be equal to the
- 215 limit value of the result.

216 **3. Results and Discussion**

217 **3.1 Land quality and characteristics controlling hybrid maize yield**

218 *3.1.1 Validity test result*

233

219 Table 3 shows the loading factor of the variables, where most indicators were more than the 220 critical limit of 0.70 with a 95% confidence level (P > 1.960). Therefore, these variables are 221 highly recommended and the indicators are considered convergently valid. In the soil texture 222 indicator for the latent variable of root conditions as well as the cation exchange capacity (CEC) 223 and base saturation (BS) indicators for nutrient retention, the loading factor was below the 224 tolerance value of 0.50 at the 95% confidence level (P < 1.960), hence, it was not used. This 225 implies that the indicators have not been established or explained properly because the standard 226 value of the loading factor must be greater than or equal to 0.50 [26].

The average variance extracted (AVE) value of almost all variables was greater than 0.50, therefore, it was considered convergently valid [36]. The AVE value of the available nutrient variable was not valid due to the smaller value of the loading factor for the CEC and BS indicators of 0.50, leading to the removal of both indicators. A similar result was discovered in the root condition variable, although the AVE value was greater than 0.50, while the soil texture indicator was not used because the loading factor value is only 0.013.

Indicators)	Latent Variables	Loading	t-Stat	Status	AVE
(land characteristic		(land quality)	Factors			
X1.1 (Temperature)	\rightarrow	X1 (Temperature)	1.000**	11.192	Valid	1.000
X2.1 (Rainfall)	\rightarrow		0.838	0.085	Valid	
X2.2 (Wet month)	\rightarrow	V2 (Watan availability)	0.989	0.999	Valid	0.906
X2.3 (Dry month)	\rightarrow	X2 (Water availability)	0.850	0.428	Valid	
X2.4 (LGP)	\rightarrow		0.993*	1.431	Valid	
X3.1 (Drainage)	<i>></i>	X3 (Oxygen availability)	1.000	0.000	Valid	1.000
X4.1 (Texture)	\rightarrow		0.013	0.066	Invalid	
X4.2 (Coarse material)	\rightarrow	X4 (Rooting condition)	0.921	1.086	Valid	0.573
X4.3 (Effective depth)	\rightarrow		-0.899	1.047	Valid	
X5.1 (pH H ₂ O)	\rightarrow		0.647	0.857	Valid	
X5.2 (pH KCl)	\rightarrow		0.570**	1.973	Valid	
X5.3 (Organic C)	\rightarrow	V5 (Nutriant notantian)	0.831**	3.135	Valid	0.360
X5.4 (CEC)	\rightarrow	X5 (Nutrient retention)	0.436*	1.381	Invalid	(invalid)
X5.5 (Base saturation)	\rightarrow		0.365	0.845	Invalid	
X6.1 (Total N)	\rightarrow		0.760**	3.226	Valid	0.585

Table 3: Outer loading (loading factor) and the average variance extracted from study variables.

X6.2 (P availability)	\rightarrow	X6 (Nutrient	0.587*	1.385	Valid	
X6.3 (K exchangeable)	\rightarrow	availability)	0.897**	6.907	Valid	
X7.1 (ESP)	\rightarrow	X7 (Sodicity)	1.000	0.000	Valid	1.000
X8.1 (Slopes)	\rightarrow	VQ (Encion harond)	0.954**	21.438	Valid	0.932
X8.2 (Soil erosion)	\rightarrow	X8 (Erosion hazard)	0.941**	18.308	Valid	0.932
X9.1 (Inundation	\rightarrow		0.984**	4.213	Valid	
height)		X9 (Flooding hazard)	0.964	4.215	vanu	0.984
X9.2 (Inundation period)	\rightarrow	X9 (Probuling hazard)	0.985**	3.918	Valid	0.964
X10.1 (Rock outcrops)	\rightarrow	X10 (Land	0.998**	189.133	Valid	0.995
X10.2 (Surface rock)	\rightarrow	preparation)	0.998**	320.273	Valid	

AVE = average variance extracted, LGP = long growth periods, CEC = cation exchange capacity, and ESP =
 exchangeable sodium percentage.

The measurement of the Fornell-Larcker criterion and cross-loading was used as the basis for assessing the discriminant validity of the model. The calculation results on the Fornell-Larcker criterion in Table 4 show that the average of the tested variables has a higher square root of AVE than the correlation value, hence, the latent variable was considered discriminantly valid. The square root value of the AVE must be greater than its correlation value with other constructs to meet the discriminant validity requirements [39]. The average loading factor value for the latent variable indicator was above that of others as shown in Table 5.

243 *3.1.2 Reliability test result*

The variables are considered reliable because composite reliability and Cronbach's alpha coefficient on average were more than 0.7 as shown in Table 6 [36], [40]. However, certain indicators still had values less than 0.6, namely soil texture but the indicators used are reliable and adequate in forming the latent variables.

The highest composite reliability and cronbach's alpha coefficients were obtained for the variables of temperature, oxygen availability, and toxicity of 1 for the variables to be very reliable. The lowest coefficient was obtained on the root condition variable, therefore, the variable was not reliable. According to Bagozzi and Yi [41] and Hair et al. [40], variables are considered good and accepted when the value is > 0.70.

The remaining variables are water availability, nutrient retention, available nutrients, erosion hazard, and land preparation variables. The coefficient of composite reliability and cronbach's alpha > 0.6, there, the variable is considered reliable. The minimum value of composite reliability and cronbach's alpha coefficients was 0.60 [36], [40], [41].

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Table 4: Fornell-Larker criterion test

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Y		
X1	1.000												
X2	0.940	0.952											
X3	0.059	0.149	1.000										
X4	0.082	0.030	-0.162	0.757									
X5	-0.360	-0.239	-0.103	-0.368	0.600								
X6	-0.069	0.021	0.012	-0.518	0.694	0.765							
X7	0.382	0.429	0.084	0.228	-0.030	-0.217	1.000						
X8	0.019	-0.082	-0.501	0.285	-0.317	-0.370	-0.009	0.966					
X9	-0.104	-0.033	0.237	-0.204	0.073	0.090	0.202	-0.250	0.992				
X10	0.198	0.093	-0.223	0.873	-0.303	-0.538	0.362	0.304	-0.126	0.998			
Y	0.018	0.152	0.169	-0.578	0.387	0.456	-0.016	-0.517	0.164	-0.568	1.000		

X1 = temperature, X2 = water availability, X3 = oxygen availability, X4 = rooting condition, X5 = nutrient retention, X6 = nutrient availability, X7 = sodicity, X8 = erosion hazard, X9 = flooding hazard, X10 = land preparation, Y = maize hybrid yield.

	Table 5: Cross-Loading of latent variables to indicators											
Indicators					Lat	ent Variab	les					
Indicators	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Y	
X1.1	1	0.8300	0.0312	0.0240	-0.2959	-0.0592	0.3270	0.0195	-0.0837	0.1680	-0.0204	
X2.1	0.9783	0.8379	-0.0035	-0.0063	-0.2488	-0.0320	0.3555	-0.0017	-0.0539	0.1552	0.0155	
X2.2	0.8534	0.9887	0.1938	-0.0557	-0.1257	0.0988	0.4025	-0.1435	-0.0279	-0.0178	0.1748	
X2.3	0.5223	0.8497	0.1523	0.2464	-0.2505	-0.1161	0.4641	-0.1494	0.0144	0.2154	0.0592	
X2.4	0.8293	0.9928	0.1721	-0.0334	-0.1524	0.0833	0.4440	-0.1713	-0.0383	-0.0031	0.1331	
X3.1	0.0312	0.1785	1	-0.1541	-0.1091	-0.0375	0.0843	-0.4964	0.2530	-0.2229	0.2156	
X4.1	-0.0058	-0.0006	-0.1696	0.0126	0.2127	0.1013	0.2173	0.1761	0.0055	-0.0225	0.0050	
X4.2	-0.0728	-0.1082	-0.0829	0.9212	-0.2754	-0.5494	0.1845	0.2891	-0.2674	0.7910	-0.5276	
X4.3	-0.1289	-0.1240	0.2071	-0.8990	0.2046	0.3209	-0.2633	-0.1587	0.0730	-0.7693	0.4666	
X5.1	-0.2975	-0.4140	-0.3824	-0.3027	0.6470	0.3024	-0.1283	0.1730	-0.0342	-0.1190	0.0718	
X5.2	-0.2033	-0.2939	-0.4480	-0.2791	0.5701	0.3176	-0.0273	0.1935	0.0801	-0.1829	0.1445	
X5.3	-0.2440	-0.0158	0.1276	-0.1134	0.8308	0.5651	0.0728	-0.5076	0.0545	-0.1147	0.3501	
X5.4	0.0537	0.1002	0.0033	0.0110	0.4360	0.4081	0.3732	-0.0504	0.1426	-0.0137	0.1395	
X5.5	-0.2717	-0.2512	-0.1053	-0.4382	0.3650	0.4343	-0.6008	-0.0619	-0.1498	-0.4876	0.0825	
X6.1	-0.0256	0.1778	0.0335	-0.1950	0.7028	0.7604	0.0453	-0.3878	-0.0809	-0.2162	0.2623	
X6.2	-0.1201	-0.2238	-0.4256	-0.2590	0.4149	0.5865	-0.2829	-0.0389	-0.0267	-0.2860	0.1025	
X6.3	-0.0437	0.0283	0.0310	-0.5607	0.5145	0.8974	-0.3341	-0.2613	0.2133	-0.6520	0.3892	
X7.1	0.3270	0.4411	0.0843	0.2420	0.0290	-0.2417	1	-0.0286	0.2142	0.3621	0.0487	
X8.1	-0.0226	-0.2234	-0.5132	0.2998	-0.2625	-0.3475	-0.0481	0.9537	-0.3383	0.3031	-0.5274	
X8.2	0.0649	-0.0590	-0.4223	0.1646	-0.2942	-0.2950	-0.0035	0.9409	-0.0988	0.2516	-0.4682	
X9.1	-0.0996	-0.0225	0.2254	-0.1949	0.1126	0.1483	0.1939	-0.2440	0.9835	-0.1342	0.2278	
X9.2	-0.0658	-0.0305	0.2717	-0.1860	0.0271	0.0449	0.2271	-0.2252	0.9849	-0.0901	0.2380	
X10.1	0.1848	0.0403	-0.2340	0.8480	-0.2309	-0.5544	0.3760	0.3058	-0.1188	0.9977	-0.5424	
X10.2	0.1503	0.0225	-0.2107	0.8629	-0.2274	-0.5592	0.3464	0.2812	-0.1076	0.9976	-0.5365	
											and the second	

Table 5. Cross-Loading of latent variables to indicators

Y.1

-0.0204

0.1413

0.2156

X1 = temperature, X2 = water availability, X3 = oxygen availability, X4 = rooting condition, X5 = nutrient retention, X6 = nutrient availability, X7 = sodicity, X8 = erosion

0.3790

0.0487

-0.5271

0.2367

-0.5408

270 hazard, X9 = flooding hazard, X10 = land preparation, Y = hybrid maize yield, X1.1 = temperature, X2.1 = rainfall, X2.2 = the wet month, X2.3 = the dry month, X2.3 = long growth period, X3.1 = drainage, X4.1 = texture, X4.2 = coarse material, X4.3 = effective depth, X5.1 = organic C, X5.2 = cation exchanges capacity, X5.3 = base

0.3425

271 272 saturation, X6.1 = total N, X6.2 = P availability, X6.3 = K exchangeable, X7.1 = the exchange sodium percentage, X8.1 = slopes, X8.2 = soil erosion, X9.1 = inundation

273 height, X9.2 = inundation period, X10.1 = rock outcrops, X10.2 = surface rock, Y.1 = hybrid maize yield.

-0.5479

Indicators (land characteristics)	Cronbach's Alpha	Composite Reliability
X1.1 (Temperature)	1.000	1.000
X2.1 (Rainfall)		
X2.2 (Wet month)	0.975	0.965
X2.3 (Dry month)	0.975	0.905
X2.4 (Long growth periods)		
X3.1 (Drainage)	1.000	1.000
X4.1 (Texture)		
X4.2 (Coarse material)	0.002^{nor}	-1.055 ^{nor}
X4.3 (Effective depth)		
X5.1 (pH H ₂ O)		
X5.2 (pH KCl)		
X5.3 (Organic C)	0.718	0.628
X5.4 (Cation exchange capacity)		
X5.5 (Base saturation)		
X6.1 (Total N)		
X6.2 (P availability)	0.805	0.681
X6.3 (K exchangeable)		
X7.1 (Exchangeable sodium percentage)	1.000	1.000
X8.1 (Slopes)	0.965	0.928
X8.2 (Soil erosion)	0.705	0.728
X9.1 (Inundation height)	0.992	0.984
X9.2 (Inundation period)	0.772	0.704
X10.1 (Rock outcrops)	0.998	0.995
X10.2 (Surface rock)	0.770	0.775

275 nor = not reliable.

276 3.1.3 Structural model test (inner models)

277 Land characteristics that have a significant correlation with hybrid maize yields show a high level of contribution to land quality in influencing hybrid maize yields as indicated in Figure 278 279 3. The figure shows a structural model of the relationship between indicator variables, namely 280 24 land characteristics, rectangular yellow, and latent variables, including 10 land qualities maize yield, and oval blue. It also shows a model for the relationship between latent variables 281 282 such as land qualities and maize yield as well as loading figures. The factor for each indicator 283 and path coefficient for land qualities has a direct effect on the value of maize yields.

284 For example, X8 (erosion hazard) significantly determines the hybrid maize yield with a path coefficient of -0.392. The negative sign indicates that the erosion hazard is negatively related 285 286 to maize yield, where the higher the erosion hazard, the lower the maize yield. Furthermore, nutrient retention (X5) contributes to the diversity of hybrid maize yields with a path coefficient 287 of 0.252. A positive sign indicates that nutrient retention is positively related to maize yield, 288 where the higher the value of nutrient retention were followed by the maize yield. 289



²⁹⁰

Figure 3: Path Coefficient of land quality on hybrid maize yield.

292 The results of this path analysis indicated that the land quality that can be a predictor of maize 293 yield diversity were oxygen availability (X3), nutrient retention (X5), nutrient availability 294 (X6), erosion hazard (X8), and land preparation (X 10). Figure 2 indicates that only 8 of the 24 295 indicators explain latent variance at the 5% real test level. The 8 indicators were coarse material and effective soil depth as an indicator of rooting condition, organic carbon content as nutrient 296 297 retention, exchangeable K as nutrient availability, soil erosion and slope as erosion hazard, as well as rock outcrop and surface rock as an indicator of land preparation. It was also indicated 298 299 that the drainage loading factor was unable to explain the diversity of oxygen availability. Therefore, oxygen availability cannot be used as a land quality because there are no indicators 300 that can represent it. Only the land qualities of nutrient retention (X5), nutrient availability 301 302 (x6), erosion hazard (x8), and land preparation (X10) were used next.

The indicators of land characteristics for effective depth, organic C, total N, and exchangeable K have a fairly strong positive relationship and a very significant effect on hybrid maize yields. In this relationship, an increase in these parameters by 1%, will be followed by a rise in hybrid maize yields of 39% to 57.7%. According to [4], effective depth affects root growth and development, making plants grow and develop properly. Moreover, the levels of organic C, total N, and CEC are influenced by soil organic matter [42], while potassium plays a role in the growth and development of maize [43].

- 310 Indicators of rough soil characteristics, slopes, soil erosion, as well as surface and rock outcrops
- 311 have a strong negative relationship with a very significant effect on hybrid maize yields. In this
- 312 relationship, a 1% decrease in coarse material, slope, soil erosion, as well as surface and rock
- 313 outcrop is followed by an increase in hybrid maize yields by 39% to 57.7%.

314 3.2. Optimum hybrid maize yield by the land quality and land characteristics

315 Table 7 shows the mathematical equations for each land characteristic and also the optimum 316 hybrid maize yield for the land equation. Figure 4 shows the diagram of the relationship between land characteristics as an independent variable (X) and maize yield as an independent 317 variable Y. Model fitting indicates that the quadratic equation is sufficient to describe the 318 319 condition of data distribution.

Land Quality/Land Characteristics	Optimum Yield (ton/ha)	Yield Equation	R
Rooting condition (rc)			
Coarse material	8.06	$Y = 0.0024800x^2 - 0.2457487x + 10.9082465$	0.9
Effective depth	8.35	$\begin{array}{l} Y = -0.0007242 x^2 + 0.1890458 x - \\ 1.2946385 \end{array}$	0.9
Nutrient retention (nr)			
Organic carbon	8.35	$Y = -24.3891969x^2 + 46.8464078X \\ - 8.8894056$	0.8
Nutrient availability (na)			
Total N	8.43	$Y = -304.4463543X^2 + 144.7590906X - 2.6328530$	1.(
K Exchangeable	5.74	$Y = -10.5596308X^2 + 17.4129832X + 2.2069179$	0.9
Erosion hazard (eh)			
Slopes	8.43	$Y = 0.0172X^2 - 0.8448X + 13.907$	0.9
Soil erosion	8.06	$y = 0.0000173X^2 - 0.0187536X + 9.0426459$	0.8
Land preparation (lp)			
Rock outcrops	7.30	$Y = 0.0046385X^2 - 0.2934756X + 8.5159674$	0.9
Surface rock	7.30	$\begin{split} Y &= 0.0046385 X^2 - 0.2934756 X + \\ 8.5159674 \end{split}$	0.9

321

320

The optimum of hybrid maize yield ranged from 5.74 to 8.43 ton/ha, where the highest yield 322 was obtained from total N and slopes of 8.43 ton/ha with an R^2 value of 100% and 91%. 323 324 Sutardjo et al (2012) showed that hybrid maize yields ranged from 7.43 to 9.2 ton/ha. This 325 indicated that the optimum yield achieved is still within the range of hybrid maize yields that 326 have been previously reported. Nitrogen is directly involved in the formation of amino acids, proteins, nucleic acids, enzymes, nucleoproteins, and alkaloids, which are needed in the plant 327 growth process [44], [45]. An extremely high amount of N causes excessive vegetative growth, 328 329 thereby making plants fall easily and increasing susceptibility to disease [46]. Meanwhile, the 330 lack of N nutrients can limit cell division, enlargement [47], and the formation of chlorophyll, 331 leading to stunted growth as well as yellowing of leaves [46].

The lowest optimum yield was obtained from exchangeable K, which was only 5.74 ton/ha 332 333 with an \mathbb{R}^2 value of 94%. This was presumably because the K content in the soil is very low,

334 thereby affecting the hybrid maize yield. Potassium (K) is required by plants for physiological

functions, including carbohydrate metabolism, enzyme activity, osmotic regulation, efficient 335

water use, N uptake, protein synthesis, and assimilate translocation [48]–[51]. It also plays a
role in improving the quality of crop yields (McKenzie, 2013, Subandi, 2013).

The optimum hybrid maize yield of the remaining is relatively diverse. This includes effective 338 depth and organic carbon, which were both 8.35 ton/ha with an R² value of 87%. Furthermore, 339 coarse material and soil erosion were 8.06 ton/ha with an R² value of 95% and 88%, while rock 340 341 outcrops and surface rock were 7.30 ton/ha with an R2 value of 91%. The absence of coarse 342 material > 2 mm in diameter indicated that plant roots can grow freely on the surface or deeper 343 parts of the soil [54], because the deeper the roots of the maize, the greater the maize yield 344 [55], [56]. The addition of organic matter will increase maize yield [57]–[59] and organic C content [60] because soil organic matter is a strong positive predictor of yield [61]. Kane et al. 345 346 [61] also stated that the addition of more organic matter will improve water retention, thereby 347 reducing maize yield losses due to drought. The slope has a significant effect on soil 348 degradation [62]. According to a previous study, erosion and maize yield are negatively correlated, hence, increased erosion will reduce maize productivity [63]. Soil erosion on flat 349 350 land is slower surface runoff [64]. It was also reported that surface rocks and outcrops are the limiting factors in the suitability of maize plantations [65]. Therefore, a high percentage of rock 351 352 outcrops will complicate land cultivation and plant root growth.

353 **3.3. Land suitability criteria for hybrid maize crops**

354 Table 8 shows the yield limit for each class from the calculation of the optimum yield, where the class range for each land characteristic is derived. Based on the optimum yield of the highest 355 356 hybrid maize, there were 2 indicators, namely the total N content and the slope. The total N indicator with a very suitable class (S1) was achieved when the value in the soil was greater 357 358 than 0.10%, while in the moderately suitable class (S2), it was achieved when the total N in 359 the soil ranges from 0.07-0.09%. In the marginally appropriate class (S3), the total N indicator 360 was achieved when the total N in the soil ranges from 0.05-0.06%, while the not suitable class (N) was achieved when the content was less than 0.05%. On the slope indicator with class S1, 361 it was obtained when the slope class ranges from 0-7.69%%, while class S2 was achieved when 362 the slope class ranges from 7.70-11.83%. Furthermore, in classes S3 and N, it was obtained 363 364 when the slope class ranged from 11.84-18.24% and greater than 18.24%, respectively.

Based on the optimum yield of the lowest hybrid maize, only the exchangeable K was the 365 indicator. In classes S1 and S2, it was achieved when the exchangeable K content in the soil 366 367 was greater than 0.24 cmol(+)/kg and ranges from 0.13-0.23 cmol(+)/kg, respectively. 368 Furthermore, class S3 was achieved when the exchangeable K content in the soil ranges from 0.04-0.12 cmol(+)/kg, while in class N, it was obtained when the exchangeable K content in 369 370 the soil was less than 0.04 cmol(+)/kg. The remaining variables and indicators were relatively 371 varied according to the optimum yield of hybrid maize and the range of land suitability classes 372 obtained as presented in Table 8.





Figure 4: Scatter diagram relationship among maize yield and land characteristics

Value of Land Suitability Criterion Yield Limits (ton/ha) Obtained Land Quality/Land **S1 - S2** S2 - S3S3 - NCharacteristics (80% x (60% x (40% x **S1 S2 S3** Ν Yoptim) Yoptim) Yoptim) Rooting condition (rc) 0 – 13.41 -27.38 -> Coarse material (%) 8.06 6.04 4.03 13.40 27.37 52.39 52.39 49.25 -33.18 -<Effective depth (cm) 8.35 6.26 4.18 ≥ 69.55 69.54 49.24 33.18 Nutrient retention (nr) 6.26 0.41 - 0.49Organic carbon (%) 8.35 4.18 ≥ 0.50 0.34 - 0.40< 0.34 Nutrient availability (na) Total N (%) 8.43 6.32 4.22 ≥ 0.10 0.07 - 0.090.05 - 0.06< 0.05 K Exchangeable 0.04 - 0.125.74 4.31 2.87 ≥ 0.24 0.13 - 0.23< 0.04(cmol(+)/kg)Erosion hazard (eh) 7.70 -0 – 11.84 -> Slopes (%) 8.43 6.32 4.22 18.24 7.69 11.83 18.24 Soil erosion > 8.06 6.04 4.03 ≤ 55.21 195.29 605.56 (ton/ha/year) 605.56 Land preparation (lp) 0 -4.46 -13.10 -> Rock outcrops (%) 3.85 7.30 5.47 4.45 13.09 31.78 31.78 0 – 4.46 -13.10 ->Surface rock (%) 7.30 5.47 3.85 4.45 13.09 31.78 31.78

 Table 8: Yield limits of hybrid maize and values obtained in each land suitability class interval by land quality and characteristics.

377 S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, and N = not suitable.

Based on the relationship between the quality and characteristics of the selected land with optimum results, the criteria for hybrid maize land suitability were obtained as shown in Table 8. These criteria described the actual state of achieving optimum, moderate, and minimum yields of hybrid maize in the field with values of 80%, 60%, and 40%, respectively. According to Sukarman et al. [66], the parameters used in the land suitability assessment must describe the actual conditions. This is due to the significant positive correlation between maize yield and land suitability class [67].

385 The land suitability criteria for the new hybrid maize are fewer and have referred to the optimum yield. Meanwhile, the land quality and characteristics in this new criterion are less 386 because it only consists of root conditions with characteristics of coarse material and effective 387 depth, nutrient retention with organic C, and nutrient availability with total N and K 388 exchangeable. It also consists of erosion hazards with characteristics of slopes and soil erosion, 389 390 as well as land preparation with surface rocks and rock outcrops only. The land qualities 391 selected and maize yields consistent with the land potential are the basis for developing suitability criteria. This will reduce the land characteristics and make the evaluation process 392 393 faster, cheaper, and easier with accurate results [14]. Some characteristics and land quality 394 criteria were not made because they did not significantly affect the yield of hybrid maize. The 395 number and distribution of the data were still limited and the diversity of values was small or 396 not measurable in the field [38].

Compared to Wahyunto et al. [68], the new land suitability criteria for hybrid maize plants in
 Table 9 is more realistic in value with the conditions in the field and is based on the
 achievement of optimum yields. The current land suitability criteria are still general and not

specific to maize yields [14], although the agronomic and yield potential of each maize variety differ, based on the diversity of characteristics and land quality in the field.

Land Quality/Land Characteristics	Nev		bility Criterio d Maize		l Suitabili General N	•		
Characteristics	S1	S2	S3	Ν	S1	S2	S3	Ν
Rooting condition (rc)								
Coarse material (%)	0 -	13.41 -	27.38 -	>	< 15	15 –	35 –	>55
Coarse material (%)	13.40	27.37	52.39	52.39		35	55	
Effective depth (cm)	\geq	49.25 -	33.18 -	<	> 60	60 –	40 -	< 25
Effective depth (chi)	69.55	69.54	49.24	33.18		40	25	
Nutrient retention (nr)								
Organic carbon (%)	\geq	0.41 0.40	0.34 - 0.40	< 0.34	>	0.8 -	< 0.8	-
Organic carbon (%)	0.50	0.41 - 0.49	0.34 - 0.40	< 0.54	1.20	1.2		
Nutrient availability (na)								
Total N (%)	≥ 0.10	0.07 - 0.09	0.05 - 0.06	< 0.05	Mo	Lo	VLo	-
K Exchangeable	\geq	0.10 0.00	0.04 0.12	.0.04	Mo-	Lo	VLo	-
(cmol(+)/kg)	0.24	0.13 - 0.23	0.04 - 0.12	< 0.04	Hi			
Erosion hazard (eh)								
<u>C1</u> (0/)	0 –	7.70 -	11.84 -	>	< 8	8 - 15	15 –	> 25
Slopes (%)	7.69	11.83	18.24	18.24			25	
Soil erosion	\leq	105 20	(05.5)	>	-	VLi	Li-	He-
(ton/ha/year)	55.21	195.29	605.56	605.56			Mo	VHe
Land preparation (lp)								
Deals automage (9/)	0 -	4.46 -	13.10 -	>	< 5	5 - 15	15 –	>40
Rock outcrops (%)	4.45	13.09	31.78	31.78			40	
Surface reals (9/)	0 -	4.46 -	13.10 -	>	< 5	5 - 15	15 –	>40
Surface rock (%)	4.45	13.09	31.78	31.78			40	

Table 9: Comparison of new and general land suitability criteria with land quality and characteristics.

404 moderate, Lo = low, VLo = very low, He = heavy, Li = light, VLi = very light, VHe = very heavy.

405 **Conclusions**

402

406 Land suitability criteria for the new hybrid maize are determined by land qualities, namely root conditions, nutrient retention, available nutrients, erosion hazard, as well as land preparation, 407 408 and land characteristics, including coarse material, effective depth, organic C, total N, exchangeable K, slopes, soil erosion, rock outcrops, and surface rocks. The highest optimum 409 yield of 8.35 ton/ha was achieved by the effective depth and organic C content for a very 410 suitable class (S1), while the lowest value of 5.47 ton/ha was attained by exchangeable K for 411 class S1. These results showed that the combination of the PLS-SEM and boundary line 412 analysis can be an alternative approach to establishing new land suitability criteria for crops 413 414 based on optimum yields and selected land quality.

415 Data Availability

416 All data can be obtained from the corresponding author upon request.

417 **Conflicts of Interest**

418 The authors declared that there is no conflict of interest regarding the publication of this paper.

419 **Funding Statement**

This study was funded by the Directorate of Research, Technology and Community Service,
Directorate General of Higher Education, Research and Technology, Ministry of Education,
Culture, Research and Technology of the Republic of Indonesia, grant number
B/105/UN47.D1/PT.01.03/2022.

424 Acknowledgments

- 425 The authors are grateful to the Ministry of Education, Culture, Research and Technology of
- 426 the Republic of Indonesia, and the Institute Research and Community Service of Universitas
- 427 Negeri Gorontalo for their financial and administrative support.

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1 Determination of Maize Hybrid Land Suitability Criteria Based

2 on Optimum Yield and Selected Land Quality

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12 Abstract

13 The significant effect of land quality on maize production has not been fully considered in the existing land suitability criteria. Therefore, this study aims to determine the hybrid maize land 14 15 suitability criteria based on the optimum yield and land quality. It was carried out in Boalemo 16 Regency, Indonesia, where the land unit of 67 units were surveyed to obtain land characteristics 17 data. A partial least square of structural equation model (PLS-SEM) with SmartPLS 8.0 was 18 used to select a robust land quality controlling hybrid maize yield, while the boundary line 19 method was used to determine optimum yield and differentiating of land suitability criteria. 20 The result showed that land qualities that define the optimum yield of hybrid maize were root 21 conditions, nutrient availability, nutrient retentions, land preparation, and erosion hazard. The 22 soil characteristics were effective depth, coarse material, organic C, total N, K exchangeable, slopes, soil erosion, rock outcrops, and surface rocks. Furthermore, the highest optimum yield 23 24 of 8.35 ton/ha was achieved by the effective depth and organic C content for a very suitable 25 class (S1), while the lowest of 5.47 ton/ha was obtained by exchangeable K for class S1. This 26 showed that the combination of PLS-SEM and boundary line analysis was a better approach to

27 developing new land suitability criteria for hybrid maize.

28 **1. Introduction**

- Food security and farmer prosperity are global concerns, this makes every country increase crop production as well as farmers' income. An important issue for countries with developing economies is ensuring food security, where the agricultural sector plays a strategic role in increasing food availability [1]. Although the global food system has placed maize (*Zea mays*
- L.) as the leading cereal crop [2], its productivity is being disrupted by land degradation, water
- 34 scarcity, and climate change [3].
- In Indonesia, the wet tropical climate with rainfall and high temperatures tends to reduce the quality of land and agricultural products [4]. This country ranked 8th among the maizeproducing nations with a contribution of 2.19% and 2.42% of the world's total harvested area [5]. However, the main problem is the relatively low level of yield in several regions because the achievement of maize production has not been followed by an increase in yield per unit area [6]. This is indicated by the average yield in 2020, which was up to 5.57 ton/ha [5].

According to a previous investigation, maize production in Indonesia can reach between 10-12
 ton/ha [7], [8] thereby making the country the 21st leading importer in the world.

In Indonesia, Gorontalo Province is one of the centers of maize production, where the hybrid
type is the most widely grown species [9]. The maize production in the province reached 1.8
million tons in 2021 [10], with several export advantages and competitiveness [11].
Furthermore, the planting of hybrid, composite, and local maize types has reached more than
98.90%, 0.68%, and 0.41% only, respectively [12] including Boalemo Regency.

48 Boalemo Regency ranks third as a maize-producing center in Gorontalo Province with a 49 contribution of 18.90% [13]. The maize plant dominates the use of agricultural land in this 50 district by 37.43% [14], therefore, the commodity has competitive and comparative advantages 51 with a PCR value of 0.80 and 0.91 DRC. This is because maize plant is supported by land area, 52 climatic conditions, production facilities, as well as market guarantees, and the basic price of 53 buying corn from the government [15]. In 2021, the average hybrid and local maize yields in 54 the regency reached 5.20 tons/ha [16] and 2.34-3.30 tons/ha, respectively [17]. This indicated 55 that the productivity of hybrid maize is still higher than local maize [18] but with lower achievement compared to the national maize production of 5.57 tons/ha [5] and has not yet 56 57 reached the target of 5.60 tons/ha in 2021 [19]. The production of hybrid maize in Gorontalo 58 can reach 9.78-13.11 tons/ha [20] because it is often cultivated on land that does not meet the 59 required qualities [6]. Therefore, there is a need to determine land quality-based hybrid maize land suitability criteria for site-specific land use planning in Boalemo District. 60

61 Maize is usually grown on land with low yield potential [21] and soil fertility, thereby causing low productivity [22]. Moreover, land productivity is determined by quality and characteristics 62 63 [23], [24], while land quality has a close relationship with maize yields [25]. The land quality 64 affecting the optimum yield of maize needs to be determined [26] and increased by using hybrid 65 varieties that have high yields. This makes it necessary to evaluate the suitability of the hybrid maize in a region to ensure optimal production. The land suitability criteria for hybrid maize 66 67 are not yet available because the current criterion is the general suitability of maize plants without distinguishing between hybrids and inbreds. Therefore, there is a need to make land 68 69 suitability criteria for hybrid maize plants.

- 70 A previous study has shown that land quality has a significant effect on suitability for certain 71 uses [27]. Meanwhile, land suitability is also important due to the continuous increase in the 72 demand for agricultural land [28]. The land suitability criteria for existing maize fields are still 73 general [29] and there are no specific criteria for hybrid maize varieties. The class assessment 74 outcomes obtained using the existing criteria are relatively many and are not in line with the 75 actual field results [30]. The current criteria consist of 3 components, namely, land quality, 76 characteristics, and ranges of land characteristic values to determine its suitability. Therefore, 77 the problem in developing criteria is choosing land quality, characteristics, and determining the 78 range of land characteristic values associated with suitability classes, namely suitable, 79 somewhat suitable, marginally suitable, and not suitable.
- 80 The selection of land quality and characteristics can be carried out through the partial least 81 square of the structural equation model (PLS-SEM), while the range limits is being determined 82 by the boundary line method. Land qualities and characteristics in the current criteria can be 83 used temporarily since structural equation model analysis with partial least squares produces
- better indicators and models than other multivariate analysis with partial least squares produces the
- variant-based PLS-SEM has a higher level of flexibility and the size of the sample used is

- relatively small ranging from 30 to 100 [36]–[39]. The use of PLS-SEM to determine land
- 87 characteristics and qualities that control maize crop yields is still relatively rare, except for Syaf
- 88 [40] on older cocoa plants, maize composite [41], and on local varieties [6]. The boundary line 89 method can help determine nutrient adequacy concentrations and the optimum yield range of
- method can help determine nutrient adequacy concentrations and the optimum yield range of a plant that affects nutrients, as well as other land characteristics [42], [43]. Currently, the land
- 91 suitability criteria for maize plants have not been determined using the boundary line method,
- 92 except by Ridayanti et al. [44], although the investigation was not specific to hybrid maize.

93 After obtaining the quality and characteristics of land affecting maize yields with PLS-SEM,

- 94 the boundary line method can be used to determine the optimum yield as well as land suitability
- 95 criteria simultaneously. This is carried out by drawing the intersection of the boundary line at
- 96 the yield and projecting with the land characteristics [29]. Therefore, this study aims to
- determine land suitability criteria for hybrid maize based on the optimum yield and landquality.

99 2. Materials and Methods

100 **2.1 Study area**

The study area extends from 0°28'5.6" - 0°57'30.02" N to 122°08'34.25" - 122°43'10.41"E 101 (Figure 1) on a scale of 1 : 65,000, which is located in the agricultural land of Boalemo 102 103 Regency, Gorontalo Province, Indonesia. The maximum air temperature was 28.19°C and the minimum was 26.79°C with an average of 28.01°C. Meanwhile, the maximum rainfall was 104 105 1,849 mm and the minimum was 1,246 mm with an average of 1,478 mm [45]. The wet and 106 dry seasons last for 3 months and 5 months respectively. The soil mapping carried out by Ritung et al. [46] become the initial reference for determining 35 soil units, where each unit 107 has information on land characteristics, namely effective depth, drainage, texture, pH, cation 108 109 exchange capacity, base saturation, landform, parent material, relief, and land unit area. This unit was detailed by adding 32 soil units to be surveyed and observed, making up to 67 soil 110 units in the area as shown in the legend Figure 1. The detailing was carried out because the soil 111 unit was previously presented at a scale of 1: 50,000, without including several key areas. 112 Meanwhile, the new soil unit is 1: 40,000 in scale and there has been a change in the agricultural 113 land use existing. This indicated that the slope class of 8 - 15% or hilly is more dominant in 114 the study area with a percentage of 29.77% and slopes > 40% or mountainous which is only 115 116 2.67%. Furthermore, the dry land is dominant with a value of 59.86% and a little shrub which was only 9.21%, while the dominant Inceptisol soil type was 36.18% and very little Ultisol soil 117 118 was 8.88%.



120

Figure 1: Study area.

121 **2.2 Dataset collection for land quality and land characteristics**

122 The quality and characteristics of the land in this study refer to Wahyunto et al. [47], consisting of 10 land qualities and 24 characteristics. The set of temperature land quality is determined 123 124 from the characteristics of the annual average air temperature, while the land quality water 125 availability is determined from the characteristics of annual rainfall, wet months, dry months, 126 and the length of the growth period (LGP). Land quality oxygen availability is determined from 127 soil drainage characteristics, rooting conditions are determined from the soil texture, coarse material, and soil effective depth, nutrient retention is identified from the pH value, C-Organic, 128 129 cation exchange capacity (CEC), and base saturation. Furthermore, the available nutrient is 130 determined from the characteristics of total N, P, and exchangeable K, the sodicity is obtained from the exchangeable sodium percentage (ESP), while erosion hazard is determined from 131 slopes and soil erosion. The quality of the flood-hazard land is determined by identifying the 132 height and the duration of the inundation, while preparation is carried out from the 133 characteristics of outcrops and surface rocks. The selection of this set of land qualities and 134 135 characteristics is based on the availability of data and their impact on maize production [26].

Data on average annual air temperature and rainfall for 10 years (2010-2021) were collected
from different climate stations, namely the Bandungrejo with 0°41' N - 122°38' E, the elevation
40 m asl, while Harapan has 0°42' N - 122°29' E and an elevation of 37 m asl. It also includes
Lakeya Rain Post with 0°42.82' N - 122°32.07' E, 32 m asl, Mohiyolo has 0°46.41' N 122°26.41' E and an elevation of 39 m asl, Saritani 0°46.45' N - 122°20.40' E, with 26 m asl,
Tangkobu 0°37.25' N - 122°36.36' E, 25 m asl, Bubaa 0°31.36' N - 122°33.39' E, 16 m asl,
Wonggahu 0°38' N - 122°33' E, 35 m asl, and Sambati Rain Post with 0°31.184' N - 122°27.074'

143 E and an elevation of 9 m asl managed by BWS II Sulawesi. Furthermore, these data determined wet months (> 200 mm) and dry months (<100 mm), which refers to the Oldeman 144 and Darmiyati criteria [48]. The land water balance was determined using the Thornwhite and 145 146 LGP methods based on the number of surplus and deficit rainy days [49]. Soil characteristics such as drainage, coarse material, effective soil depth, slope, inundation 147 148 height and duration, rock outcrops and surface rocks were determined by conducting soil 149 profile descriptions and direct observation on 67 pedons referring to the description guidelines in the field [50]. Meanwhile, soil erosion was determined by the USLE method [51]. Other soil 150 151 characteristics were further analyzed in the soil laboratory using samples from each pedon. Soil samples were dried for 3 days and sieved through a 2 mesh sieve. The method of soil 152 153 physics laboratory analysis was carried out according to the procedures by Kurnia et al. [52]. 154 Based on this procedure, soil texture was analyzed in terms of sand, clay, and silt fractions using the pipette method, while soil moisture storage was evaluated using the gravimetric 155 method that can be applied in water balance analysis. The method of soil chemistry laboratory 156 157 analysis was carried out according to the procedures by Eviyati and Sulaeman [53]. The soil pH was determined with a pH meter in a 1:2.5 soil and water solution, while the organic C 158 159 content was assessed using the Walkley and Black method. The total N was assessed using the 160 Kjeldahl method, while the available P content was measured using the Olsen method. The basic cations and CEC was extracted with 1N NH₄OAc pH 7.0 (ammonium acetate) on a dry 161 sample of 105°C. The base saturation was determined by calculating the percentage of basic 162 163 cations number with CEC, ESP was evaluated using the percentage ratio of sodium to CEC [54] [55]. Subsequently, the data from the chemical analysis were averaged to a depth of 0-30 164 cm using the weighted averaging technique. The framework of this study is presented in Figure 165 2.



169 2.3 Dataset collection for hybrid maize yield

167 168

The areas currently planted with hybrid maize were identified and blocks with a size of 2.5 m 170 171 x 2.5 m were made in each map unit (Figure 1). Maize plants in each block passed through 172 standardized management according to farmers' technology. After harvesting, weighting was carried out to obtain hybrid maize yield data from the results of tiles on each land unit. 173 174 Subsequently, the results were calculated using the formula [56], as expressed below: $Y(t) = H x \frac{A}{6.25 m}$ 175 (1)Meanwhile, productivity is calculated using the formula [56] below: 176 H x 1.64 x 56.73 $(t h a^{-1})$ 177 (2)100

where Y = hybrid maize yield, H = tile yield (kg), A = maize area 1 per hectare (ha), 1.64
and 56.73 = constant.

180 **2.4 Selection of land quality and land characteristics**

The quality and characteristics of the land in the suitability criteria were used as presented in 181 182 Tables 1 and 2, which show brief statistics. Generally, most data are relatively homogenous, except for coarse material, available P, slopes, soil erosion, height and inundation, as well as 183 rock outcrops and surface rocks. The selection used the partial least squares of the structural 184 equation model (PLS-SEM) refers to Hair et al. [38] with tools SmartPLS, where land quality 185 and characteristics were selected as the latent and manifest variables, respectively. The analysis 186 in PLS-SEM has 2 main steps, namely (1) the measurement model (outer model) and (2) the 187 188 structural model test (inner model).

La	tent variables		Indicators		
Notation	Land quality	Notation	Land characteristics	Data Sources	
X1	Temperature (t)	X1.1	Temperature	[45]	
<mark>X2</mark>	Water availability	X2.1	Rainfall	<mark>[45]</mark>	
	(wa)	<mark>X2.2</mark>	<mark>Wet month</mark>	Rainfall > 200 mm	
		<mark>X2.3</mark>	Dry month	Rainfall < 100 mm	
		<mark>X2.4</mark>	Long growth period	Water balance (Thorn	
			(LGP)	method), soil moisture	
				storage (Gravimetric method), water surplu	
				defisit days	
X3	Oxygen availability	X3.1	Drainage	Soil survey and land	
210	(oa)	713.1	Drumage	observation	
X4	Rooting condition	X4.1	Texture		
	(rc)	X4.1.1	Sand fraction	Pipet method	
		X4.1.2	Silt fraction	ripet method	
		X4.1.3	Clay		
		X4.2	Coarse material	Soil survey and land	
V.C		X4.3	Effective depth	observation	
X5	Nutrient retention (nr)	X5.1 X5.2	pH H2O pH KCl	pH meter (1 : 2.5)	
		X5.2 X5.3	Organic C	Walkley and Black me	
		X5.4	Cation exchange	1N NH ₄ OAc pH 7.0	
			capacity (CEC)	Extracted	
		<mark>X5.5</mark>	Base saturation	Calculation	
X6	Nutrient	<mark>X6.1</mark>	Total N	Kjeldahl method	
	availability (na)	<mark>X6.2</mark>	P availability	Olsen method	
		X6.3	K exchangeable	1N NH ₄ OAc pH 7.0	
V7	$0 \cdot 1! \cdot ! + \cdot (-)$	V7 1	F 1 = 1 = 1'	Extracted	
<mark>X7</mark>	Sodicity (xn)	X7.1	Exchangeable sodium percentage (ESP)	Calculation	
<mark>X8</mark>	Erosion hazard (eh)	X8.1	Slopes	Soil survey and land	
210		X8.2	Soil erosion	observation	
X9	Flooding hazard	X9.1	Inundation height	Soil survey and land	
	(fh)	X9.2	Inundation period	observation	
<mark>X10</mark>	Land preparation	X10.1	Rock outcrops	Soil survey and land	
	(lp)	X10.2	Surface rock	observation	

(3)

(4)

191 Step 1 consists of validity and reliability tests, wherein the validity test is conducted with 192 convergent and discriminant validity. The convergent validity is in form of outer loadings (loading factor) and average variance extracted (AVE), while discriminant validity is in form 193 of cross-loading and the Fornell-Larcker criterion. Meanwhile, the reliability test uses 194 195 composite reliability and Cronbach's alpha.

Convergent validity was observed from the magnitude of the outer loading and the AVE value 196 of each indicator on the latent variable. The validity was calculated according to the equation 197 [57][58][59][60]: 198

- 199 $x_i = \lambda x_i \xi_1 + \delta_i$
- $y_i = \lambda y_i \eta_1 + \varepsilon_i$ 200

203

where x and y = exogenous (ξ) and endogenous (η) latent variable indicator, λx and λy = 201 loading factors, δ and ε = residual/measurement errors or noise.

Table 2: Brief statistics of land quality and characteristics.							
Latent variables /	Unit	n	Min	Median	Mean	Max	<mark>SD</mark>
Indicators X1 (Temperature)							
X1.1 (Temperature)	°C	<mark>67</mark>	<mark>26.79</mark>	27.80	28.01	28.19	<mark>0.63</mark>
X2 (Water availability)	<u> </u>	07	20.79	27.00	20.01	20.17	0.05
X2.1 (Rainfall)	mm	<mark>67</mark>	1,246.00	1,533.42	1,478.00	1,849.00	232.69
X2.2 (Wet month)	month	<u>67</u>	0.00	1,000.12	1,170.00	3.00	0.85
X2.3 (Dry month)	month	67	2.00	3.39	4.00	5.00	1.06
X2.4 (LGP)	day	67	211.00	246.00	214.00	304.00	44.54
X3 (Oxygen availability)							
X3.1 (Drainage)	class	<mark>67</mark>	0.00	3.76	4.00	<mark>6.00</mark>	1.82
X4 (Rooting conditions)							
X4.1 (texture)	class	<mark>67</mark>	<mark>1.00</mark>	<mark>2.21</mark>	<mark>2.00</mark>	<mark>5.00</mark>	<mark>0.99</mark>
X4.1.1 (Sand fraction)	<mark>%</mark>	<mark>67</mark>	<mark>5.00</mark>	<mark>41.58</mark>	<mark>43.00</mark>	81.33	18.51
X4.1.2 (Silt fraction)	<mark>%</mark>	<mark>67</mark>	7.33	27.31	<mark>24.50</mark>	<mark>51.50</mark>	11.54
X4.1.3 (Clay)	<mark>%</mark>	<mark>67</mark>	11.33	<mark>31.90</mark>	<mark>30.00</mark>	56.33	12.72
X4.2 (Coarse material)	<mark>%</mark>	<mark>67</mark>	<mark>5.00</mark>	17.27	10.00	70.00	16.58
X4.3 (Effective depth)	cm	<mark>67</mark>	10.00	74.55	74.00	160.00	36.40
X5 (Nutrient retention)							
X5.1 (pH H ₂ O)		<mark>67</mark>	<mark>5.00</mark>	<mark>5.92</mark>	<mark>5.90</mark>	7.15	0.52
X5.2 (pH KCl)	_	<mark>67</mark>	<mark>4.35</mark>	<mark>5.24</mark>	<mark>5.17</mark>	<mark>6.60</mark>	<mark>0.56</mark>
X5.3 (Organic C)	<mark>%</mark>	<mark>67</mark>	0.41	<mark>0.85</mark>	<mark>0.77</mark>	<mark>2.35</mark>	<mark>0.39</mark>
X5.4 (CEC)	cmol(+)/kg	<mark>67</mark>	<mark>8.94</mark>	<mark>24.89</mark>	22.43	<mark>59.57</mark>	11.41
X5.5 (Base saturation)	<mark>%</mark>	<mark>67</mark>	<mark>45.03</mark>	<mark>56.22</mark>	<mark>52.85</mark>	<mark>81.89</mark>	<mark>9.76</mark>
X6 (Nutrient availability)	_	_					
X6.1 (Total N)	<mark>%</mark>	<mark>67</mark>	0.04	0.09	0.08	0.27	0.04
X6.2 (P availability)	mg/kg	<mark>67</mark>	0.73	<mark>8.62</mark>	3.77	<mark>58.67</mark>	12.61
X6.3 (K exchangeable)	cmol(+)/kg	<mark>67</mark>	<mark>0.07</mark>	<mark>0.39</mark>	<mark>0.24</mark>	<mark>1.92</mark>	0.42
X7 (Sodicity)	_	-		_			
X7.1 (ESP)	<mark>%</mark>	<mark>67</mark>	<mark>0.76</mark>	<mark>7.06</mark>	<mark>6.20</mark>	24.17	<mark>5.62</mark>
X8 (Erosion hazard)		~ =	1.00	0.50	6.00		
X8.1 (Slopes)	<mark>%</mark>	<mark>67</mark>	1.00	9.58	6.00	25.00	7.29
X8.2 (Soil erosion)	ton/ha/year	<mark>67</mark>	<mark>3.66</mark>	<mark>334.51</mark>	110.27	1772.43	<mark>439.08</mark>

	X9 (Flooding hazard) X9.1 (Inundation height) cm 67 0.00 7.58 0.00 50.00 17.10 X9.2 (Inundation period) day 67 0.00 0.64 0.00 5.00 1.52
	X10 (Land preparation) X10.1 (Rock outcrops) % 67 0.00 6.64 0.00 45.00 11.56 X10.2 (Surface rock) % 67 0.00 6.58 0.00 45.00 11.59
204 205	Y (Hybrid maize yield)ton/ha 67 2.85 4.95 4.68 8.07 1.15 n = the number of the land unit, min = minimum, max is maximum, SD = standard deviations, LGP = long growth periods, CEC = cation exchange capacity, and ESP = exchangeable sodium percentage.
206 207	Meanwhile, the average variance extracted (AVE) value was calculated using the equation [61][62][63][64][65]:
208	$AVE = \frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i var(\varepsilon_i)} $ (5)
209	Where λ^2_i = the loading factor, var = the variance, and ε_i = the error variance.
210 211 212 213 214	The loading factor of an indicator with the highest value is the strongest or most important measure in reflecting the latent variable. In this study, the loading factor value is > 0.70 for selecting best land characteristics, but values ranging from 0.50-0.60 can still be tolerated with a t-statistic > 1.96 or a small p-value of 0.05 [37], [66]. Meanwhile, the AVE value used was more than 0.50, showing that the convergent validity on the latent variable has been reached.
215 216 217 218 219 220 221 222	The discriminant validity test used the cross-loading value and the Fornell-Larker criterion to test discriminantly valid indicators in explaining or reflecting latent variables. When the correlation between the latent variables and the core measurement of each indicator is high, the latent variable can predict the indicator better and is considered valid. The discriminant validity is measured by the square root of the average variance extracted, which will be compared with the correlation value between variables. The value calculated based on the square root of AVE must be higher than the correlation between constructs [61]. The equation is expressed below [61][67][63][64][65]:
223	Square Root of AVE = $\sqrt{\frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i var(\varepsilon_i)}}$ (6)
224	where λ^2_i = the loading factor, var = the variance, and ε_i = the error variance.
225 226 227 228	Furthermore, the composite reliability and Cronbach's alpha were used to test the reliability value between indicators of the latent variables. They are considered good and accepted when the value is > 0.70 and has a minimum value of 0.60 [37]. The composite reliability value is calculated using the equation [68][62][69][65]:
229	$\rho c = \frac{(\sum \lambda_i)^2}{(\sum \lambda_i)^2 + \sum i var(\varepsilon_i)} \tag{7}$
230	where λ_i = the loading factor, var = the variance, and ε_i = the error variance.
231	Meanwhile, the value of Cronbach's Alpha is calculated according to the equation [70][65]:

(9)

(10)

232
$$\alpha = \left(\frac{\sum p \neq p'}{p_{q+\sum p \neq p'}} \left(\frac{p_{q,X_{p'q}}}{p_{q+\sum p \neq p'}}\right) \left(\frac{p_{q}}{p_{q-1}}\right) \right)$$
(8)

233 where P_q = the number of indicators or manifest variables, and q = the indicator block.

- For step 2, the structural model testing (inner model) was carried out after the relationship model was built in line with the observed data and the overall suitability, namely goodness of
- fit. The structural equation (inner model) is as follows [62][59][60]:
- 237 $H_j = \gamma_j \xi_1 + \gamma_j \xi_2 + \dots + \gamma_j \xi_n + \zeta_j$
- 238 where η_j = endogenous variable vector (dependent), $\gamma_j \xi_1 + \gamma_j \xi_2 + \dots + \gamma_j \xi_n$ = exogenous latent 239 variable vector, and ς_j = residual vector (error).
- 240 Meanwhile, the determinant coefficient and goodness of fit (Q^2) were calculated using the 241 equation [62][64][70]:
- 242 Q^2 (*Predictive relevance*) = 1 (1 R₁²) (1 R₂²) ... (1 R_p²)
- 243 where R_1^2 , R_2^2 , ... $R_p^2 = R$ square of endogenous variables in the equation model [68].

The quantity of Q^2 has a value with a range of 0 < Q2 < 1, the closer the value to 1, the better the model [37]. It is also equivalent to the coefficient of total determination in path analysis. Furthermore, the effect and significance were tested based on the estimated value of the path coefficient and the critical point value (t-statistics or p-value) at = 0.05. The relationship model between variables was measured by testing the direct correlation coefficient between variables. The results of testing the relationship between *X* and *Y* variables were indicated by the correlation coefficient as well as t-statistics, and are also presented in the path diagram.

251 2.5 Class assignment

To determine the class-required data for optimum results, class limits were calculated from the percentage of optimum results. After knowing the highest and lowest yields, the values were connected with the range of land characteristics values. The land suitability class and yield used referred to FAO [71], namely class S1 (very suitable) when the values reach 80-100%, S2 was moderately suitable 60-80%, S3 marginally suitable 40-60%, and N not suitable <40% of the optimum capacity.

258 The optimum yield was determined using the boundary line method. This method is carried out by drawing a boundary line on the graph of the relationship between yield and land 259 characteristics to obtain optimum results. In the boundary line method according to 260 Widiatmaka et al. [72], each land characteristic is plotted on the X-axis, while hybrid maize 261 yields are plotted on the Y-axis. Bhat and Sujatha [42] stated that the preparation of the hybrid 262 263 maize yield boundary line includes the preparation of a scatter diagram between the X and the Y variable, (2) division of the X-axis into several classes of intervals, (3) determination of the 264 highest data points in each class interval, (4) preparation of boundary lines based on the highest 265 266 data points from each class interval, (5) draw a line parallel to the X-axis according to the 267 percentage of the result class.
Furthermore, with the Microsoft Excel application tools, the boundary between classes S1 to S2, S2 to S3, and S3 to N were determined by the Data menu \rightarrow What-if-Analysis \rightarrow Goal Seek \rightarrow Set the cell at the location containing the regression equation \rightarrow to value fill with the result limit values S1 to S2, S2 to S3, and S3 to N \rightarrow By changing cell \rightarrow the location where the value of the characteristics of the land will be sought \rightarrow Ok. On location "By changing cell", the number being searched will appear, and at the location "set cell" will be equal to the limit value of the result.

275 **3. Results and Discussion**

276 **3.1 Land quality and characteristics controlling hybrid maize yield**

277 3.1.1 Validity test result

278 Table 3 shows the loading factor of the variables, where most indicators were more than the 279 critical limit of 0.70 with a 95% confidence level (P > 1.960). Therefore, these variables are highly recommended and the indicators are considered convergently valid. In the soil texture 280 indicator for the latent variable of root conditions as well as the cation exchange capacity (CEC) 281 and base saturation (BS) indicators for nutrient retention, the loading factor was below the 282 tolerance value of 0.50 at the 95% confidence level (P < 1.960), hence, it was not used. This 283 284 implies that the indicators have not been established or explained properly because the standard 285 value of the loading factor must be greater than or equal to 0.50 [37], [38], [66].

The average variance extracted (AVE) value of almost all variables was greater than 0.50, therefore, it was considered convergently valid [61][73]. The AVE value of the available nutrient variable was not valid due to the smaller value of the loading factor for the CEC and BS indicators of 0.50, leading to the removal of both indicators. A similar result was discovered in the root condition variable, although the AVE value was greater than 0.50, while the soil texture indicator was not used because the loading factor value is only 0.013.

2	g	2
4	/	-

Table 3: Outer loading (loading factor) and the average variance extracted from study variables.

Indicators (land characteristics)		Latent Variables (land quality)	Loading Factors	t-Stat	Status	AVE
X1.1 (Temperature)	\rightarrow	X1 (Temperature)	1.000**	11.192	Valid	1.000
X2.1 (Rainfall)	\rightarrow		0.838	0.085	Valid	
X2.2 (Wet month)	\rightarrow	V2 (Watan availability)	0.989	0.999	Valid	0.906
X2.3 (Dry month)	\rightarrow	X2 (Water availability)	0.850	0.428	Valid	0.900
X2.4 (LGP)	\rightarrow		0.993*	1.431	Valid	
X3.1 (Drainage)	\rightarrow	X3 (Oxygen availability)	1.000	0.000	Valid	1.000
X4.1 (Texture)	\rightarrow		0.013	0.066	Invalid	
X4.2 (Coarse material)	÷	X4 (Rooting condition)	0.921	1.086	Valid	0.573
X4.3 (Effective depth)	\rightarrow		-0.899	1.047	Valid	
X5.1 (pH H ₂ O)	\rightarrow		0.647	0.857	Valid	0.360
X5.2 (pH KCl)	\rightarrow	X5 (Nutrient retention)	0.570**	1.973	Valid	(invalid)
X5.3 (Organic C)	\rightarrow		0.831**	3.135	Valid	(mvand)

X5.4 (CEC)	\rightarrow		0.436*	1.381	Invalid	
X5.5 (Base saturation)	\rightarrow		0.365	0.845	Invalid	
X6.1 (Total N)	\rightarrow		0.760**	3.226	Valid	
X6.2 (P availability)	\rightarrow	X6 (Nutrient	0.587*	1.385	Valid	0.595
X6.3 (K exchangeable)	\rightarrow	availability)	0.897**	6.907	Valid	0.585
X7.1 (ESP)	\rightarrow	X7 (Sodicity)	1.000	0.000	Valid	1.000
X8.1 (Slopes)	\rightarrow	V9 (English hand)	0.954**	21.438	Valid	0.022
X8.2 (Soil erosion)	\rightarrow	X8 (Erosion hazard)	0.941**	18.308	Valid	0.932
X9.1 (Inundation height)	<i>></i>	V0 (Election charged)	0.984**	4.213	Valid	0.084
X9.2 (Inundation period)	\rightarrow	X9 (Flooding hazard)	0.985**	3.918	Valid	0.984
X10.1 (Rock	\rightarrow	X10 (Land	0.998**	189.133	Valid	
outcrops)		preparation)	0.770	107.133	v allu	0.995
X10.2 (Surface rock)	\rightarrow	preparation)	0.998**	320.273	Valid	

AVE = average variance extracted, LGP = long growth periods, CEC = cation exchange capacity, and ESP = exchangeable sodium percentage

exchangeable sodium percentage.

The measurement of the Fornell-Larcker criterion and cross-loading was used as the basis for assessing the discriminant validity of the model. The calculation results on the Fornell-Larcker criterion in Table 4 show that the average of the tested variables has a higher square root of AVE than the correlation value, hence, the latent variable was considered discriminantly valid. The square root value of the AVE must be greater than its correlation value with other constructs to meet the discriminant validity requirements [69][74]. The average loading factor value for the latent variable indicator was above that of others as shown in Table 5.

302 *3.1.2 Reliability test result*

The variables are considered reliable because composite reliability and Cronbach's alpha coefficient on average were more than 0.7 [61], [75] as shown in Table 6. However, certain indicators still had values less than 0.6, namely soil texture but the indicators used are reliable and adequate in forming the latent variables.

The highest composite reliability and cronbach's alpha coefficients were obtained for the variables of temperature, oxygen availability, and toxicity of 1 for the variables to be very reliable. The lowest coefficient was obtained on the root condition variable, therefore, the variable was not reliable. According to Bagozzi and Yi [76] and Hair et al. [75], variables are considered good and accepted when the value is > 0.70.

The remaining variables are water availability, nutrient retention, available nutrients, erosion hazard, and land preparation variables. The coefficient of composite reliability and cronbach's alpha > 0.6, there, the variable is considered reliable. The minimum value of composite reliability and cronbach's alpha coefficients was 0.60 [61], [75], [76].

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Table 4: Fornell-Larker criterion test

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Y
X1	1.000										
X2	0.940	0.952									
X3	0.059	0.149	1.000								
X4	0.082	0.030	-0.162	0.757							
X5	-0.360	-0.239	-0.103	-0.368	0.600						
X6	-0.069	0.021	0.012	-0.518	0.694	0.765					
X7	0.382	0.429	0.084	0.228	-0.030	-0.217	1.000				
X8	0.019	-0.082	-0.501	0.285	-0.317	-0.370	-0.009	0.966			
X9	-0.104	-0.033	0.237	-0.204	0.073	0.090	0.202	-0.250	0.992		
X10	0.198	0.093	-0.223	0.873	-0.303	-0.538	0.362	0.304	-0.126	0.998	
Y	0.018	0.152	0.169	-0.578	0.387	0.456	-0.016	-0.517	0.164	-0.568	1.000

X1 = temperature, X2 = water availability, X3 = oxygen availability, X4 = rooting condition, X5 = nutrient retention, X6 = nutrient availability, X7 = sodicity, X8 = erosion hazard, X9 = flooding hazard, X10 = land preparation, Y = maize hybrid yield.

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Table 5: Cross-Loading of latent variables to indicators

Indiastana					Lat	ent Variab	les				
Indicators	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Y
X1.1	1	0.8300	0.0312	0.0240	-0.2959	-0.0592	0.3270	0.0195	-0.0837	0.1680	-0.0204
X2.1	0.9783	0.8379	-0.0035	-0.0063	-0.2488	-0.0320	0.3555	-0.0017	-0.0539	0.1552	0.0155
X2.2	0.8534	0.9887	0.1938	-0.0557	-0.1257	0.0988	0.4025	-0.1435	-0.0279	-0.0178	0.1748
X2.3	0.5223	0.8497	0.1523	0.2464	-0.2505	-0.1161	0.4641	-0.1494	0.0144	0.2154	0.0592
X2.4	0.8293	0.9928	0.1721	-0.0334	-0.1524	0.0833	0.4440	-0.1713	-0.0383	-0.0031	0.1331
X3.1	0.0312	0.1785	1	-0.1541	-0.1091	-0.0375	0.0843	-0.4964	0.2530	-0.2229	0.2156
X4.1	-0.0058	-0.0006	-0.1696	0.0126	0.2127	0.1013	0.2173	0.1761	0.0055	-0.0225	0.0050
X4.2	-0.0728	-0.1082	-0.0829	0.9212	-0.2754	-0.5494	0.1845	0.2891	-0.2674	0.7910	-0.5276
X4.3	-0.1289	-0.1240	0.2071	-0.8990	0.2046	0.3209	-0.2633	-0.1587	0.0730	-0.7693	0.4666
X5.1	-0.2975	-0.4140	-0.3824	-0.3027	0.6470	0.3024	-0.1283	0.1730	-0.0342	-0.1190	0.0718
X5.2	-0.2033	-0.2939	-0.4480	-0.2791	0.5701	0.3176	-0.0273	0.1935	0.0801	-0.1829	0.1445
X5.3	-0.2440	-0.0158	0.1276	-0.1134	0.8308	0.5651	0.0728	-0.5076	0.0545	-0.1147	0.3501
X5.4	0.0537	0.1002	0.0033	0.0110	0.4360	0.4081	0.3732	-0.0504	0.1426	-0.0137	0.1395
X5.5	-0.2717	-0.2512	-0.1053	-0.4382	0.3650	0.4343	-0.6008	-0.0619	-0.1498	-0.4876	0.0825
X6.1	-0.0256	0.1778	0.0335	-0.1950	0.7028	0.7604	0.0453	-0.3878	-0.0809	-0.2162	0.2623
X6.2	-0.1201	-0.2238	-0.4256	-0.2590	0.4149	0.5865	-0.2829	-0.0389	-0.0267	-0.2860	0.1025
X6.3	-0.0437	0.0283	0.0310	-0.5607	0.5145	0.8974	-0.3341	-0.2613	0.2133	-0.6520	0.3892
X7.1	0.3270	0.4411	0.0843	0.2420	0.0290	-0.2417	1	-0.0286	0.2142	0.3621	0.0487
X8.1	-0.0226	-0.2234	-0.5132	0.2998	-0.2625	-0.3475	-0.0481	0.9537	-0.3383	0.3031	-0.5274
X8.2	0.0649	-0.0590	-0.4223	0.1646	-0.2942	-0.2950	-0.0035	0.9409	-0.0988	0.2516	-0.4682
X9.1	-0.0996	-0.0225	0.2254	-0.1949	0.1126	0.1483	0.1939	-0.2440	0.9835	-0.1342	0.2278
X9.2	-0.0658	-0.0305	0.2717	-0.1860	0.0271	0.0449	0.2271	-0.2252	0.9849	-0.0901	0.2380
X10.1	0.1848	0.0403	-0.2340	0.8480	-0.2309	-0.5544	0.3760	0.3058	-0.1188	0.9977	-0.5424
X10.2	0.1503	0.0225	-0.2107	0.8629	-0.2274	-0.5592	0.3464	0.2812	-0.1076	0.9976	-0.5365
Y.1	-0.0204	0.1413	0.2156	-0.5479	0.3425	0.3790	0.0487	-0.5271	0.2367	-0.5408	1

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 $\frac{Y.1}{X1 = \text{temperature}, X2 = \text{water availability}, X3 = \text{oxygen availability}, X4 = \text{rooting condition}, X5 = \text{nutrient retention}, X6 = \text{nutrient availability}, X7 = \text{sodicity}, X8 = \text{erosion}}$ 329 hazard, X9 = flooding hazard, X10 = land preparation, Y = hybrid maize yield, X1.1 = temperature, X2.1 = rainfall, X2.2 = the wet month, X2.3 = the dry month, X2.3 =

330 long growth period, X3.1 = drainage, X4.1 = texture, X4.2 = coarse material, X4.3 = effective depth, X5.1 = organic C, X5.2 = cation exchanges capacity, X5.3 = base

331 saturation, X6.1 = total N, X6.2 = P availability, X6.3 = K exchangeable, X7.1 = the exchange sodium percentage, <math>X8.1 = slopes, X8.2 = soil erosion, X9.1 = inundation

332 height, X9.2 = inundation period, X10.1 = rock outcrops, X10.2 = surface rock, Y.1 = hybrid maize yield.

Indicators (land characteristics)	Cronbach's Alpha	Composite Reliability
X1.1 (Temperature)	1.000	1.000
X2.1 (Rainfall)		
X2.2 (Wet month)	0.975	0.965
X2.3 (Dry month)	0.975	0.905
X2.4 (Long growth periods)		
X3.1 (Drainage)	1.000	1.000
X4.1 (Texture)		
X4.2 (Coarse material)	0.002^{nor}	-1.055 ^{nor}
X4.3 (Effective depth)		
X5.1 (pH H ₂ O)		
X5.2 (pH KCl)		
X5.3 (Organic C)	0.718	0.628
X5.4 (Cation exchange capacity)		
X5.5 (Base saturation)		
X6.1 (Total N)		
X6.2 (P availability)	0.805	0.681
X6.3 (K exchangeable)		
X7.1 (Exchangeable sodium percentage)	1.000	1.000
X8.1 (Slopes)	0.965	0.928
X8.2 (Soil erosion)	0.905	0.928
X9.1 (Inundation height)	0.992	0.984
X9.2 (Inundation period)	0.772	0.704
X10.1 (Rock outcrops)	0.998	0.995
X10.2 (Surface rock)	0.990	0.995

 $\overline{nor} = not reliable.$

335 *3.1.3 Structural model test (inner models)*

Land characteristics that have a significant correlation with hybrid maize yields show a high level of contribution to land quality in influencing hybrid maize yields as indicated in Figure 3. The figure shows a structural model of the relationship between indicator variables, namely 24 land characteristics, rectangular yellow, and latent variables, including 10 land qualities maize yield, and oval blue. It also shows a model for the relationship between latent variables such as land qualities and maize yield as well as loading figures. The factor for each indicator and path coefficient for land qualities has a direct effect on the value of maize yields.

For example, X8 (erosion hazard) significantly determines the hybrid maize yield with a path coefficient of -0.392. The negative sign indicates that the erosion hazard is negatively related to maize yield, where the higher the erosion hazard, the lower the maize yield. Furthermore, nutrient retention (X5) contributes to the diversity of hybrid maize yields with a path coefficient of 0.252. A positive sign indicates that nutrient retention is positively related to maize yield, where the higher the value of nutrient retention were followed by the maize yield.



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Figure 3: Path Coefficient of land quality on hybrid maize yield.

351 The results of this path analysis indicated that the land quality that can be a predictor of maize 352 yield diversity were oxygen availability (X3), nutrient retention (X5), nutrient availability 353 (X6), erosion hazard (X8), and land preparation (X 10). Figure 2 indicates that only 8 of the 24 354 indicators explain latent variance at the 5% real test level. The 8 indicators were coarse material 355 and effective soil depth as an indicator of rooting condition, organic carbon content as nutrient 356 retention, exchangeable K as nutrient availability, soil erosion and slope as erosion hazard, as well as rock outcrop and surface rock as an indicator of land preparation. It was also indicated 357 358 that the drainage loading factor was unable to explain the diversity of oxygen availability. Therefore, oxygen availability cannot be used as a land quality because there are no indicators 359 that can represent it. Only the land qualities of nutrient retention (X5), nutrient availability 360 361 (x6), erosion hazard (x8), and land preparation (X10) were used next.

The indicators of land characteristics for effective depth, organic C, total N, and exchangeable K have a fairly strong positive relationship and a very significant effect on hybrid maize yields. In this relationship, an increase in these parameters by 1%, will be followed by a rise in hybrid maize yields of 39% to 57.7%. According to [4], effective depth affects root growth and development, making plants grow and develop properly. Moreover, the levels of organic C, total N, and CEC are influenced by soil organic matter [77], while potassium plays a role in the growth and development of maize [78].

- 369 Indicators of rough soil characteristics, slopes, soil erosion, as well as surface and rock outcrops
- have a strong negative relationship with a very significant effect on hybrid maize yields. In this
- 371 relationship, a 1% decrease in coarse material, slope, soil erosion, as well as surface and rock
- outcrop is followed by an increase in hybrid maize yields by 39% to 57.7%.

373 **3.2.** Optimum hybrid maize yield by the land quality and land characteristics

Table 7 shows the mathematical equations for each land characteristic and also the optimum hybrid maize yield for the land equation. Figure 4 shows the diagram of the relationship between land characteristics as an independent variable (X) and maize yield as an independent variable Y. Model fitting indicates that the quadratic equation is sufficient to describe the condition of data distribution.

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Land Quality/Land Characteristics	Optimum Yield (ton/ha)	Yield Equation]
Rooting condition (rc)			
Coarse material	8.06	$Y = 0.0024800x^2 - 0.2457487x + 10.9082465$	0.
Effective depth	8.35	$\begin{array}{l} Y = -0.0007242 x^2 + 0.1890458 x - \\ 1.2946385 \end{array}$	0.
Nutrient retention (nr)			
Organic carbon	8.35	$Y = -24.3891969x^2 + 46.8464078X \\ - 8.8894056$	0.
Nutrient availability (na)			
Total N	8.43	$Y = -304.4463543X^2 + 144.7590906X - 2.6328530$	1.
K Exchangeable	5.74	$Y = -10.5596308X^2 + 17.4129832X + 2.2069179$	0.
Erosion hazard (eh)			
Slopes	8.43	$Y = 0.0172X^2 - 0.8448X + 13.907$	0.
Soil erosion	8.06	$y = 0.0000173X^2 - 0.0187536X + 9.0426459$	0.
Land preparation (lp)			
Rock outcrops	7.30	$Y = 0.0046385X^2 - 0.2934756X + 8.5159674$	0.
Surface rock	7.30	$Y = 0.0046385X^2 - 0.2934756X + 8.5159674$	0.

380

379

The optimum of hybrid maize yield ranged from 5.74 to 8.43 ton/ha, where the highest yield 381 was obtained from total N and slopes of 8.43 ton/ha with an R^2 value of 100% and 91%. 382 383 Sutardjo et al (2012) showed that hybrid maize yields ranged from 7.43 to 9.2 ton/ha. This indicated that the optimum yield achieved is still within the range of hybrid maize yields that 384 385 have been previously reported. Nitrogen is directly involved in the formation of amino acids, proteins, nucleic acids, enzymes, nucleoproteins, and alkaloids, which are needed in the plant 386 growth process [79], [80]. An extremely high amount of N causes excessive vegetative growth, 387 thereby making plants fall easily and increasing susceptibility to disease [81]. Meanwhile, the 388 389 lack of N nutrients can limit cell division, enlargement [82], and the formation of chlorophyll, 390 leading to stunted growth as well as yellowing of leaves [81].

The lowest optimum yield was obtained from exchangeable K, which was only 5.74 ton/ha with an R^2 value of 94%. This was presumably because the K content in the soil is very low,

393 thereby affecting the hybrid maize yield. Potassium (K) is required by plants for physiological

394 functions, including carbohydrate metabolism, enzyme activity, osmotic regulation, efficient

water use, N uptake, protein synthesis, and assimilate translocation [83]–[86]. It also plays a
 role in improving the quality of crop yields (McKenzie, 2013, Subandi, 2013).

397 The optimum hybrid maize yield of the remaining is relatively diverse. This includes effective depth and organic carbon, which were both 8.35 ton/ha with an R² value of 87%. Furthermore, 398 coarse material and soil erosion were 8.06 ton/ha with an R² value of 95% and 88%, while rock 399 400 outcrops and surface rock were 7.30 ton/ha with an R2 value of 91%. The absence of coarse 401 material > 2 mm in diameter indicated that plant roots can grow freely on the surface or deeper 402 parts of the soil [89], because the deeper the roots of the maize, the greater the maize yield 403 [90], [91]. The addition of organic matter will increase maize yield [92]-[94] and organic C content [95] because soil organic matter is a strong positive predictor of yield [96]. Kane et al. 404 405 [96] also stated that the addition of more organic matter will improve water retention, thereby 406 reducing maize yield losses due to drought. The slope has a significant effect on soil degradation [97]. According to a previous study, erosion and maize yield are negatively 407 408 correlated, hence, increased erosion will reduce maize productivity [98]. Soil erosion on flat land is slower surface runoff [99]. It was also reported that surface rocks and outcrops are the 409 limiting factors in the suitability of maize plantations [100]. Therefore, a high percentage of 410 411 rock outcrops will complicate land cultivation and plant root growth.

412 **3.3. Land suitability criteria for hybrid maize crops**

413 Table 8 shows the yield limit for each class from the calculation of the optimum yield, where 414 the class range for each land characteristic is derived. Based on the optimum yield of the highest 415 hybrid maize, there were 2 indicators, namely the total N content and the slope. The total N indicator with a very suitable class (S1) was achieved when the value in the soil was greater 416 417 than 0.10%, while in the moderately suitable class (S2), it was achieved when the total N in 418 the soil ranges from 0.07-0.09%. In the marginally appropriate class (S3), the total N indicator 419 was achieved when the total N in the soil ranges from 0.05-0.06%, while the not suitable class 420 (N) was achieved when the content was less than 0.05%. On the slope indicator with class S1, it was obtained when the slope class ranges from 0-7.69%%, while class S2 was achieved when 421 the slope class ranges from 7.70-11.83%. Furthermore, in classes S3 and N, it was obtained 422 423 when the slope class ranged from 11.84-18.24% and greater than 18.24%, respectively.

424 Based on the optimum yield of the lowest hybrid maize, only the exchangeable K was the indicator. In classes S1 and S2, it was achieved when the exchangeable K content in the soil 425 426 was greater than 0.24 cmol(+)/kg and ranges from 0.13-0.23 cmol(+)/kg, respectively. 427 Furthermore, class S3 was achieved when the exchangeable K content in the soil ranges from 428 0.04-0.12 cmol(+)/kg, while in class N, it was obtained when the exchangeable K content in 429 the soil was less than 0.04 cmol(+)/kg. The remaining variables and indicators were relatively 430 varied according to the optimum yield of hybrid maize and the range of land suitability classes obtained as presented in Table 8. 431



432



Figure 4: Scatter diagram relationship among maize yield and land characteristics

Value of Land Suitability Criterion Yield Limits (ton/ha) Obtained Land Quality/Land **S1 - S2** S2 - S3S3 - NCharacteristics (80% x (60% x (40% x **S1 S2 S3** Ν Yoptim) Yoptim) Yoptim) Rooting condition (rc) 0 – 13.41 -27.38 -> Coarse material (%) 8.06 6.04 4.03 13.40 27.37 52.39 52.39 49.25 -33.18 -< Effective depth (cm) 8.35 6.26 4.18 ≥ 69.55 69.54 49.24 33.18 Nutrient retention (nr) 6.26 Organic carbon (%) 8.35 4.18 ≥ 0.50 0.41 - 0.490.34 - 0.40< 0.34 Nutrient availability (na) Total N (%) 8.43 6.32 4.22 ≥ 0.10 0.07 - 0.090.05 - 0.06< 0.05 K Exchangeable 5.74 4.31 2.87 ≥ 0.24 0.13 - 0.230.04 - 0.12< 0.04(cmol(+)/kg)Erosion hazard (eh) 0 – 7.70 -11.84 -> Slopes (%) 8.43 6.32 4.22 18.24 7.69 11.83 18.24 Soil erosion > 8.06 6.04 4.03 ≤ 55.21 195.29 605.56 (ton/ha/year) 605.56 Land preparation (lp) 0 -4.46 -13.10 -> Rock outcrops (%) 3.85 7.30 5.47 4.45 13.09 31.78 31.78 0 – 4.46 -13.10 ->7.30 5.47 Surface rock (%) 3.85 4.45 13.09 31.78 31.78

Table 8: Yield limits of hybrid maize and values obtained in each land suitability class interval by land quality and characteristics.

436 S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, and N = not suitable.

437 Based on the relationship between the quality and characteristics of the selected land with 438 optimum results, the criteria for hybrid maize land suitability were obtained as shown in Table 8. These criteria described the actual state of achieving optimum, moderate, and minimum 439 440 yields of hybrid maize in the field with values of 80%, 60%, and 40%, respectively. According 441 to Sukarman et al. [101], the parameters used in the land suitability assessment must describe 442 the actual conditions. This is due to the significant positive correlation between maize yield 443 and land suitability class [102].

444 The land suitability criteria for the new hybrid maize are fewer and have referred to the optimum yield. Meanwhile, the land quality and characteristics in this new criterion are less 445 because it only consists of root conditions with characteristics of coarse material and effective 446 depth, nutrient retention with organic C, and nutrient availability with total N and K 447 exchangeable. It also consists of erosion hazards with characteristics of slopes and soil erosion, 448 449 as well as land preparation with surface rocks and rock outcrops only. The land qualities 450 selected and maize yields consistent with the land potential are the basis for developing suitability criteria. This will reduce the land characteristics and make the evaluation process 451 452 faster, cheaper, and easier with accurate results [26]. Some characteristics and land quality 453 criteria were not made because they did not significantly affect the yield of hybrid maize. The 454 number and distribution of the data were still limited and the diversity of values was small or 455 not measurable in the field [72].

Compared to Wahyunto et al. [47], the new land suitability criteria for hybrid maize plants in 456 Table 9 is more realistic in value with the conditions in the field and is based on the 457 458 achievement of optimum yields. The current land suitability criteria are still general and not

459	specific to maize yields [26], although the agronomic and yield potential of each maize variety
460	differ, based on the diversity of characteristics and land quality in the field. There are still
461	limitations on the use of these results for the development of hybrid maize in the Boalemo
462	Regency because the setting is only based on land characteristics and optimum yields in this
463	regency. Therefore, further investigation to expand the scope of the research area nationally
464	with more diverse and contrasting land characteristic values is recommended to determine the
465	effect on hybrid maize production.

Land Quality/Land	New Land Suitability Criterion of Hybrid Maize					Land Suitability Criterion o General Maize [47]			
Characteristics	S1	S2	S3	Ν	S1	S2	S3	Ν	
Rooting condition (rc)									
Coarse material (%)	0 -	13.41 -	27.38 -	>	< 15	15 –	35 –	>5	
Coarse material (76)	13.40	27.37	52.39	52.39		35	55		
Effective depth (cm)	\geq	49.25 -	33.18 -	<	> 60	60 –	40 –	< 2	
Effective deput (effi)	69.55	69.54	49.24	33.18		40	25		
Nutrient retention (nr)									
Organic carbon (%)	\ge 0.50	0.41 0.40	0.34 - 0.40	< 0.34	>	0.8 -	< 0.8	-	
Organic carbon (78)	0.50	0.41 - 0.49	0.34 - 0.40	< 0.54	1.20	1.2			
Nutrient availability (na)									
Total N (%)	\geq	0.07 - 0.09	0.05 - 0.06	< 0.05	Mo	Lo	VLo	-	
· · ·	0.10	0.07 - 0.09	0.03 - 0.00	< 0.05					
K Exchangeable	\geq	0.13 - 0.23	0.04 - 0.12	< 0.04	Mo-	Lo	VLo	-	
(cmol(+)/kg)	0.24	0.13 - 0.23	0.04 - 0.12	< 0.04	Hi				
Erosion hazard (eh)									
Slopes (%)	0 -	7.70 -	11.84 -	>	< 8	8 - 15	15 –	>2	
	7.69	11.83	18.24	18.24			25		
Soil erosion	\leq	195.29	605.56	>	-	VLi	Li-	Н	
(ton/ha/year)	55.21	195.29	005.50	605.56			Mo	VI	
Land preparation (lp)									
Rock outcrops (%)	0 -	4.46 -	13.10 -	>	< 5	5 - 15	15 –	> 4	
Rock outcrops (76)	4.45	13.09	31.78	31.78			40		
S_{22}	0 -	4.46 -	13.10 -	>	< 5	5 - 15	15 –	> 4	
Surface rock (%)	4.45	13.09	31.78	31.78			40		

466 Table 9: Comparison of new and general land suitability criteria with land quality and characteristics.

S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable, Hi = high, Mo =
moderate, Lo = low, VLo = very low, He = heavy, Li = light, VLi = very light, VHe = very heavy.

469 **Conclusions**

470 Land suitability criteria for the new hybrid maize are determined by land qualities, namely root conditions, nutrient retention, available nutrients, erosion hazard, as well as land preparation, 471 and land characteristics, including coarse material, effective depth, organic C, total N, 472 473 exchangeable K, slopes, soil erosion, rock outcrops, and surface rocks. The highest optimum yield of 8.35 ton/ha was achieved by the effective depth and organic C content for a very 474 suitable class (S1), while the lowest value of 5.47 ton/ha was attained by exchangeable K for 475 476 class S1. These results showed that the combination of the PLS-SEM and boundary line 477 analysis can be an alternative approach to establishing new land suitability criteria for crops based on optimum yields and selected land quality. 478

479 Data Availability

480 All data can be obtained from the corresponding author upon request.

481 **Conflicts of Interest**

482 The authors declared that there is no conflict of interest regarding the publication of this paper.

483 **Funding Statement**

This study was funded by the Directorate of Research, Technology and Community Service,
Directorate General of Higher Education, Research and Technology, Ministry of Education,
Culture, Research and Technology of the Republic of Indonesia, grant number
B/105/UN47.D1/PT.01.03/2022.

488 Acknowledgments

489 The authors are grateful to the Ministry of Education, Culture, Research and Technology of 490 the Republic of Indonesia, and the Institute Research and Community Service of Universitas

491 Negeri Gorontalo for their financial and administrative support.

492 **References**

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regency and the urgency of determining land suitability criteria the revision article). In the methods section: - Lines 85-87 hav Line 88 states that there are 35 land units, but in the legend F et al. and the map in Figure 1? Why is the land mapping unit i mapping carried out by Ritung et al. (20016) as many as 35 la changed from a scale of 1: 50,000 to a scale of 1: 40,000, so t units. In addition, the land units have been described, both in t 110: It is better to explain each component/variable of soil cha to obtain the data. In this line, each component/variable of soil cha to obtain the data. In this line, each component/variable of soil 99: Give reasons why it is necessary to update the available la (32 pedons) to the map. Explain how to collect climate data an 112-113: these identifications must be shown on the map and included in the map of the research location (sample points ar This line has been fixed Lines 127-145, 175-184: please ad indicating secondary data sources for each land characteristic been fixed Lines 397-401: It should be noted that the result	a for hybrid maize in a been added citatio igure 1 there are 32 h Figure 1 not expla nd units became the hat the coverage of erms of slope, relief racteristics at the bu- characteristic distan nd characteristics a id place equipment, indicate the points d tiled plots) Line d a quote. This line or method of obtain s of this study are o nd optimum yields in	npared to local maize) has been added, the choice of research locations in this Boalemi Regency by including some of the latest references (lines 43-63 of ons/references - Soil map scale has been listed (nominal scale and bar scale) 2 SMUs. Is there a relationship between the soil mapping carried out by Ritung ined in paragraphs 83-91? It has been improved again, where the land e initial reference for adding 32 new land units because the map scale the land map was more detailed and the number of land units became 67 f, land use and soil types and their distribution in the study area Lines 95- eginning of the paragraph. In the next section, each variable is explained how nce has been explained and continued with how to obtain the data Lines 97- nd justification for determining the additional 32 points. Add sampling points /stations. In that line it has been corrected according to the correction Lines where the 2.5 x 2.5 m beams are placed. This line has been corrected and is 117, 119, 142, 143, etc.: each formula must be accompanied by a reference. has been fixed Lines 131: Table 1 should be completed with a column ing data in the field (as a summary of updated lines 95-110). This line has f limited use for the development of hybrid corn in Boalemo, because the n Boalemo Regency (not representing the national scale). On the line has been bod response for publication Regards Nurdin
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- In this research, the land suitability criteria are only based or manuscript needs to be adjusted. For example: "Determination	land characteristics of Land Suitability land suitability crite nd combined with l	

1 Determination of Maize Hybrid Land Suitability Criteria Based

2 on Optimum Yield and Selected Land Quality

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12 Abstract

13 The significant effect of land quality on maize production has not been fully considered in the existing land suitability criteria. Therefore, this study aims to determine the hybrid maize land 14 15 suitability criteria based on the optimum yield and land quality. It was carried out in Boalemo 16 Regency, Indonesia, where the land unit of 67 units were surveyed to obtain land characteristics 17 data. A partial least square of structural equation model (PLS-SEM) with SmartPLS 8.0 was 18 used to select a robust land quality controlling hybrid maize yield, while the boundary line 19 method was used to determine optimum yield and differentiating of land suitability criteria. 20 The result showed that land qualities that define the optimum yield of hybrid maize were root 21 conditions, nutrient availability, nutrient retentions, land preparation, and erosion hazard. The 22 soil characteristics were effective depth, coarse material, organic C, total N, K exchangeable, slopes, soil erosion, rock outcrops, and surface rocks. Furthermore, the highest optimum yield 23 24 of 8.35 ton/ha was achieved by the effective depth and organic C content for a very suitable 25 class (S1), while the lowest of 5.47 ton/ha was obtained by exchangeable K for class S1. This 26 showed that the combination of PLS-SEM and boundary line analysis was a better approach to

27 developing new land suitability criteria for hybrid maize.

28 **1. Introduction**

- Food security and farmer prosperity are global concerns, this makes every country increase crop production as well as farmers' income. An important issue for countries with developing economies is ensuring food security, where the agricultural sector plays a strategic role in increasing food availability [1]. Although the global food system has placed maize (*Zea mays*
- L.) as the leading cereal crop [2], its productivity is being disrupted by land degradation, water
- 34 scarcity, and climate change [3].
- In Indonesia, the wet tropical climate with rainfall and high temperatures tends to reduce the quality of land and agricultural products [4]. This country ranked 8th among the maizeproducing nations with a contribution of 2.19% and 2.42% of the world's total harvested area [5]. However, the main problem is the relatively low level of yield in several regions because the achievement of maize production has not been followed by an increase in yield per unit area [6]. This is indicated by the average yield in 2020, which was up to 5.57 ton/ha [5].

41 According to a previous investigation, maize production in Indonesia can reach between 10-12

42 ton/ha [7], [8] thereby making the country the 21st leading importer in the world.

In Indonesia, Gorontalo Province is one of the centers of maize production, where the hybrid
type is the most widely grown species [9]. The maize production in the province reached 1.8
million tons in 2021 [10], with several export advantages and competitiveness [11].
Furthermore, the planting of hybrid, composite, and local maize types has reached more than
98.90%, 0.68%, and 0.41% only, respectively [12] including Boalemo Regency.

48 Boalemo Regency ranks third as a maize-producing center in Gorontalo Province with a 49 contribution of 18.90% [13]. The maize plant dominates the use of agricultural land in this 50 district by 37.43% [14], therefore, the commodity has competitive and comparative advantages 51 with a PCR value of 0.80 and 0.91 DRC. This is because maize plant is supported by land area, 52 climatic conditions, production facilities, as well as market guarantees, and the basic price of 53 buying corn from the government [15]. In 2021, the average hybrid and local maize yields in 54 the regency reached 5.20 tons/ha [16] and 2.34-3.30 tons/ha, respectively [17]. This indicated 55 that the productivity of hybrid maize is still higher than local maize [18] but with lower 56 achievement compared to the national maize production of 5.57 tons/ha [5] and has not yet 57 reached the target of 5.60 tons/ha in 2021 [19]. The production of hybrid maize in Gorontalo 58 can reach 9.78-13.11 tons/ha [20] because it is often cultivated on land that does not meet the 59 required qualities [6]. Therefore, there is a need to determine land quality-based hybrid maize 60 land suitability criteria for site-specific land use planning in Boalemo District.

61 Maize is usually grown on land with low yield potential [21] and soil fertility, thereby causing 62 low productivity [22]. Moreover, land productivity is determined by quality and characteristics 63 [23], [24], while land quality has a close relationship with maize yields [25]. The land quality 64 affecting the optimum yield of maize needs to be determined [26] and increased by using hybrid 65 varieties that have high yields. This makes it necessary to evaluate the suitability of the hybrid maize in a region to ensure optimal production. The land suitability criteria for hybrid maize 66 67 are not yet available because the current criterion is the general suitability of maize plants without distinguishing between hybrids and inbreds. Therefore, there is a need to make land 68 69 suitability criteria for hybrid maize plants.

70 A previous study has shown that land quality has a significant effect on suitability for certain 71 uses [27]. Meanwhile, land suitability is also important due to the continuous increase in the 72 demand for agricultural land [28]. The land suitability criteria for existing maize fields are still 73 general [29] and there are no specific criteria for hybrid maize varieties. The class assessment 74 outcomes obtained using the existing criteria are relatively many and are not in line with the 75 actual field results [30]. The current criteria consist of 3 components, namely, land quality, 76 characteristics, and ranges of land characteristic values to determine its suitability. Therefore, 77 the problem in developing criteria is choosing land quality, characteristics, and determining the 78 range of land characteristic values associated with suitability classes, namely suitable, 79 somewhat suitable, marginally suitable, and not suitable.

80 The selection of land quality and characteristics can be carried out through the partial least 81 square of the structural equation model (PLS-SEM), while the range limits is being determined 82 by the boundary line method. Land qualities and characteristics in the current criteria can be

83 used temporarily since structural equation model analysis with partial least squares produces

- 84 better indicators and models than other multivariate analyses [31]–[35]. This is because the
- 85 variant-based PLS-SEM has a higher level of flexibility and the size of the sample used is

- relatively small ranging from 30 to 100 [36]–[39]. The use of PLS-SEM to determine land
- 87 characteristics and qualities that control maize crop yields is still relatively rare, except for Syaf
- [40] on older cocoa plants, maize composite [41], and on local varieties [6]. The boundary line
 method can help determine nutrient adequacy concentrations and the optimum yield range of
- method can help determine nutrient adequacy concentrations and the optimum yield range of a plant that affects nutrients, as well as other land characteristics [42], [43]. Currently, the land
- 91 suitability criteria for maize plants have not been determined using the boundary line method,
- 92 except by Ridayanti et al. [44], although the investigation was not specific to hybrid maize.

93 After obtaining the quality and characteristics of land affecting maize yields with PLS-SEM,

94 the boundary line method can be used to determine the optimum yield as well as land suitability

95 criteria simultaneously. This is carried out by drawing the intersection of the boundary line at

- 96 the yield and projecting with the land characteristics [29]. Therefore, this study aims to
- determine land suitability criteria for hybrid maize based on the optimum yield and landquality.

99 2. Materials and Methods

100 **2.1 Study area**

The study area extends from 0°28'5.6" - 0°57'30.02" N to 122°08'34.25" - 122°43'10.41"E 101 (Figure 1) on a scale of 1 : 65,000, which is located in the agricultural land of Boalemo 102 103 Regency, Gorontalo Province, Indonesia. The maximum air temperature was 28.19°C and the minimum was 26.79°C with an average of 28.01°C. Meanwhile, the maximum rainfall was 104 1,849 mm and the minimum was 1,246 mm with an average of 1,478 mm [45]. The wet and 105 106 dry seasons last for 3 months and 5 months respectively. The soil mapping carried out by Ritung et al. [46] become the initial reference for determining 35 soil units, where each unit 107 has information on land characteristics, namely effective depth, drainage, texture, pH, cation 108 109 exchange capacity, base saturation, landform, parent material, relief, and land unit area. This unit was detailed by adding 32 soil units to be surveyed and observed, making up to 67 soil 110 units in the area as shown in the legend Figure 1. The detailing was carried out because the soil 111 unit was previously presented at a scale of 1: 50,000, without including several key areas. 112 Meanwhile, the new soil unit is 1: 40,000 in scale and there has been a change in the agricultural 113 land use existing. This indicated that the slope class of 8 - 15% or hilly is more dominant in 114 the study area with a percentage of 29.77% and slopes > 40% or mountainous which is only 115 116 2.67%. Furthermore, the dry land is dominant with a value of 59.86% and a little shrub which was only 9.21%, while the dominant Inceptisol soil type was 36.18% and very little Ultisol soil 117 118 was 8.88%.



- 119
- 120

Figure 1: Study area.

121 **2.2 Dataset collection for land quality and land characteristics**

122 The quality and characteristics of the land in this study refer to Wahyunto et al. [47], consisting 123 of 10 land qualities and 24 characteristics. The set of temperature land quality is determined 124 from the characteristics of the annual average air temperature, while the land quality water availability is determined from the characteristics of annual rainfall, wet months, dry months, 125 126 and the length of the growth period (LGP). Land quality oxygen availability is determined from 127 soil drainage characteristics, rooting conditions are determined from the soil texture, coarse material, and soil effective depth, nutrient retention is identified from the pH value, C-Organic, 128 129 cation exchange capacity (CEC), and base saturation. Furthermore, the available nutrient is 130 determined from the characteristics of total N, P, and exchangeable K, the sodicity is obtained 131 from the exchangeable sodium percentage (ESP), while erosion hazard is determined from slopes and soil erosion. The quality of the flood-hazard land is determined by identifying the 132 height and the duration of the inundation, while preparation is carried out from the 133 134 characteristics of outcrops and surface rocks. The selection of this set of land qualities and 135 characteristics is based on the availability of data and their impact on maize production [26].

Data on average annual air temperature and rainfall for 10 years (2010-2021) were collected
from different climate stations, namely the Bandungrejo with 0°41' N - 122°38' E, the elevation
40 m asl, while Harapan has 0°42' N - 122°29' E and an elevation of 37 m asl. It also includes
Lakeya Rain Post with 0°42.82' N - 122°32.07' E, 32 m asl, Mohiyolo has 0°46.41' N 122°26.41' E and an elevation of 39 m asl, Saritani 0°46.45' N - 122°20.40' E, with 26 m asl,
Tangkobu 0°37.25' N - 122°36.36' E, 25 m asl, Bubaa 0°31.36' N - 122°33.39' E, 16 m asl,
Wonggahu 0°38' N - 122°33' E, 35 m asl, and Sambati Rain Post with 0°31.184' N - 122°27.074'

E and an elevation of 9 m asl managed by BWS II Sulawesi. Furthermore, these data
determined wet months (> 200 mm) and dry months (<100 mm), which refers to the Oldeman
and Darmiyati criteria [48]. The land water balance was determined using the Thornwhite and

146 LGP methods based on the number of surplus and deficit rainy days [49].

Soil characteristics such as drainage, coarse material, effective soil depth, slope, inundation
height and duration, rock outcrops and surface rocks were determined by conducting soil
profile descriptions and direct observation on 67 pedons referring to the description guidelines
in the field [50]. Meanwhile, soil erosion was determined by the USLE method [51]. Other soil

151 characteristics were further analyzed in the soil laboratory using samples from each pedon.

152 Soil samples were dried for 3 days and sieved through a 2 mesh sieve. The method of soil 153 physics laboratory analysis was carried out according to the procedures by Kurnia et al. [52]. 154 Based on this procedure, soil texture was analyzed in terms of sand, clay, and silt fractions using the pipette method, while soil moisture storage was evaluated using the gravimetric 155 method that can be applied in water balance analysis. The method of soil chemistry laboratory 156 157 analysis was carried out according to the procedures by Eviyati and Sulaeman [53]. The soil 158 pH was determined with a pH meter in a 1:2.5 soil and water solution, while the organic C 159 content was assessed using the Walkley and Black method. The total N was assessed using the 160 Kjeldahl method, while the available P content was measured using the Olsen method. The basic cations and CEC was extracted with 1N NH₄OAc pH 7.0 (ammonium acetate) on a dry 161 162 sample of 105°C. The base saturation was determined by calculating the percentage of basic 163 cations number with CEC, ESP was evaluated using the percentage ratio of sodium to CEC [54] [55]. Subsequently, the data from the chemical analysis were averaged to a depth of 0-30 164 165 cm using the weighted averaging technique. The framework of this study is presented in Figure

166 2.



167 168

Figure 2: Research framework.

169 **2.3 Dataset collection for hybrid maize yield**

The areas currently planted with hybrid maize were identified and blocks with a size of 2.5 m x 2.5 m were made in each map unit (Figure 1). Maize plants in each block passed through standardized management according to farmers' technology. After harvesting, weighting was carried out to obtain hybrid maize yield data from the results of tiles on each land unit. Subsequently, the results were calculated using the formula [56], as expressed below:

175
$$Y(t) = H x \frac{A}{6.25 m^2}$$
 (1)

176 Meanwhile, productivity is calculated using the formula [56] below:

177
$$Y(t ha^{-1}) = \frac{H x \, 1.64 \, x \, 56.73}{100}$$
 (2)

178 where Y = hybrid maize yield, H = tile yield (kg), A = maize area 1 per hectare (ha), 1.64

179 and 56.73 = constant.

180 **2.4 Selection of land quality and land characteristics**

181 The quality and characteristics of the land in the suitability criteria were used as presented in

182 Tables 1 and 2, which show brief statistics. Generally, most data are relatively homogenous,

183 except for coarse material, available P, slopes, soil erosion, height and inundation, as well as

rock outcrops and surface rocks. The selection used the partial least squares of the structural

185 equation model (PLS-SEM) refers to Hair et al. [38] with tools SmartPLS, where land quality

and characteristics were selected as the latent and manifest variables, respectively. The analysis
 in PLS-SEM has 2 main steps, namely (1) the measurement model (outer model) and (2) the

188 structural model test (inner model).

189

Latent variables Indicators Data Samuel								
Notation Land quality		Notation Land characteristics		- Data Sources				
X1	Temperature (t)	X1.1	Temperature	[45]				
X2	Water availability	X2.1	Rainfall	[45]				
	(wa)	X2.2	Wet month	Rainfall > 200 mm				
		X2.3	Dry month	Rainfall < 100 mm				
		X2.4	Long growth period	Water balance (Thornwhit				
			(LGP)	method), soil moisture				
				storage (Gravimetric				
				method), water surplus an				
				defisit days				
X3	Oxygen availability	X3.1	Drainage	Soil survey and land				
	(oa)			observation				
X4	Rooting condition	X4.1	Texture					
	(rc)	X4.1.1	Sand fraction	Pipet method				
		X4.1.2	Silt fraction	Tipet method				
		X4.1.3	Clay					
		X4.2	Coarse material	Soil survey and land				
		X4.3	Effective depth	observation				
X5	Nutrient retention	X5.1	pH H ₂ O	pH meter (1 : 2.5)				
	(nr)	X5.2	pH KCl	pri meter (1 . 2.3)				
		X5.3	Organic C	Walkley and Black metho				
		X5.4	Cation exchange	1N NH4OAc pH 7.0				
			capacity (CEC)	Extracted				
		X5.5	Base saturation	Calculation				
X6	Nutrient	X6.1	Total N	Kjeldahl method				
	availability (na)	X6.2	P availability	Olsen method				
		X6.3	K exchangeable	1N NH ₄ OAc pH 7.0				
				Extracted				
X7	Sodicity (xn)	X7.1	Exchangeable sodium	Calculation				
			percentage (ESP)					
X8	Erosion hazard (eh)	X8.1	Slopes	Soil survey and land				
		X8.2	Soil erosion	observation				
X9	Flooding hazard	X9.1	Inundation height	Soil survey and land				
	(fh)	X9.2	Inundation period	observation				
X10	Land preparation	X10.1	Rock outcrops	Soil survey and land				
	(lp)	X10.2	Surface rock	observation				
Y	Hybrid maize yield	Y.1	Hybrid maize yield	Tile box methods				

(3)

(4)

191 Step 1 consists of validity and reliability tests, wherein the validity test is conducted with 192 convergent and discriminant validity. The convergent validity is in form of outer loadings 193 (loading factor) and average variance extracted (AVE), while discriminant validity is in form 194 of cross-loading and the Fornell-Larcker criterion. Meanwhile, the reliability test uses 195 composite reliability and Cronbach's alpha.

Convergent validity was observed from the magnitude of the outer loading and the AVE value
of each indicator on the latent variable. The validity was calculated according to the equation
[57][58][59][60]:

199
$$x_i = \lambda x_i \xi_I + \delta_i$$

$$200 y_i = \lambda y_i \eta_1 + \varepsilon_i$$

201 where x and y = exogenous (ξ) and endogenous (η) latent variable indicator, λx and $\lambda y =$ 202 loading factors, δ and ϵ = residual/measurement errors or noise.

Table 2: Brief statistics of land quality and characteristics.

Latent variables /	Unit	n	Min	Median	Mean	Max	SD
Indicators	Unit	п	171111	Wiculan	Witan		50
X1 (Temperature)							
X1.1 (Temperature)	°C	67	26.79	27.80	28.01	28.19	0.6
X2 (Water availability)							
X2.1 (Rainfall)	mm	67	1,246.00	1,533.42	1,478.00	1,849.00	232.6
X2.2 (Wet month)	month	67	0.00	1.03	1.00	3.00	0.8
X2.3 (Dry month)	month	67	2.00	3.39	4.00	5.00	1.0
X2.4 (LGP)	day	67	211.00	246.00	214.00	304.00	44.5
X3 (Oxygen availability)							
X3.1 (Drainage)	class	67	0.00	3.76	4.00	6.00	1.8
X4 (Rooting conditions)							
X4.1 (texture)	class	67	1.00	2.21	2.00	5.00	0.9
X4.1.1 (Sand fraction)	%	67	5.00	41.58	43.00	81.33	18.5
X4.1.2 (Silt fraction)	%	67	7.33	27.31	24.50	51.50	11.5
X4.1.3 (Clay)	%	67	11.33	31.90	30.00	56.33	12.7
X4.2 (Coarse material)	%	67	5.00	17.27	10.00	70.00	16.5
X4.3 (Effective depth)	cm	67	10.00	74.55	74.00	160.00	36.4
X5 (Nutrient retention)							
X5.1 (pH H ₂ O)		67	5.00	5.92	5.90	7.15	0.5
X5.2 (pH KCl)		67	4.35	5.24	5.17	6.60	0.5
X5.3 (Organic C)	%	67	0.41	0.85	0.77	2.35	0.3
X5.4 (CEC)	cmol(+)/kg	67	8.94	24.89	22.43	59.57	11.4
X5.5 (Base saturation)	%	67	45.03	56.22	52.85	81.89	9.7
X6 (Nutrient availability)							
X6.1 (Total N)	%	67	0.04	0.09	0.08	0.27	0.0
X6.2 (P availability)	mg/kg	67	0.73	8.62	3.77	58.67	12.6
X6.3 (K exchangeable)	cmol(+)/kg	67	0.07	0.39	0.24	1.92	0.4
X7 (Sodicity)							
X7.1 (ESP)	%	67	0.76	7.06	6.20	24.17	5.6
X8 (Erosion hazard)							
X8.1 (Slopes)	%	67	1.00	9.58	6.00	25.00	7.2
X8.2 (Soil erosion)	ton/ha/year	67	3.66	334.51	110.27	1772.43	439.0

X9 (Flooding hazard)							
X9.1 (Inundation height)	cm	67	0.00	7.58	0.00	50.00	17.10
X9.2 (Inundation period)	day	67	0.00	0.64	0.00	5.00	1.52
X10 (Land preparation)							
X10.1 (Rock outcrops)	%	67	0.00	6.64	0.00	45.00	11.56
X10.2 (Surface rock)	%	67	0.00	6.58	0.00	45.00	11.59
Y (Hybrid maize yield)	ton/ha	67	2.85	4.95	4.68	8.07	1.15

n =the number of the land unit, min = minimum, max is maximum, SD = standard deviations, LGP = long growth periods, CEC = cation exchange capacity, and ESP = exchangeable sodium percentage.

Meanwhile, the average variance extracted (AVE) value was calculated using the equation [61][62][63][64][65]:

208 AVE =
$$\frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i \operatorname{var}(\varepsilon_i)}$$
 (5)

209 Where λ_i^2 = the loading factor, var = the variance, and ε_i = the error variance.

The loading factor of an indicator with the highest value is the strongest or most important measure in reflecting the latent variable. In this study, the loading factor value is > 0.70 for selecting best land characteristics, but values ranging from 0.50-0.60 can still be tolerated with a t-statistic > 1.96 or a small p-value of 0.05 [37], [66]. Meanwhile, the AVE value used was

214 more than 0.50, showing that the convergent validity on the latent variable has been reached.

215 The discriminant validity test used the cross-loading value and the Fornell-Larker criterion to 216 test discriminantly valid indicators in explaining or reflecting latent variables. When the 217 correlation between the latent variables and the core measurement of each indicator is high, the 218 latent variable can predict the indicator better and is considered valid. The discriminant validity 219 is measured by the square root of the average variance extracted, which will be compared with 220 the correlation value between variables. The value calculated based on the square root of AVE 221 must be higher than the correlation between constructs [61]. The equation is expressed below 222 [61][67][63][64][65]:

223 Square Root of AVE =
$$\sqrt{\frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i \, var(\varepsilon_i)}}$$
 (6)

224 where λ_i^2 = the loading factor, var = the variance, and ε_i = the error variance.

Furthermore, the composite reliability and Cronbach's alpha were used to test the reliability value between indicators of the latent variables. They are considered good and accepted when the value is > 0.70 and has a minimum value of 0.60 [37]. The composite reliability value is calculated using the equation [68][62][69][65]:

229
$$\rho c = \frac{(\Sigma \lambda_i)^2}{(\Sigma \lambda_i)^2 + \Sigma i \, var(\varepsilon_i)}$$
(7)

- 230 where λ_i = the loading factor, var = the variance, and ε_i = the error variance.
- 231 Meanwhile, the value of Cronbach's Alpha is calculated according to the equation [70][65]:

232
$$\alpha = \left(\frac{\sum p \neq p'^{cor(X_{pq}, X_{p'q})}}{p_{q+\sum p \neq p'}^{cor(X_{pq}, X_{p'q})}}\right) \left(\frac{p_q}{p_{q-1}}\right)$$
(8)

233 where P_q = the number of indicators or manifest variables, and q = the indicator block.

For step 2, the structural model testing (inner model) was carried out after the relationship model was built in line with the observed data and the overall suitability, namely goodness of fit. The structural equation (inner model) is as follows [62][59][60]:

237
$$H_j = \gamma_j \xi_1 + \gamma_j \xi_2 + \dots + \gamma_j \xi_n + \zeta_j$$
(9)

238 where η_j = endogenous variable vector (dependent), $\gamma_j \xi_1 + \gamma_j \xi_2 + \dots + \gamma_j \xi_n$ = exogenous latent 239 variable vector, and ς_j = residual vector (error).

240 Meanwhile, the determinant coefficient and goodness of fit (Q^2) were calculated using the 241 equation [62][64][70]:

242
$$Q^2$$
 (Predictive relevance) = 1 - (1 - R₁²) (1 - R₂²) ... (1 - R_p²) (10)

243 where R_1^2 , R_2^2 , ... $R_p^2 = R$ square of endogenous variables in the equation model [68].

The quantity of Q^2 has a value with a range of 0 < Q2 < 1, the closer the value to 1, the better the model [37]. It is also equivalent to the coefficient of total determination in path analysis. Furthermore, the effect and significance were tested based on the estimated value of the path coefficient and the critical point value (t-statistics or p-value) at = 0.05. The relationship model between variables was measured by testing the direct correlation coefficient between variables. The results of testing the relationship between *X* and *Y* variables were indicated by the correlation coefficient as well as t-statistics, and are also presented in the path diagram.

251 2.5 Class assignment

To determine the class-required data for optimum results, class limits were calculated from the percentage of optimum results. After knowing the highest and lowest yields, the values were connected with the range of land characteristics values. The land suitability class and yield used referred to FAO [71], namely class S1 (very suitable) when the values reach 80-100%, S2 was moderately suitable 60-80%, S3 marginally suitable 40-60%, and N not suitable <40% of

the optimum capacity.

258 The optimum yield was determined using the boundary line method. This method is carried out by drawing a boundary line on the graph of the relationship between yield and land 259 characteristics to obtain optimum results. In the boundary line method according to 260 Widiatmaka et al. [72], each land characteristic is plotted on the X-axis, while hybrid maize 261 yields are plotted on the Y-axis. Bhat and Sujatha [42] stated that the preparation of the hybrid 262 263 maize yield boundary line includes the preparation of a scatter diagram between the X and the Y variable, (2) division of the X-axis into several classes of intervals, (3) determination of the 264 highest data points in each class interval, (4) preparation of boundary lines based on the highest 265 266 data points from each class interval, (5) draw a line parallel to the X-axis according to the

267 percentage of the result class.
Furthermore, with the Microsoft Excel application tools, the boundary between classes S1 to S2, S2 to S3, and S3 to N were determined by the Data menu \rightarrow What-if-Analysis \rightarrow Goal Seek \rightarrow Set the cell at the location containing the regression equation \rightarrow to value fill with the result limit values S1 to S2, S2 to S3, and S3 to N \rightarrow By changing cell \rightarrow the location where the value of the characteristics of the land will be sought \rightarrow Ok. On location "By changing cell", the number being searched will appear, and at the location "set cell" will be equal to the limit value of the result.

275 **3. Results and Discussion**

276 **3.1 Land quality and characteristics controlling hybrid maize yield**

277 *3.1.1 Validity test result*

278 Table 3 shows the loading factor of the variables, where most indicators were more than the 279 critical limit of 0.70 with a 95% confidence level (P > 1.960). Therefore, these variables are highly recommended and the indicators are considered convergently valid. In the soil texture 280 indicator for the latent variable of root conditions as well as the cation exchange capacity (CEC) 281 and base saturation (BS) indicators for nutrient retention, the loading factor was below the 282 tolerance value of 0.50 at the 95% confidence level (P < 1.960), hence, it was not used. This 283 284 implies that the indicators have not been established or explained properly because the standard 285 value of the loading factor must be greater than or equal to 0.50 [37], [38], [66].

The average variance extracted (AVE) value of almost all variables was greater than 0.50, therefore, it was considered convergently valid [61][73]. The AVE value of the available nutrient variable was not valid due to the smaller value of the loading factor for the CEC and BS indicators of 0.50, leading to the removal of both indicators. A similar result was discovered in the root condition variable, although the AVE value was greater than 0.50, while the soil texture indicator was not used because the loading factor value is only 0.013.

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Table 3: Outer loading (loading factor) and the average variance extracted from study variables.

Indicators (land characteristics)		Latent Variables (land quality)	Loading Factors	t-Stat	Status	AVE
X1.1 (Temperature)	\rightarrow	X1 (Temperature)	1.000**	11.192	Valid	1.000
X2.1 (Rainfall)	\rightarrow		0.838	0.085	Valid	
X2.2 (Wet month)	\rightarrow	V2 (Watan availability)	0.989	0.999	Valid	0.906
X2.3 (Dry month)	\rightarrow	X2 (Water availability)	0.850	0.428	Valid	0.900
X2.4 (LGP)	\rightarrow		0.993*	1.431	Valid	
X3.1 (Drainage)	\rightarrow	X3 (Oxygen availability)	1.000	0.000	Valid	1.000
X4.1 (Texture)	\rightarrow		0.013	0.066	Invalid	
X4.2 (Coarse material)	÷	X4 (Rooting condition)	0.921	1.086	Valid	0.573
X4.3 (Effective depth)	\rightarrow		-0.899	1.047	Valid	
X5.1 (pH H ₂ O)	\rightarrow		0.647	0.857	Valid	0.360
X5.2 (pH KCl)	\rightarrow	X5 (Nutrient retention)	0.570**	1.973	Valid	(invalid)
X5.3 (Organic C)	\rightarrow		0.831**	3.135	Valid	(mvand)

X5.4 (CEC)	\rightarrow		0.436*	1.381	Invalid	
X5.5 (Base saturation)	\rightarrow		0.365	0.845	Invalid	
X6.1 (Total N)	\rightarrow		0.760**	3.226	Valid	
X6.2 (P availability)	\rightarrow	X6 (Nutrient	0.587*	1.385	Valid	0.595
X6.3 (K exchangeable)	\rightarrow	availability)	0.897**	6.907	Valid	0.585
X7.1 (ESP)	\rightarrow	X7 (Sodicity)	1.000	0.000	Valid	1.000
X8.1 (Slopes)	\rightarrow	V9 (Energian harrowd)	0.954**	21.438	Valid	0.022
X8.2 (Soil erosion)	\rightarrow	X8 (Erosion hazard)	0.941**	18.308	Valid	0.932
X9.1 (Inundation height)	\rightarrow	V0 (Election charged)	0.984**	4.213	Valid	0.084
X9.2 (Inundation period)	\rightarrow	X9 (Flooding hazard)	0.985**	3.918	Valid	0.984
X10.1 (Rock	\rightarrow	X10 (Land	0.998**	189.133	Valid	
outcrops)		preparation)	0.770	107.133	v allu	0.995
X10.2 (Surface rock)	\rightarrow	preparation)	0.998**	320.273	Valid	

AVE = average variance extracted, LGP = long growth periods, CEC = cation exchange capacity, and ESP = exchangeable sodium percentage

exchangeable sodium percentage.

The measurement of the Fornell-Larcker criterion and cross-loading was used as the basis for assessing the discriminant validity of the model. The calculation results on the Fornell-Larcker criterion in Table 4 show that the average of the tested variables has a higher square root of AVE than the correlation value, hence, the latent variable was considered discriminantly valid. The square root value of the AVE must be greater than its correlation value with other constructs to meet the discriminant validity requirements [69][74]. The average loading factor value for the latent variable indicator was above that of others as shown in Table 5.

302 *3.1.2 Reliability test result*

The variables are considered reliable because composite reliability and Cronbach's alpha coefficient on average were more than 0.7 [61], [75] as shown in Table 6. However, certain indicators still had values less than 0.6, namely soil texture but the indicators used are reliable and adequate in forming the latent variables.

The highest composite reliability and cronbach's alpha coefficients were obtained for the variables of temperature, oxygen availability, and toxicity of 1 for the variables to be very reliable. The lowest coefficient was obtained on the root condition variable, therefore, the variable was not reliable. According to Bagozzi and Yi [76] and Hair et al. [75], variables are considered good and accepted when the value is > 0.70.

The remaining variables are water availability, nutrient retention, available nutrients, erosion hazard, and land preparation variables. The coefficient of composite reliability and cronbach's alpha > 0.6, there, the variable is considered reliable. The minimum value of composite reliability and cronbach's alpha coefficients was 0.60 [61], [75], [76].

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Table 4: Fornell-Larker criterion test

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Y
X1	1.000										
X2	0.940	0.952									
X3	0.059	0.149	1.000								
X4	0.082	0.030	-0.162	0.757							
X5	-0.360	-0.239	-0.103	-0.368	0.600						
X6	-0.069	0.021	0.012	-0.518	0.694	0.765					
X7	0.382	0.429	0.084	0.228	-0.030	-0.217	1.000				
X8	0.019	-0.082	-0.501	0.285	-0.317	-0.370	-0.009	0.966			
X9	-0.104	-0.033	0.237	-0.204	0.073	0.090	0.202	-0.250	0.992		
X10	0.198	0.093	-0.223	0.873	-0.303	-0.538	0.362	0.304	-0.126	0.998	
Y	0.018	0.152	0.169	-0.578	0.387	0.456	-0.016	-0.517	0.164	-0.568	1.000

X1 = temperature, X2 = water availability, X3 = oxygen availability, X4 = rooting condition, X5 = nutrient retention, X6 = nutrient availability, X7 = sodicity, X8 = erosion hazard, X9 = flooding hazard, X10 = land preparation, Y = maize hybrid yield.

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Table 5: Cross-Loading of latent variables to indicators

Indiastana					Lat	ent Variab	les				
Indicators	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Y
X1.1	1	0.8300	0.0312	0.0240	-0.2959	-0.0592	0.3270	0.0195	-0.0837	0.1680	-0.0204
X2.1	0.9783	0.8379	-0.0035	-0.0063	-0.2488	-0.0320	0.3555	-0.0017	-0.0539	0.1552	0.0155
X2.2	0.8534	0.9887	0.1938	-0.0557	-0.1257	0.0988	0.4025	-0.1435	-0.0279	-0.0178	0.1748
X2.3	0.5223	0.8497	0.1523	0.2464	-0.2505	-0.1161	0.4641	-0.1494	0.0144	0.2154	0.0592
X2.4	0.8293	0.9928	0.1721	-0.0334	-0.1524	0.0833	0.4440	-0.1713	-0.0383	-0.0031	0.1331
X3.1	0.0312	0.1785	1	-0.1541	-0.1091	-0.0375	0.0843	-0.4964	0.2530	-0.2229	0.2156
X4.1	-0.0058	-0.0006	-0.1696	0.0126	0.2127	0.1013	0.2173	0.1761	0.0055	-0.0225	0.0050
X4.2	-0.0728	-0.1082	-0.0829	0.9212	-0.2754	-0.5494	0.1845	0.2891	-0.2674	0.7910	-0.5276
X4.3	-0.1289	-0.1240	0.2071	-0.8990	0.2046	0.3209	-0.2633	-0.1587	0.0730	-0.7693	0.4666
X5.1	-0.2975	-0.4140	-0.3824	-0.3027	0.6470	0.3024	-0.1283	0.1730	-0.0342	-0.1190	0.0718
X5.2	-0.2033	-0.2939	-0.4480	-0.2791	0.5701	0.3176	-0.0273	0.1935	0.0801	-0.1829	0.1445
X5.3	-0.2440	-0.0158	0.1276	-0.1134	0.8308	0.5651	0.0728	-0.5076	0.0545	-0.1147	0.3501
X5.4	0.0537	0.1002	0.0033	0.0110	0.4360	0.4081	0.3732	-0.0504	0.1426	-0.0137	0.1395
X5.5	-0.2717	-0.2512	-0.1053	-0.4382	0.3650	0.4343	-0.6008	-0.0619	-0.1498	-0.4876	0.0825
X6.1	-0.0256	0.1778	0.0335	-0.1950	0.7028	0.7604	0.0453	-0.3878	-0.0809	-0.2162	0.2623
X6.2	-0.1201	-0.2238	-0.4256	-0.2590	0.4149	0.5865	-0.2829	-0.0389	-0.0267	-0.2860	0.1025
X6.3	-0.0437	0.0283	0.0310	-0.5607	0.5145	0.8974	-0.3341	-0.2613	0.2133	-0.6520	0.3892
X7.1	0.3270	0.4411	0.0843	0.2420	0.0290	-0.2417	1	-0.0286	0.2142	0.3621	0.0487
X8.1	-0.0226	-0.2234	-0.5132	0.2998	-0.2625	-0.3475	-0.0481	0.9537	-0.3383	0.3031	-0.5274
X8.2	0.0649	-0.0590	-0.4223	0.1646	-0.2942	-0.2950	-0.0035	0.9409	-0.0988	0.2516	-0.4682
X9.1	-0.0996	-0.0225	0.2254	-0.1949	0.1126	0.1483	0.1939	-0.2440	0.9835	-0.1342	0.2278
X9.2	-0.0658	-0.0305	0.2717	-0.1860	0.0271	0.0449	0.2271	-0.2252	0.9849	-0.0901	0.2380
X10.1	0.1848	0.0403	-0.2340	0.8480	-0.2309	-0.5544	0.3760	0.3058	-0.1188	0.9977	-0.5424
X10.2	0.1503	0.0225	-0.2107	0.8629	-0.2274	-0.5592	0.3464	0.2812	-0.1076	0.9976	-0.5365
Y.1	-0.0204	0.1413	0.2156	-0.5479	0.3425	0.3790	0.0487	-0.5271	0.2367	-0.5408	1

 $\frac{Y.1}{X1 = \text{temperature}, X2 = \text{water availability}, X3 = \text{oxygen availability}, X4 = \text{rooting condition}, X5 = \text{nutrient retention}, X6 = \text{nutrient availability}, X7 = \text{sodicity}, X8 = \text{erosion}}$ 329 hazard, X9 = flooding hazard, X10 = land preparation, Y = hybrid maize yield, X1.1 = temperature, X2.1 = rainfall, X2.2 = the wet month, X2.3 = the dry month, X2.3 =

330 long growth period, X3.1 = drainage, X4.1 = texture, X4.2 = coarse material, X4.3 = effective depth, X5.1 = organic C, X5.2 = cation exchanges capacity, X5.3 = base

331 saturation, X6.1 = total N, X6.2 = P availability, X6.3 = K exchangeable, X7.1 = the exchange sodium percentage, <math>X8.1 = slopes, X8.2 = soil erosion, X9.1 = inundation

332 height, X9.2 = inundation period, X10.1 = rock outcrops, X10.2 = surface rock, Y.1 = hybrid maize yield.

Indicators (land characteristics)	Cronbach's Alpha	Composite Reliability
X1.1 (Temperature)	1.000	1.000
X2.1 (Rainfall)		
X2.2 (Wet month)	0.975	0.965
X2.3 (Dry month)	0.975	0.905
X2.4 (Long growth periods)		
X3.1 (Drainage)	1.000	1.000
X4.1 (Texture)		
X4.2 (Coarse material)	0.002^{nor}	-1.055 ^{nor}
X4.3 (Effective depth)		
X5.1 (pH H ₂ O)		
X5.2 (pH KCl)		
X5.3 (Organic C)	0.718	0.628
X5.4 (Cation exchange capacity)		
X5.5 (Base saturation)		
X6.1 (Total N)		
X6.2 (P availability)	0.805	0.681
X6.3 (K exchangeable)		
X7.1 (Exchangeable sodium percentage)	1.000	1.000
X8.1 (Slopes)	0.965	0.928
X8.2 (Soil erosion)	0.905	0.928
X9.1 (Inundation height)	0.992	0.984
X9.2 (Inundation period)	0.772	0.704
X10.1 (Rock outcrops)	0.998	0.995
X10.2 (Surface rock)	0.990	0.995

 $\overline{nor} = not reliable.$

335 *3.1.3 Structural model test (inner models)*

Land characteristics that have a significant correlation with hybrid maize yields show a high level of contribution to land quality in influencing hybrid maize yields as indicated in Figure 3. The figure shows a structural model of the relationship between indicator variables, namely 24 land characteristics, rectangular yellow, and latent variables, including 10 land qualities maize yield, and oval blue. It also shows a model for the relationship between latent variables such as land qualities and maize yield as well as loading figures. The factor for each indicator and path coefficient for land qualities has a direct effect on the value of maize yields.

For example, X8 (erosion hazard) significantly determines the hybrid maize yield with a path coefficient of -0.392. The negative sign indicates that the erosion hazard is negatively related to maize yield, where the higher the erosion hazard, the lower the maize yield. Furthermore, nutrient retention (X5) contributes to the diversity of hybrid maize yields with a path coefficient of 0.252. A positive sign indicates that nutrient retention is positively related to maize yield, where the higher the value of nutrient retention were followed by the maize yield.



³⁴⁹

Figure 3: Path Coefficient of land quality on hybrid maize yield.

351 The results of this path analysis indicated that the land quality that can be a predictor of maize 352 yield diversity were oxygen availability (X3), nutrient retention (X5), nutrient availability 353 (X6), erosion hazard (X8), and land preparation (X 10). Figure 2 indicates that only 8 of the 24 354 indicators explain latent variance at the 5% real test level. The 8 indicators were coarse material 355 and effective soil depth as an indicator of rooting condition, organic carbon content as nutrient 356 retention, exchangeable K as nutrient availability, soil erosion and slope as erosion hazard, as well as rock outcrop and surface rock as an indicator of land preparation. It was also indicated 357 358 that the drainage loading factor was unable to explain the diversity of oxygen availability. Therefore, oxygen availability cannot be used as a land quality because there are no indicators 359 that can represent it. Only the land qualities of nutrient retention (X5), nutrient availability 360 361 (x6), erosion hazard (x8), and land preparation (X10) were used next.

The indicators of land characteristics for effective depth, organic C, total N, and exchangeable K have a fairly strong positive relationship and a very significant effect on hybrid maize yields. In this relationship, an increase in these parameters by 1%, will be followed by a rise in hybrid maize yields of 39% to 57.7%. According to [4], effective depth affects root growth and development, making plants grow and develop properly. Moreover, the levels of organic C, total N, and CEC are influenced by soil organic matter [77], while potassium plays a role in the growth and development of maize [78].

- 369 Indicators of rough soil characteristics, slopes, soil erosion, as well as surface and rock outcrops
- have a strong negative relationship with a very significant effect on hybrid maize yields. In this
- 371 relationship, a 1% decrease in coarse material, slope, soil erosion, as well as surface and rock
- outcrop is followed by an increase in hybrid maize yields by 39% to 57.7%.

373 **3.2.** Optimum hybrid maize yield by the land quality and land characteristics

Table 7 shows the mathematical equations for each land characteristic and also the optimum hybrid maize yield for the land equation. Figure 4 shows the diagram of the relationship between land characteristics as an independent variable (X) and maize yield as an independent variable Y. Model fitting indicates that the quadratic equation is sufficient to describe the condition of data distribution.

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Land Quality/Land Characteristics	Optimum Yield (ton/ha)	Yield Equation]
Rooting condition (rc)			
Coarse material	8.06	$Y = 0.0024800x^2 - 0.2457487x + 10.9082465$	0.
Effective depth	8.35	$\begin{array}{l} Y = -0.0007242 x^2 + 0.1890458 x - \\ 1.2946385 \end{array}$	0.
Nutrient retention (nr)			
Organic carbon	8.35	$Y = -24.3891969x^2 + 46.8464078X \\ - 8.8894056$	0.
Nutrient availability (na)			
Total N	8.43	$Y = -304.4463543X^2 + 144.7590906X - 2.6328530$	1.
K Exchangeable	5.74	$Y = -10.5596308X^2 + 17.4129832X + 2.2069179$	0.
Erosion hazard (eh)			
Slopes	8.43	$Y = 0.0172X^2 - 0.8448X + 13.907$	0.
Soil erosion	8.06	$y = 0.0000173X^2 - 0.0187536X + 9.0426459$	0.
Land preparation (lp)			
Rock outcrops	7.30	$Y = 0.0046385X^2 - 0.2934756X + 8.5159674$	0.
Surface rock	7.30	$Y = 0.0046385X^2 - 0.2934756X + 8.5159674$	0.

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The optimum of hybrid maize yield ranged from 5.74 to 8.43 ton/ha, where the highest yield 381 was obtained from total N and slopes of 8.43 ton/ha with an R^2 value of 100% and 91%. 382 383 Sutardjo et al (2012) showed that hybrid maize yields ranged from 7.43 to 9.2 ton/ha. This indicated that the optimum yield achieved is still within the range of hybrid maize yields that 384 385 have been previously reported. Nitrogen is directly involved in the formation of amino acids, proteins, nucleic acids, enzymes, nucleoproteins, and alkaloids, which are needed in the plant 386 growth process [79], [80]. An extremely high amount of N causes excessive vegetative growth, 387 thereby making plants fall easily and increasing susceptibility to disease [81]. Meanwhile, the 388 389 lack of N nutrients can limit cell division, enlargement [82], and the formation of chlorophyll, 390 leading to stunted growth as well as yellowing of leaves [81].

The lowest optimum yield was obtained from exchangeable K, which was only 5.74 ton/ha with an R^2 value of 94%. This was presumably because the K content in the soil is very low,

393 thereby affecting the hybrid maize yield. Potassium (K) is required by plants for physiological

394 functions, including carbohydrate metabolism, enzyme activity, osmotic regulation, efficient

water use, N uptake, protein synthesis, and assimilate translocation [83]–[86]. It also plays a
 role in improving the quality of crop yields (McKenzie, 2013, Subandi, 2013).

397 The optimum hybrid maize yield of the remaining is relatively diverse. This includes effective depth and organic carbon, which were both 8.35 ton/ha with an R² value of 87%. Furthermore, 398 coarse material and soil erosion were 8.06 ton/ha with an R² value of 95% and 88%, while rock 399 400 outcrops and surface rock were 7.30 ton/ha with an R2 value of 91%. The absence of coarse 401 material > 2 mm in diameter indicated that plant roots can grow freely on the surface or deeper 402 parts of the soil [89], because the deeper the roots of the maize, the greater the maize yield 403 [90], [91]. The addition of organic matter will increase maize yield [92]-[94] and organic C content [95] because soil organic matter is a strong positive predictor of yield [96]. Kane et al. 404 405 [96] also stated that the addition of more organic matter will improve water retention, thereby 406 reducing maize yield losses due to drought. The slope has a significant effect on soil degradation [97]. According to a previous study, erosion and maize yield are negatively 407 408 correlated, hence, increased erosion will reduce maize productivity [98]. Soil erosion on flat land is slower surface runoff [99]. It was also reported that surface rocks and outcrops are the 409 limiting factors in the suitability of maize plantations [100]. Therefore, a high percentage of 410 411 rock outcrops will complicate land cultivation and plant root growth.

412 **3.3. Land suitability criteria for hybrid maize crops**

413 Table 8 shows the yield limit for each class from the calculation of the optimum yield, where 414 the class range for each land characteristic is derived. Based on the optimum yield of the highest 415 hybrid maize, there were 2 indicators, namely the total N content and the slope. The total N indicator with a very suitable class (S1) was achieved when the value in the soil was greater 416 417 than 0.10%, while in the moderately suitable class (S2), it was achieved when the total N in 418 the soil ranges from 0.07-0.09%. In the marginally appropriate class (S3), the total N indicator 419 was achieved when the total N in the soil ranges from 0.05-0.06%, while the not suitable class 420 (N) was achieved when the content was less than 0.05%. On the slope indicator with class S1, it was obtained when the slope class ranges from 0-7.69%%, while class S2 was achieved when 421 the slope class ranges from 7.70-11.83%. Furthermore, in classes S3 and N, it was obtained 422 423 when the slope class ranged from 11.84-18.24% and greater than 18.24%, respectively.

424 Based on the optimum yield of the lowest hybrid maize, only the exchangeable K was the indicator. In classes S1 and S2, it was achieved when the exchangeable K content in the soil 425 426 was greater than 0.24 cmol(+)/kg and ranges from 0.13-0.23 cmol(+)/kg, respectively. 427 Furthermore, class S3 was achieved when the exchangeable K content in the soil ranges from 428 0.04-0.12 cmol(+)/kg, while in class N, it was obtained when the exchangeable K content in 429 the soil was less than 0.04 cmol(+)/kg. The remaining variables and indicators were relatively 430 varied according to the optimum yield of hybrid maize and the range of land suitability classes obtained as presented in Table 8. 431





Figure 4: Scatter diagram relationship among maize yield and land characteristics

Value of Land Suitability Criterion Yield Limits (ton/ha) Obtained Land Quality/Land **S1 - S2** S2 - S3S3 - NCharacteristics (80% x (60% x (40% x **S1 S2 S3** Ν Yoptim) Yoptim) Yoptim) Rooting condition (rc) 0 – 13.41 -27.38 -> Coarse material (%) 8.06 6.04 4.03 13.40 27.37 52.39 52.39 49.25 -33.18 -<Effective depth (cm) 8.35 6.26 4.18 ≥ 69.55 69.54 49.24 33.18 Nutrient retention (nr) 6.26 Organic carbon (%) 8.35 4.18 ≥ 0.50 0.41 - 0.490.34 - 0.40< 0.34 Nutrient availability (na) Total N (%) 8.43 6.32 4.22 ≥ 0.10 0.07 - 0.090.05 - 0.06< 0.05 K Exchangeable 5.74 4.31 2.87 ≥ 0.24 0.13 - 0.230.04 - 0.12< 0.04(cmol(+)/kg)Erosion hazard (eh) 0 – 7.70 -11.84 -> Slopes (%) 8.43 6.32 4.22 18.24 7.69 11.83 18.24 Soil erosion > 8.06 6.04 4.03 ≤ 55.21 195.29 605.56 (ton/ha/year) 605.56 Land preparation (lp) 0 -4.46 -13.10 -> Rock outcrops (%) 3.85 7.30 5.47 4.45 13.09 31.78 31.78 0 – 4.46 -13.10 ->7.30 5.47 Surface rock (%) 3.85 4.45 13.09 31.78 31.78

 Table 8: Yield limits of hybrid maize and values obtained in each land suitability class interval by land quality and characteristics.

436 S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, and N = not suitable.

437 Based on the relationship between the quality and characteristics of the selected land with 438 optimum results, the criteria for hybrid maize land suitability were obtained as shown in Table 439 8. These criteria described the actual state of achieving optimum, moderate, and minimum 440 yields of hybrid maize in the field with values of 80%, 60%, and 40%, respectively. According 441 to Sukarman et al. [101], the parameters used in the land suitability assessment must describe 442 the actual conditions. This is due to the significant positive correlation between maize yield 443 and land suitability class [102].

444 The land suitability criteria for the new hybrid maize are fewer and have referred to the optimum yield. Meanwhile, the land quality and characteristics in this new criterion are less 445 because it only consists of root conditions with characteristics of coarse material and effective 446 depth, nutrient retention with organic C, and nutrient availability with total N and K 447 exchangeable. It also consists of erosion hazards with characteristics of slopes and soil erosion, 448 449 as well as land preparation with surface rocks and rock outcrops only. The land qualities 450 selected and maize yields consistent with the land potential are the basis for developing suitability criteria. This will reduce the land characteristics and make the evaluation process 451 452 faster, cheaper, and easier with accurate results [26]. Some characteristics and land quality 453 criteria were not made because they did not significantly affect the yield of hybrid maize. The 454 number and distribution of the data were still limited and the diversity of values was small or 455 not measurable in the field [72].

456 Compared to Wahyunto et al. [47], the new land suitability criteria for hybrid maize plants in 457 Table 9 is more realistic in value with the conditions in the field and is based on the 458 achievement of optimum yields. The current land suitability criteria are still general and not 459 specific to maize yields [26], although the agronomic and yield potential of each maize variety 460 differ, based on the diversity of characteristics and land quality in the field. There are still 461 limitations on the use of these results for the development of hybrid maize in the Boalemo 462 Regency because the setting is only based on land characteristics and optimum yields in this 463 regency. Therefore, further investigation to expand the scope of the research area nationally 464 with more diverse and contrasting land characteristic values is recommended to determine the 465 effect on hybrid maize production.

1		0	5			1 2			
Land Quality/Land	New Land Suitability Criterion of Hybrid Maize					Land Suitability Criterion of General Maize [47]			
Characteristics	S1	S2	S3	Ν	S1	S2	S3	Ν	
Rooting condition (rc)									
Coarse material (%)	0 -	13.41 -	27.38 -	>	< 15	15 –	35 –	>55	
Coarse material (76)	13.40	27.37	52.39	52.39		35	55		
Effective depth (cm)	\geq	49.25 -	33.18 -	<	> 60	60 –	40 –	< 25	
Effective depth (cm)	69.55	69.54	49.24	33.18		40	25		
Nutrient retention (nr)									
Organic carbon (%)	\geq	0.41 - 0.49	0.34 - 0.40	< 0.34	>	0.8 -	< 0.8	-	
Organie carbon (78)	0.50	0.41 - 0.49	0.34 - 0.40	< 0.54	1.20	1.2			
Nutrient availability (na)									
Total N (%)	\geq 0.10	0.07 - 0.09	0.05 - 0.06	< 0.05	Mo	Lo	VLo	-	
K Exchangeable	\geq	0.12 0.22	0.04 - 0.12	< 0.04	Mo-	Lo	VLo	-	
(cmol(+)/kg)	0.24	0.13 - 0.23	0.04 - 0.12	< 0.04	Hi				
Erosion hazard (eh)									
Slopes (%)	0 -	7.70 -	11.84 -	>	< 8	8 - 15	15 –	> 25	
Stopes (70)	7.69	11.83	18.24	18.24			25		
Soil erosion	\leq	195.29	605.56	>	-	VLi	Li-	He-	
(ton/ha/year)	55.21	195.29	005.50	605.56			Mo	VHe	
Land preparation (lp)									
Rock outcrops (%)	0 -	4.46 -	13.10 -	>	< 5	5 - 15	15 –	>4(
Nock outerops (70)	4.45	13.09	31.78	31.78			40		
Surface rock (%)	0 -	4.46 -	13.10 -	>	< 5	5 - 15	15 –	>40	
Surface fock (70)	4.45	13.09	31.78	31.78			40		

466 Table 9: Comparison of new and general land suitability criteria with land quality and characteristics.

467 S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable, Hi = high, Mo =
468 moderate, Lo = low, VLo = very low, He = heavy, Li = light, VLi = very light, VHe = very heavy.

469 **Conclusions**

470 Land suitability criteria for the new hybrid maize are determined by land qualities, namely root conditions, nutrient retention, available nutrients, erosion hazard, as well as land preparation, 471 and land characteristics, including coarse material, effective depth, organic C, total N, 472 473 exchangeable K, slopes, soil erosion, rock outcrops, and surface rocks. The highest optimum yield of 8.35 ton/ha was achieved by the effective depth and organic C content for a very 474 suitable class (S1), while the lowest value of 5.47 ton/ha was attained by exchangeable K for 475 476 class S1. These results showed that the combination of the PLS-SEM and boundary line analysis can be an alternative approach to establishing new land suitability criteria for crops 477 based on optimum yields and selected land quality. 478

479 Data Availability

480 All data can be obtained from the corresponding author upon request.

481 **Conflicts of Interest**

482 The authors declared that there is no conflict of interest regarding the publication of this paper.

483 **Funding Statement**

This study was funded by the Directorate of Research, Technology and Community Service,
Directorate General of Higher Education, Research and Technology, Ministry of Education,
Culture, Research and Technology of the Republic of Indonesia, grant number
B/105/UN47.D1/PT.01.03/2022.

488 Acknowledgments

489 The authors are grateful to the Ministry of Education, Culture, Research and Technology of 490 the Republic of Indonesia, and the Institute Research and Community Service of Universitas

491 Negeri Gorontalo for their financial and administrative support.

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1 Determination of Land Suitability Criteria for Maize Hybrid in

2 Boalemo Regency Based on Optimum Yield and Selected Land

3 Quality

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13 Abstract

- 14 The significant effect of land quality on maize production has not been fully considered in the 15 existing land suitability criteria. Therefore, this study aims to determine land suitability criteria for hybrid maize in Boalemo Regency based on the optimum yield and land quality. It was 16 17 carried out in Boalemo Regency, Indonesia, where the land unit of 67 units were surveyed to 18 obtain land characteristics data. A partial least square of structural equation model (PLS-SEM) 19 with SmartPLS 8.0 was used to select a robust land quality controlling hybrid maize yield, 20 while the boundary line method was used to determine optimum yield and differentiating of 21 land suitability criteria. The result showed that land qualities that define the optimum yield of 22 hybrid maize were root conditions, nutrient availability, nutrient retentions, land preparation, 23 and erosion hazard. The soil characteristics were effective depth, coarse material, organic C, 24 total N, K exchangeable, slopes, soil erosion, rock outcrops, and surface rocks. Furthermore, 25 the highest optimum yield of 8.54 ton/ha was achieved by the total N and slopes for a very 26 suitable class (S1), while the lowest of 5.58 ton/ha was obtained by exchangeable K for class 27 S1. This showed that the combination of PLS-SEM and boundary line analysis was a better
- 28 approach to developing new land suitability criteria for hybrid maize.

29 **1. Introduction**

- Food security and farmer prosperity are global concerns, this makes every country increase crop production as well as farmers' income. An important issue for countries with developing economies is ensuring food security, where the agricultural sector plays a strategic role in increasing food availability [1]. Although the global food system has placed maize (*Zea mays* L.) as the leading cereal crop [2], its productivity is being disrupted by land degradation, water
- 35 scarcity, and climate change [3].
- In Indonesia, the wet tropical climate with rainfall and high temperatures tends to reduce the quality of land and agricultural products [4]. This country ranked 8th among the maizeproducing nations with a contribution of 2.19% and 2.42% of the world's total harvested area
- 39 [5]. However, the main problem is the relatively low level of yield in several regions because

- 40 the achievement of maize production has not been followed by an increase in yield per unit
- 41 area [6]. This is indicated by the average yield in 2020, which was up to 5.57 ton/ha [5].
- 42 According to a previous investigation, maize production in Indonesia can reach between 10-12
- 43 ton/ha [7], [8] thereby making the country the 21st leading importer in the world.

In Indonesia, Gorontalo Province is one of the centers of maize production, where the hybrid
type is the most widely grown species [9]. The maize production in the province reached 1.8
million tons in 2021 [10], with several export advantages and competitiveness [11].
Furthermore, the planting of hybrid, composite, and local maize types has reached more than
98.90%, 0.68%, and 0.41% only, respectively [12] including Boalemo Regency.

- 49 Boalemo Regency ranks third as a maize-producing center in Gorontalo Province with a 50 contribution of 18.90% [13]. The maize plant dominates the use of agricultural land in this district by 37.43% [14], therefore, the commodity has competitive and comparative advantages 51 52 with a PCR value of 0.80 and 0.91 DRC. This is because maize plant is supported by land area, 53 climatic conditions, production facilities, as well as market guarantees, and the basic price of 54 buying corn from the government [15]. In 2021, the average hybrid and local maize yields in 55 the regency reached 5.20 tons/ha [16] and 2.34-3.30 tons/ha, respectively [17]. This indicated 56 that the productivity of hybrid maize is still higher than local maize [18] but with lower 57
- 57 achievement compared to the national maize production of 5.57 tons/ha [5] and has not yet 58 reached the target of 5.60 tons/ha in 2021 [19]. The production of hybrid maize in Gorontalo
- 59 can reach 9.78-13.11 tons/ha [20] because it is often cultivated on land that does not meet the
- 60 required qualities [6]. Therefore, there is a need to determine land quality-based hybrid maize
- 61 land suitability criteria for site-specific land use planning in Boalemo District.
- 62 Maize is usually grown on land with low yield potential [21] and soil fertility, thereby causing 63 low productivity [22]. Moreover, land productivity is determined by quality and characteristics 64 [23], [24], while land quality has a close relationship with maize yields [25]. The land quality affecting the optimum yield of maize needs to be determined [26] and increased by using hybrid 65 66 varieties that have high yields. This makes it necessary to evaluate the suitability of the hybrid maize in a region to ensure optimal production. The land suitability criteria for hybrid maize 67 68 are not yet available because the current criterion is the general suitability of maize plants 69 without distinguishing between hybrids and inbreds. Therefore, there is a need to make land 70 suitability criteria for hybrid maize plants.
- 71 A previous study has shown that land quality has a significant effect on suitability for certain 72 uses [27]. Meanwhile, land suitability is also important due to the continuous increase in the 73 demand for agricultural land [28]. The land suitability criteria for existing maize fields are still 74 general [29] and there are no specific criteria for hybrid maize varieties. The class assessment 75 outcomes obtained using the existing criteria are relatively many and are not in line with the 76 actual field results [30]. The current criteria consist of 3 components, namely, land quality, 77 characteristics, and ranges of land characteristic values to determine its suitability. Therefore, 78 the problem in developing criteria is choosing land quality, characteristics, and determining the 79 range of land characteristic values associated with suitability classes, namely suitable, 80 somewhat suitable, marginally suitable, and not suitable.
- 81 The selection of land quality and characteristics can be carried out through the partial least
- square of the structural equation model (PLS-SEM), while the range limits is being determined
- 83 by the boundary line method. Land qualities and characteristics in the current criteria can be

- 85 better indicators and models than other multivariate analyses [31]–[35]. This is because the
- variant-based PLS-SEM has a higher level of flexibility and the size of the sample used is relatively small ranging from 30 to 100 [36]–[39]. The use of PLS-SEM to determine land
- relatively small ranging from 30 to 100 [36]–[39]. The use of PLS-SEM to determine land characteristics and qualities that control maize crop yields is still relatively rare, except for Syaf
- [40] on older cocoa plants, maize composite [41], and on local varieties [6]. The boundary line
- 90 method can help determine nutrient adequacy concentrations and the optimum yield range of
- 91 a plant that affects nutrients, as well as other land characteristics [42], [43]. Currently, the land
- 92 suitability criteria for maize plants have not been determined using the boundary line method,
- 93 except by Ridayanti et al. [44], although the investigation was not specific to hybrid maize.

After obtaining the quality and characteristics of land affecting maize yields with PLS-SEM, the boundary line method can be used to determine the optimum yield as well as land suitability criteria simultaneously. This is carried out by drawing the intersection of the boundary line at the yield and projecting with the land characteristics [29]. Therefore, this study aims to determine land suitability criteria for hybrid maize in Boalemo Regency based on the optimum

99 yield and land quality.

100 2. Materials and Methods

101 **2.1 Study area**

102 The study area extends from 0°28'5.6" - 0°57'30.02" N to 122°08'34.25" - 122°43'10.41"E (Figure 1) on a scale of 1 : 40,000, which is located in the agricultural land of Boalemo 103 Regency, Gorontalo Province, Indonesia. The maximum air temperature was 28.19°C and the 104 105 minimum was 26.79°C with an average of 28.01°C. Meanwhile, the maximum rainfall was 1,849 mm and the minimum was 1,246 mm with an average of 1,478 mm [45]. The wet and 106 dry seasons last for 3 months and 5 months respectively. The soil mapping carried out by 107 108 Ritung et al. [46] at a scale of 1 : 50,000 become the initial reference for determining 35 soil 109 units, where each unit has information on land characteristics, namely effective depth, drainage, texture, pH, cation exchange capacity, base saturation, landform, parent material, 110 relief, and land unit area. Meanwhile, the new soil unit is 1:40,000 in scale and there has been 111 a change in the agricultural land use existing. This indicated that the slope class of 8 - 15% or 112 113 hilly is more dominant in the study area with a percentage of 29.77% and slopes > 40% or mountainous which is only 2.67%. Furthermore, the dry land is dominant with a value of 114 59.86% and a little shrub which was only 9.21%, while the dominant Typic Haplustalfs of soil 115 sub group classification was 22.47%, then the Fluventic Haplustepts was 21.31% and very little 116 117 Vertic Haplustepts of soil sub group classification was 0.04% only (Figure 1).



119

- Figure 1: Study area.

120 **2.2 Dataset collection for land quality and land characteristics**

121 The quality and characteristics of the land in this study refer to Wahyunto et al. [47], consisting 122 of 10 land qualities and 24 characteristics. The set of temperature land quality is determined 123 from the characteristics of the annual average air temperature, while the land quality water availability is determined from the characteristics of annual rainfall, wet months, dry months, 124 125 and the length of the growth period (LGP). Land quality oxygen availability is determined from 126 soil drainage characteristics, rooting conditions are determined from the soil texture, coarse material, and soil effective depth, nutrient retention is identified from the pH value, C-Organic, 127 cation exchange capacity (CEC), and base saturation. Furthermore, the available nutrient is 128 129 determined from the characteristics of total N, P, and exchangeable K, the sodicity is obtained 130 from the exchangeable sodium percentage (ESP), while erosion hazard is determined from slopes and soil erosion. The quality of the flood-hazard land is determined by identifying the 131 height and the duration of the inundation, while preparation is carried out from the 132 133 characteristics of outcrops and surface rocks. The selection of this set of land qualities and 134 characteristics is based on the availability of data and their impact on maize production [26].

Data on average annual air temperature and rainfall for 10 years (2010-2021) were collected
from different climate stations, namely the Bandungrejo with 0°41' N - 122°38' E, the elevation
40 m asl, while Harapan has 0°42' N - 122°29' E and an elevation of 37 m asl. It also includes
Lakeya Rain Post with 0°42.82' N - 122°32.07' E, 32 m asl, Mohiyolo has 0°46.41' N 122°26.41' E and an elevation of 39 m asl, Saritani 0°46.45' N - 122°20.40' E, with 26 m asl,
Tangkobu 0°37.25' N - 122°36.36' E, 25 m asl, Bubaa 0°31.36' N - 122°33.39' E, 16 m asl,
Wonggahu 0°38' N - 122°33' E, 35 m asl, and Sambati Rain Post with 0°31.184' N - 122°27.074'

E and an elevation of 9 m asl managed by BWS II Sulawesi. Furthermore, these data
determined wet months (> 200 mm) and dry months (<100 mm), which refers to the Oldeman
and Darmiyati criteria [48]. The land water balance was determined using the Thornwhite and
LGP methods based on the number of surplus and deficit rainy days [49].

Based on the previous soil unit [46], then these soil unit was detailed again by adding 32 of 146 147 soil units to be surveyed and observed, making up to 67 soil units in the area as shown in the legend Figure 1. Soil characteristics such as drainage, coarse material, effective soil depth, 148 slope, inundation height and duration, rock outcrops and surface rocks were determined by 149 150 conducting soil profile descriptions and direct observation on 67 pedons referring to the description guidelines in the field [50]. Meanwhile, soil erosion was determined by the USLE 151 152 method [51]. Other soil characteristics were further analyzed in the soil laboratory using 153 samples from each pedon.

154 Soil samples were dried for 3 days and sieved through a 2 mesh sieve. The method of soil 155 physics laboratory analysis was carried out according to the procedures by Kurnia et al. [52]. 156 Based on this procedure, soil texture was analyzed in terms of sand, clay, and silt fractions using the pipette method, while soil moisture storage was evaluated using the gravimetric 157 method that can be applied in water balance analysis. The method of soil chemistry laboratory 158 159 analysis was carried out according to the procedures by Eviyati and Sulaeman [53]. The soil pH was determined with a pH meter in a 1:2.5 soil and water solution, while the organic C 160 161 content was assessed using the Walkley and Black method. The total N was assessed using the 162 Kjeldahl method, while the available P content was measured using the Olsen method. The basic cations and CEC was extracted with 1N NH₄OAc pH 7.0 (ammonium acetate) on a dry 163 sample of 105°C. The base saturation was determined by calculating the percentage of basic 164 cations number with CEC, ESP was evaluated using the percentage ratio of sodium to CEC 165 [54] [55]. Subsequently, the data from the chemical analysis were averaged to a depth of 0-30 166 cm using the weighted averaging technique. The framework of this study is presented in Figure 167 168 2.



Figure 2: Research framework.

171 **2.3 Dataset collection for hybrid maize yield**

The areas currently planted with hybrid maize were identified and blocks with a size of 2.5 m x 2.5 m were made in each map unit (Figure 1). Maize plants in each block passed through standardized management according to farmers' technology. After harvesting, weighting was carried out to obtain hybrid maize yield data from the results of tiles on each land unit.

176 Subsequently, the results were calculated using the formula [56], as expressed below:

177
$$Y(t) = H x \frac{A}{6.25 m^2}$$
 (1)

178 Meanwhile, productivity is calculated using the formula [56] below:

179
$$Y(t ha^{-1}) = \frac{H x \, 1.64 \, x \, 56.73}{100}$$
 (2)

180 where Y = hybrid maize yield, H = tile yield (kg), A = maize area 1 per hectare (ha), 1.64

181 and 56.73 = constant.

182 **2.4 Selection of land quality and land characteristics**

183 The quality and characteristics of the land in the suitability criteria were used as presented in

184 Tables 1 and 2, which show brief statistics. Generally, most data are relatively homogenous,

185 except for coarse material, available P, slopes, soil erosion, height and inundation, as well as

186 rock outcrops and surface rocks. The selection used the partial least squares of the structural

187 equation model (PLS-SEM) refers to Hair et al. [38] with tools SmartPLS, where land quality188 and characteristics were selected as the latent and manifest variables, respectively. The analysis

in PLS-SEM has 2 main steps, namely (1) the measurement model (outer model) and (2) the

190 structural model test (inner model).

Lat	ent variables		Indicators	Data Saunaan
Notation Land quality		Notation	Land characteristics	- Data Sources
X1	Temperature (t)	X1.1	Temperature	[45]
X2	Water availability (wa)	X2.1 X2.2	Rainfall Wet month	[45] Rainfall > 200 mm
	(""")	X2.3	Dry month	Rainfall $< 100 \text{ mm}$
		X2.3 X2.4	Long growth period	Water balance (Thornwhit
		Λ2.7	(LGP)	method), soil moisture storage (Gravimetric method), water surplus an
				defisit days
X3	Oxygen availability	X3.1	Drainage	Soil survey and land
110	(oa)	110.1	Diamage	observation
X4	Rooting condition	X4.1	Texture	555 91 (WHO II
111	(rc)	X4.1.1	Sand fraction	
	(10)	X4.1.2	Silt fraction	Pipet method
		X4.1.2	Clay	
		X4.2	Coarse material	Soil survey and land
		X4.3	Effective depth	observation
X5	Nutrient retention	X5.1	pH H ₂ O	
	(nr)	X5.2	pH KCl	pH meter (1 : 2.5)
	()	X5.3	Organic C	Walkley and Black metho
		X5.4	Cation exchange	1N NH ₄ OAc pH 7.0
			capacity (CEC)	Extracted
		X5.5	Base saturation	Calculation
X6	Nutrient	X6.1	Total N	Kjeldahl method
-	availability (na)	X6.2	P availability	Olsen method
	······································	X6.3	K exchangeable	1N NH ₄ OAc pH 7.0
				Extracted
X7	Sodicity (xn)	X7.1	Exchangeable sodium	
	• · ·		percentage (ESP)	Calculation
X8	Erosion hazard (eh)	X8.1	Slopes	Soil survey and land
		X8.2	Soil erosion	observation
X9	Flooding hazard	X9.1	Inundation height	Soil survey and land
	(fh)	X9.2	Inundation period	observation
X10	Land preparation	X10.1	Rock outcrops	Soil survey and land
	(lp)	X10.2	Surface rock	observation
Y	Hybrid maize yield	Y.1	Hybrid maize yield	Tile box methods

191

(4)

Step 1 consists of validity and reliability tests, wherein the validity test is conducted with convergent and discriminant validity. The convergent validity is in form of outer loadings (loading factor) and average variance extracted (AVE), while discriminant validity is in form of cross-loading and the Fornell-Larcker criterion. Meanwhile, the reliability test uses composite reliability and Cronbach's alpha.

Convergent validity was observed from the magnitude of the outer loading and the AVE value
of each indicator on the latent variable. The validity was calculated according to the equation
[57][58][59][60]:

$$201 x_i = \lambda x_i \xi_I + \delta_i (3)$$

202
$$y_i = \lambda y_i \eta_1 + \varepsilon_i$$

203 where x and y = exogenous (ξ) and endogenous (η) latent variable indicator, λx and $\lambda y =$ 204 loading factors, δ and ϵ = residual/measurement errors or noise.

Table 2: Brief statistics of land quality and characteristics.

Latent variables /	Unit	n	Min	Median	Mean	Max	SD
Indicators	Unit	п	141111	Wiculan	Witan	1 114 A	50
X1 (Temperature)							
X1.1 (Temperature)	°C	67	26.79	27.80	28.01	28.19	0.6
X2 (Water availability)							
X2.1 (Rainfall)	mm	67	1,246.00	1,533.42	1,478.00	1,849.00	232.6
X2.2 (Wet month)	month	67	0.00	1.03	1.00	3.00	0.8
X2.3 (Dry month)	month	67	2.00	3.39	4.00	5.00	1.0
X2.4 (LGP)	day	67	211.00	246.00	214.00	304.00	44.5
X3 (Oxygen availability)							
X3.1 (Drainage)	class	67	0.00	3.76	4.00	6.00	1.8
X4 (Rooting conditions)							
X4.1 (texture)	class	67	1.00	2.21	2.00	5.00	0.9
X4.1.1 (Sand fraction)	%	67	5.00	41.58	43.00	81.33	18.5
X4.1.2 (Silt fraction)	%	67	7.33	27.31	24.50	51.50	11.5
X4.1.3 (Clay)	%	67	11.33	31.90	30.00	56.33	12.7
X4.2 (Coarse material)	%	67	5.00	17.27	10.00	70.00	16.5
X4.3 (Effective depth)	cm	67	10.00	74.55	74.00	160.00	36.4
X5 (Nutrient retention)							
X5.1 (pH H ₂ O)		67	5.00	5.92	5.90	7.15	0.5
X5.2 (pH KCl)		67	4.35	5.24	5.17	6.60	0.5
X5.3 (Organic C)	%	67	0.41	0.85	0.77	2.35	0.3
X5.4 (CEC)	cmol(+)/kg	67	8.94	24.89	22.43	59.57	11.4
X5.5 (Base saturation)	%	67	45.03	56.22	52.85	81.89	9.7
X6 (Nutrient availability)							
X6.1 (Total N)	%	67	0.04	0.09	0.08	0.27	0.0
X6.2 (P availability)	mg/kg	67	0.73	8.62	3.77	58.67	12.6
X6.3 (K exchangeable)	cmol(+)/kg	67	0.07	0.39	0.24	1.92	0.4
X7 (Sodicity)	() 0						
X7.1 (ESP)	%	67	0.76	7.06	6.20	24.17	5.6
X8 (Erosion hazard)							
X8.1 (Slopes)	%	67	1.00	9.58	6.00	25.00	7.2
X8.2 (Soil erosion)	ton/ha/year	67	3.66	334.51	110.27	1772.43	439.0

1 (11)0110 110120 (1010)	101111	01	2.00			0.07	1110
Y (Hybrid maize yield)	ton/ha	67	2.85	4.95	4.68	8.07	1.1
X10.2 (Surface rock)	%	67	0.00	6.58	0.00	45.00	11.5
X10.1 (Rock outcrops)	%	67	0.00	6.64	0.00	45.00	11.5
X10 (Land preparation)							
X9.2 (Inundation period)	day	67	0.00	0.64	0.00	5.00	1.5
X9.1 (Inundation height)	cm	67	0.00	7.58	0.00	50.00	17.1
X9 (Flooding hazard)							

n =the number of the land unit, min = minimum, max is maximum, SD = standard deviations, LGP = long growth periods, CEC = cation exchange capacity, and ESP = exchangeable sodium percentage.

Meanwhile, the average variance extracted (AVE) value was calculated using the equation [61][62][63][64][65]:

210
$$AVE = \frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i var(\varepsilon_i)}$$
 (5)

211 Where λ_i^2 = the loading factor, var = the variance, and ε_i = the error variance.

The loading factor of an indicator with the highest value is the strongest or most important measure in reflecting the latent variable. In this study, the loading factor value is > 0.70 for selecting best land characteristics, but values ranging from 0.50-0.60 can still be tolerated with a t-statistic > 1.96 or a small p-value of 0.05 [37], [66]. Meanwhile, the AVE value used was

216 more than 0.50, showing that the convergent validity on the latent variable has been reached.

217 The discriminant validity test used the cross-loading value and the Fornell-Larker criterion to 218 test discriminantly valid indicators in explaining or reflecting latent variables. When the 219 correlation between the latent variables and the core measurement of each indicator is high, the 220 latent variable can predict the indicator better and is considered valid. The discriminant validity 221 is measured by the square root of the average variance extracted, which will be compared with 222 the correlation value between variables. The value calculated based on the square root of AVE 223 must be higher than the correlation between constructs [61]. The equation is expressed below 224 [61][67][63][64][65]:

225 Square Root of AVE =
$$\sqrt{\frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i \, var(\varepsilon_i)}}$$
 (6)

226 where λ_i^2 = the loading factor, var = the variance, and ε_i = the error variance.

Furthermore, the composite reliability and Cronbach's alpha were used to test the reliability value between indicators of the latent variables. They are considered good and accepted when the value is > 0.70 and has a minimum value of 0.60 [37]. The composite reliability value is calculated using the equation [68][62][69][65]:

231
$$\rho c = \frac{(\Sigma \lambda_i)^2}{(\Sigma \lambda_i)^2 + \Sigma i \, var(\varepsilon_i)}$$
(7)

- 232 where λ_i = the loading factor, var = the variance, and ε_i = the error variance.
- 233 Meanwhile, the value of Cronbach's Alpha is calculated according to the equation [70][65]:

234
$$\alpha = \left(\frac{\sum p \neq p'^{cor(X_{pq}, X_{p'q})}}{p_{q+\sum p \neq p'}^{cor(X_{pq}, X_{p'q})}}\right) \left(\frac{p_q}{p_{q-1}}\right)$$
(8)

235 where P_q = the number of indicators or manifest variables, and q = the indicator block.

For step 2, the structural model testing (inner model) was carried out after the relationship model was built in line with the observed data and the overall suitability, namely goodness of fit. The structural equation (inner model) is as follows [62][59][60]:

239
$$H_j = \gamma_j \xi_1 + \gamma_j \xi_2 + \dots + \gamma_j \xi_n + \zeta_j$$
(9)

240 where η_j = endogenous variable vector (dependent), $\gamma_j \xi_1 + \gamma_j \xi_2 + \dots + \gamma_j \xi_n$ = exogenous latent 241 variable vector, and ς_j = residual vector (error).

242 Meanwhile, the determinant coefficient and goodness of fit (Q^2) were calculated using the 243 equation [62][64][70]:

244
$$Q^2$$
 (Predictive relevance) = 1 - (1 - R₁²) (1 - R₂²) ... (1 - R_p²) (10)

245 where R_1^2 , R_2^2 , ... $R_p^2 = R$ square of endogenous variables in the equation model [68].

The quantity of Q^2 has a value with a range of 0 < Q2 < 1, the closer the value to 1, the better the model [37]. It is also equivalent to the coefficient of total determination in path analysis. Furthermore, the effect and significance were tested based on the estimated value of the path coefficient and the critical point value (t-statistics or p-value) at = 0.05. The relationship model between variables was measured by testing the direct correlation coefficient between variables. The results of testing the relationship between *X* and *Y* variables were indicated by the correlation coefficient as well as t-statistics, and are also presented in the path diagram.

253 2.5 Class assignment

To determine the class-required data for optimum results, class limits were calculated from the percentage of optimum results. After knowing the highest and lowest yields, the values were connected with the range of land characteristics values. The land suitability class and yield used referred to FAO [71], namely class S1 (very suitable) when the values reach 80-100%, S2 was moderately suitable 60-80%, S3 marginally suitable 40-60%, and N not suitable <40% of the optimum conscience.

the optimum capacity.

260 The optimum yield was determined using the boundary line method. This method is carried out by drawing a boundary line on the graph of the relationship between yield and land 261 characteristics to obtain optimum results. In the boundary line method according to 262 Widiatmaka et al. [72], each land characteristic is plotted on the X-axis, while hybrid maize 263 yields are plotted on the Y-axis. Bhat and Sujatha [42] stated that the preparation of the hybrid 264 265 maize yield boundary line includes the preparation of a scatter diagram between the X and the Y variable, (2) division of the X-axis into several classes of intervals, (3) determination of the 266 highest data points in each class interval, (4) preparation of boundary lines based on the highest 267 268 data points from each class interval, (5) draw a line parallel to the X-axis according to the

269 percentage of the result class.

Furthermore, with the Microsoft Excel application tools, the boundary between classes S1 to S2, S2 to S3, and S3 to N were determined by the Data menu \rightarrow What-if-Analysis \rightarrow Goal Seek \rightarrow Set the cell at the location containing the regression equation \rightarrow to value fill with the result limit values S1 to S2, S2 to S3, and S3 to N \rightarrow By changing cell \rightarrow the location where the value of the characteristics of the land will be sought \rightarrow Ok. On location "By changing cell", the number being searched will appear, and at the location "set cell" will be equal to the limit value of the result.

277 **3. Results and Discussion**

278 **3.1 Land quality and characteristics controlling hybrid maize yield**

279 *3.1.1 Validity test result*

280 Table 3 shows the loading factor of the variables, where most indicators were more than the 281 critical limit of 0.70 with a 95% confidence level (P > 1.960). Therefore, these variables are highly recommended and the indicators are considered convergently valid. In the soil texture 282 indicator for the latent variable of root conditions as well as the cation exchange capacity (CEC) 283 and base saturation (BS) indicators for nutrient retention, the loading factor was below the 284 285 tolerance value of 0.50 at the 95% confidence level (P < 1.960), hence, it was not used. This 286 implies that the indicators have not been established or explained properly because the standard 287 value of the loading factor must be greater than or equal to 0.50 [37], [38], [66].

The average variance extracted (AVE) value of almost all variables was greater than 0.50, therefore, it was considered convergently valid [61][73]. The AVE value of the available nutrient variable was not valid due to the smaller value of the loading factor for the CEC and BS indicators of 0.50, leading to the removal of both indicators. A similar result was discovered in the root condition variable, although the AVE value was greater than 0.50, while the soil texture indicator was not used because the loading factor value is only 0.013

texture indicator was not used because the loading factor value is only 0.013.

Table 3: Outer loading (loading factor) and the average variance extracted from study variables.

Indicators (land characteristics)		Latent Variables (land quality)	Loading Factors	t-Stat	Status	AVE
X1.1 (Temperature)	\rightarrow	X1 (Temperature)	1.000**	11.192	Valid	1.000
X2.1 (Rainfall)	\rightarrow		0.838	0.085	Valid	
X2.2 (Wet month)	\rightarrow	V2 (Watan availability)	0.989	0.999	Valid	0.906
X2.3 (Dry month)	\rightarrow	X2 (Water availability)	0.850	0.428	Valid	0.900
X2.4 (LGP)	\rightarrow		0.993*	1.431	Valid	
X3.1 (Drainage)	\rightarrow	X3 (Oxygen availability)	1.000	0.000	Valid	1.000
X4.1 (Texture)	\rightarrow		0.013	0.066	Invalid	
X4.2 (Coarse material)	\rightarrow	X4 (Rooting condition)	0.921	1.086	Valid	0.573
X4.3 (Effective depth)	\rightarrow		-0.899	1.047	Valid	
X5.1 (pH H ₂ O)	\rightarrow		0.647	0.857	Valid	0.260
X5.2 (pH KCl)	\rightarrow	X5 (Nutrient retention)	0.570**	1.973	Valid	0.360
X5.3 (Organic C)	\rightarrow		0.831**	3.135	Valid	(invalid)

X5.4 (CEC)	\rightarrow		0.436*	1.381	Invalid	
X5.5 (Base saturation)	\rightarrow		0.365	0.845	Invalid	
X6.1 (Total N)	\rightarrow		0.760**	3.226	Valid	
X6.2 (P availability)	\rightarrow	X6 (Nutrient	0.587*	1.385	Valid	0.595
X6.3 (K exchangeable)	\rightarrow	availability)	0.897**	6.907	Valid	0.585
X7.1 (ESP)	\rightarrow	X7 (Sodicity)	1.000	0.000	Valid	1.000
X8.1 (Slopes)	\rightarrow	V9 (English hand)	0.954**	21.438	Valid	0.022
X8.2 (Soil erosion)	\rightarrow	X8 (Erosion hazard)	0.941**	18.308	Valid	0.932
X9.1 (Inundation height)	<i>></i>	V0 (Election charged)	0.984**	4.213	Valid	0.084
X9.2 (Inundation period)	\rightarrow	X9 (Flooding hazard)	0.985**	3.918	Valid	0.984
X10.1 (Rock	\rightarrow	X10 (Land	0.998**	189.133	Valid	
outcrops)		·	0.770	107.133	v allu	0.995
X10.2 (Surface rock)	\rightarrow	preparation)	0.998**	320.273	Valid	

AVE = average variance extracted, LGP = long growth periods, CEC = cation exchange capacity, and ESP = $\frac{296}{1000}$

exchangeable sodium percentage.

The measurement of the Fornell-Larcker criterion and cross-loading was used as the basis for assessing the discriminant validity of the model. The calculation results on the Fornell-Larcker criterion in Table 4 show that the average of the tested variables has a higher square root of AVE than the correlation value, hence, the latent variable was considered discriminantly valid. The square root value of the AVE must be greater than its correlation value with other constructs to meet the discriminant validity requirements [69][74]. The average loading factor value for the latent variable indicator was above that of others as shown in Table 5.

304 *3.1.2 Reliability test result*

The variables are considered reliable because composite reliability and Cronbach's alpha coefficient on average were more than 0.7 [61], [75] as shown in Table 6. However, certain indicators still had values less than 0.6, namely soil texture but the indicators used are reliable and adequate in forming the latent variables.

The highest composite reliability and cronbach's alpha coefficients were obtained for the variables of temperature, oxygen availability, and toxicity of 1 for the variables to be very reliable. The lowest coefficient was obtained on the root condition variable, therefore, the variable was not reliable. According to Bagozzi and Yi [76] and Hair et al. [75], variables are considered good and accepted when the value is > 0.70.

The remaining variables are water availability, nutrient retention, available nutrients, erosion hazard, and land preparation variables. The coefficient of composite reliability and cronbach's alpha > 0.6, there, the variable is considered reliable. The minimum value of composite reliability and cronbach's alpha coefficients was 0.60 [61], [75], [76].

2	1	0
Э	T	0

Table 4: Fornell-Larker criterion test

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Y
X1	1.000										
X2	0.940	0.952									
X3	0.059	0.149	1.000								
X4	0.082	0.030	-0.162	0.757							
X5	-0.360	-0.239	-0.103	-0.368	0.600						
X6	-0.069	0.021	0.012	-0.518	0.694	0.765					
X7	0.382	0.429	0.084	0.228	-0.030	-0.217	1.000				
X8	0.019	-0.082	-0.501	0.285	-0.317	-0.370	-0.009	0.966			
X9	-0.104	-0.033	0.237	-0.204	0.073	0.090	0.202	-0.250	0.992		
X10	0.198	0.093	-0.223	0.873	-0.303	-0.538	0.362	0.304	-0.126	0.998	
Y	0.018	0.152	0.169	-0.578	0.387	0.456	-0.016	-0.517	0.164	-0.568	1.000

 $\begin{array}{l} 319\\ 320 \end{array} \quad \hline X1 = \text{temperature}, X2 = \text{water availability}, X3 = \text{oxygen availability}, X4 = \text{rooting condition}, X5 = \text{nutrient retention}, X6 = \text{nutrient availability}, X7 = \text{sodicity}, X8 = \text{erosion} \\ \text{hazard}, X9 = \text{flooding hazard}, X10 = \text{land preparation}, Y = \text{maize hybrid yield}. \end{array}$

Table 5.	Cross I and	ng of laton	t wariablas	to indicators
Table 5.	CIOSS-LOadi	ng or raten	it variables	

Indiastans					Lat	ent Variab	les				
Indicators	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Y
X1.1	1	0.8300	0.0312	0.0240	-0.2959	-0.0592	0.3270	0.0195	-0.0837	0.1680	-0.0204
X2.1	0.9783	0.8379	-0.0035	-0.0063	-0.2488	-0.0320	0.3555	-0.0017	-0.0539	0.1552	0.0155
X2.2	0.8534	0.9887	0.1938	-0.0557	-0.1257	0.0988	0.4025	-0.1435	-0.0279	-0.0178	0.1748
X2.3	0.5223	0.8497	0.1523	0.2464	-0.2505	-0.1161	0.4641	-0.1494	0.0144	0.2154	0.0592
X2.4	0.8293	0.9928	0.1721	-0.0334	-0.1524	0.0833	0.4440	-0.1713	-0.0383	-0.0031	0.1331
X3.1	0.0312	0.1785	1	-0.1541	-0.1091	-0.0375	0.0843	-0.4964	0.2530	-0.2229	0.2156
X4.1	-0.0058	-0.0006	-0.1696	0.0126	0.2127	0.1013	0.2173	0.1761	0.0055	-0.0225	0.0050
X4.2	-0.0728	-0.1082	-0.0829	0.9212	-0.2754	-0.5494	0.1845	0.2891	-0.2674	0.7910	-0.5276
X4.3	-0.1289	-0.1240	0.2071	-0.8990	0.2046	0.3209	-0.2633	-0.1587	0.0730	-0.7693	0.4666
X5.1	-0.2975	-0.4140	-0.3824	-0.3027	0.6470	0.3024	-0.1283	0.1730	-0.0342	-0.1190	0.0718
X5.2	-0.2033	-0.2939	-0.4480	-0.2791	0.5701	0.3176	-0.0273	0.1935	0.0801	-0.1829	0.1445
X5.3	-0.2440	-0.0158	0.1276	-0.1134	0.8308	0.5651	0.0728	-0.5076	0.0545	-0.1147	0.3501
X5.4	0.0537	0.1002	0.0033	0.0110	0.4360	0.4081	0.3732	-0.0504	0.1426	-0.0137	0.1395
X5.5	-0.2717	-0.2512	-0.1053	-0.4382	0.3650	0.4343	-0.6008	-0.0619	-0.1498	-0.4876	0.0825
X6.1	-0.0256	0.1778	0.0335	-0.1950	0.7028	0.7604	0.0453	-0.3878	-0.0809	-0.2162	0.2623
X6.2	-0.1201	-0.2238	-0.4256	-0.2590	0.4149	0.5865	-0.2829	-0.0389	-0.0267	-0.2860	0.1025
X6.3	-0.0437	0.0283	0.0310	-0.5607	0.5145	0.8974	-0.3341	-0.2613	0.2133	-0.6520	0.3892
X7.1	0.3270	0.4411	0.0843	0.2420	0.0290	-0.2417	1	-0.0286	0.2142	0.3621	0.0487
X8.1	-0.0226	-0.2234	-0.5132	0.2998	-0.2625	-0.3475	-0.0481	0.9537	-0.3383	0.3031	-0.5274
X8.2	0.0649	-0.0590	-0.4223	0.1646	-0.2942	-0.2950	-0.0035	0.9409	-0.0988	0.2516	-0.4682
X9.1	-0.0996	-0.0225	0.2254	-0.1949	0.1126	0.1483	0.1939	-0.2440	0.9835	-0.1342	0.2278
X9.2	-0.0658	-0.0305	0.2717	-0.1860	0.0271	0.0449	0.2271	-0.2252	0.9849	-0.0901	0.2380
X10.1	0.1848	0.0403	-0.2340	0.8480	-0.2309	-0.5544	0.3760	0.3058	-0.1188	0.9977	-0.5424
X10.2	0.1503	0.0225	-0.2107	0.8629	-0.2274	-0.5592	0.3464	0.2812	-0.1076	0.9976	-0.5365
Y.1	-0.0204	0.1413	0.2156	-0.5479	0.3425	0.3790	0.0487	-0.5271	0.2367	-0.5408	1

X1 = temperature, X2 = water availability, X3 = oxygen availability, X4 = rooting condition, X5 = nutrient retention, X6 = nutrient availability, X7 = sodicity, X8 = erosion hazard, X9 = flooding hazard, X10 = land preparation, Y = hybrid maize yield, X1.1 = temperature, X2.1 = rainfall, X2.2 = the wet month, X2.3 = the dry month, X2.3 =

331 332 long growth period, X3.1 = drainage, X4.1 = texture, X4.2 = coarse material, X4.3 = effective depth, X5.1 = organic C, X5.2 = cation exchanges capacity, X5.3 = base

333 saturation, X6.1 = total N, X6.2 = P availability, X6.3 = K exchangeable, X7.1 = the exchange sodium percentage, <math>X8.1 = slopes, X8.2 = soil erosion, X9.1 = inundation

334 height, X9.2 = inundation period, X10.1 = rock outcrops, X10.2 = surface rock, Y.1 = hybrid maize yield.

Indicators (land characteristics)	Cronbach's Alpha	Composite Reliability
X1.1 (Temperature)	1.000	1.000
X2.1 (Rainfall)		
X2.2 (Wet month)	0.975	0.965
X2.3 (Dry month)	0.775	0.705
X2.4 (Long growth periods)		
X3.1 (Drainage)	1.000	1.000
X4.1 (Texture)		
X4.2 (Coarse material)	0.002^{nor}	-1.055 ^{nor}
X4.3 (Effective depth)		
X5.1 (pH H ₂ O)		
X5.2 (pH KCl)		
X5.3 (Organic C)	0.718	0.628
X5.4 (Cation exchange capacity)		
X5.5 (Base saturation)		
X6.1 (Total N)		
X6.2 (P availability)	0.805	0.681
X6.3 (K exchangeable)		
X7.1 (Exchangeable sodium percentage)	1.000	1.000
X8.1 (Slopes)	0.965	0.928
X8.2 (Soil erosion)	0.705	0.720
X9.1 (Inundation height)	0.992	0.984
X9.2 (Inundation period)	0.772	0.704
X10.1 (Rock outcrops)	0.998	0.995
X10.2 (Surface rock)	0.220	0.775

 $\overline{nor} = not reliable.$

337 *3.1.3 Structural model test (inner models)*

Land characteristics that have a significant correlation with hybrid maize yields show a high level of contribution to land quality in influencing hybrid maize yields as indicated in Figure 3. The figure shows a structural model of the relationship between indicator variables, namely 24 land characteristics, rectangular yellow, and latent variables, including 10 land qualities 342 maize yield, and oval blue. It also shows a model for the relationship between latent variables 343 such as land qualities and maize yield as well as loading figures. The factor for each indicator 344 and path coefficient for land qualities has a direct effect on the value of maize yields.

For example, X8 (erosion hazard) significantly determines the hybrid maize yield with a path coefficient of -0.392. The negative sign indicates that the erosion hazard is negatively related to maize yield, where the higher the erosion hazard, the lower the maize yield. Furthermore, nutrient retention (X5) contributes to the diversity of hybrid maize yields with a path coefficient of 0.252. A positive sign indicates that nutrient retention is positively related to maize yield, where the higher the value of nutrient retention were followed by the maize yield.



³⁵¹

Figure 3: Path Coefficient of land quality on hybrid maize yield.

353 The results of this path analysis indicated that the land quality that can be a predictor of maize 354 yield diversity were oxygen availability (X3), nutrient retention (X5), nutrient availability 355 (X6), erosion hazard (X8), and land preparation (X 10). Figure 2 indicates that only 8 of the 24 356 indicators explain latent variance at the 5% real test level. The 8 indicators were coarse material and effective soil depth as an indicator of rooting condition, organic carbon content as nutrient 357 358 retention, exchangeable K as nutrient availability, soil erosion and slope as erosion hazard, as well as rock outcrop and surface rock as an indicator of land preparation. It was also indicated 359 360 that the drainage loading factor was unable to explain the diversity of oxygen availability. Therefore, oxygen availability cannot be used as a land quality because there are no indicators 361 that can represent it. Only the land qualities of nutrient retention (X5), nutrient availability 362 363 (x6), erosion hazard (x8), and land preparation (X10) were used next.

The indicators of land characteristics for effective depth, organic C, total N, and exchangeable K have a fairly strong positive relationship and a very significant effect on hybrid maize yields. In this relationship, an increase in these parameters by 1%, will be followed by a rise in hybrid maize yields of 39% to 57.7%. According to Wirosoedarmo et al. [4], effective depth affects root growth and development, making plants grow and develop properly. Moreover, the levels of organic C, total N, and CEC are influenced by soil organic matter [77], while potassium plays a role in the growth and development of maize [78].

- 371 Indicators of rough soil characteristics, slopes, soil erosion, as well as surface and rock outcrops
- have a strong negative relationship with a very significant effect on hybrid maize yields. In this
- 373 relationship, a 1% decrease in coarse material, slope, soil erosion, as well as surface and rock
- outcrop is followed by an increase in hybrid maize yields by 39% to 57.7%.

375 3.2. Optimum hybrid maize yield by the land quality and land characteristics

376 Table 7 shows the mathematical equations for each land characteristic and also the optimum 377 hybrid maize yield for the land equation. Figure 4 shows the diagram of the relationship between land characteristics as an independent variable (X) and maize yield as an independent 378 variable Y. Model fitting indicates that the quadratic equation is sufficient to describe the 379 380 condition of data distribution.

Land Quality/Land Characteristics	Optimum Yield Equation		
Rooting condition (rc)			
Coarse material	8.17	$Y = 0.0025900x^2 - 0.2568578x + 11.9093576$	0.9
Effective depth	8.46	$\begin{array}{l} Y = -0.0008354x^2 + 0.29100569x - \\ 1.3957496 \end{array}$	0.9
Nutrient retention (nr)			
Organic carbon	8.46	$\begin{array}{l} Y = -25.492979x^2 + 47.9575089X - \\ 8.9895067 \end{array}$	0.9
Nutrient availability (na)			
Total N	8.54	$Y = -305.5574654X^2 + 155.8690907X - 2.7439640$	1.0
K Exchangeable	5.58	$Y = -10.6697409X^2 + 18.5239943X + 2.3179289$	0.9
Erosion hazard (eh)			
Slopes	8.54	$Y = 0.0183X^2 - 0.9559X + 14.806$	0.9
Soil erosion	8.17	$y = 0.0000184X^2 - 0.0198647X + 9.0537569$	0.8
Land preparation (lp)			
Rock outcrops	7.41	$Y = 0.0057496X^2 - 0.3845867X + 8.6269785$	0.9
Surface rock	7.41	$Y = 0.0057496X^2 - 0.3945867X + 8.6269785$	0.9

382

381

The optimum of hybrid maize yield ranged from 5.58 to 8.54 ton/ha, where the highest yield 383 was obtained from total N and slopes of 8.54 ton/ha with an R^2 value of 100% and 92%. 384 385 Sutardjo et al (2012) showed that hybrid maize yields ranged from 7.43 to 9.2 ton/ha. This indicated that the optimum yield achieved is still within the range of hybrid maize yields that 386 387 have been previously reported. Nitrogen is directly involved in the formation of amino acids, proteins, nucleic acids, enzymes, nucleoproteins, and alkaloids, which are needed in the plant 388 growth process [79], [80]. An extremely high amount of N causes excessive vegetative growth, 389 390 thereby making plants fall easily and increasing susceptibility to disease [81]. Meanwhile, the 391 lack of N nutrients can limit cell division, enlargement [82], and the formation of chlorophyll, 392 leading to stunted growth as well as yellowing of leaves [81].

393 The lowest optimum yield was obtained from exchangeable K, which was only 5.58 ton/ha 394 with an \mathbb{R}^2 value of 95%. This was presumably because the K content in the soil is very low, 395 thereby affecting the hybrid maize yield. Potassium (K) is required by plants for physiological

functions, including carbohydrate metabolism, enzyme activity, osmotic regulation, efficient 396
water use, N uptake, protein synthesis, and assimilate translocation [83]–[86]. It also plays a
role in improving the quality of crop yields (McKenzie, 2013, Subandi, 2013).

399 The optimum hybrid maize yield of the remaining is relatively diverse. This includes effective depth and organic carbon, which were both 8.46 ton/ha with an R² value of 97%. Furthermore, 400 coarse material and soil erosion were 8.17 ton/ha with an R² value of 96% and 89%, while rock 401 402 outcrops and surface rock were 7.41 ton/ha with an R2 value of 92%. The absence of coarse material > 2 mm in diameter indicated that plant roots can grow freely on the surface or deeper 403 404 parts of the soil [89], because the deeper the roots of the maize, the greater the maize yield 405 [90], [91]. The addition of organic matter will increase maize yield [92]-[94] and organic C content [95] because soil organic matter is a strong positive predictor of yield [96]. Kane et al. 406 407 [96] also stated that the addition of more organic matter will improve water retention, thereby 408 reducing maize yield losses due to drought. The slope has a significant effect on soil degradation [97]. According to a previous study, erosion and maize yield are negatively 409 correlated, hence, increased erosion will reduce maize productivity [98]. Soil erosion on flat 410 411 land is slower surface runoff [99]. It was also reported that surface rocks and outcrops are the limiting factors in the suitability of maize plantations [100]. Therefore, a high percentage of 412 413 rock outcrops will complicate land cultivation and plant root growth.

414 **3.3. Land suitability criteria for hybrid maize crops**

415 Table 8 shows the yield limit for each class from the calculation of the optimum yield, where the class range for each land characteristic is derived. Based on the optimum yield of the highest 416 417 hybrid maize, there were 2 indicators, namely the total N content and the slope. The total N indicator with a very suitable class (S1) was achieved when the value in the soil was greater 418 419 than 0.11%, while in the moderately suitable class (S2), it was achieved when the total N in 420 the soil ranges from 0.08-0.10%. In the marginally appropriate class (S3), the total N indicator was achieved when the total N in the soil ranges from 0.06-0.07%, while the not suitable class 421 422 (N) was achieved when the content was less than 0.06%. On the slope indicator with class S1, it was obtained when the slope class ranges from 0-7.70%%, while class S2 was achieved when 423 the slope class ranges from 7.71-11.84%. Furthermore, in classes S3 and N, it was obtained 424 425 when the slope class ranged from 11.85-18.25% and greater than 18.25%, respectively.

426 Based on the optimum yield of the lowest hybrid maize, only the exchangeable K was the indicator. In classes S1 and S2, it was achieved when the exchangeable K content in the soil 427 428 was greater than 0.25 cmol(+)/kg and ranges from 0.14-0.24 cmol(+)/kg, respectively. 429 Furthermore, class S3 was achieved when the exchangeable K content in the soil ranges from 430 0.05-0.13 cmol(+)/kg, while in class N, it was obtained when the exchangeable K content in 431 the soil was less than 0.05 cmol(+)/kg. The remaining variables and indicators were relatively 432 varied according to the optimum yield of hybrid maize and the range of land suitability classes obtained as presented in Table 8. 433



434



Figure 4: Scatter diagram relationship among maize yield and land characteristics

	Yield	l Limits (te	on/ha)	Value of Land Suitability Criterion Obtained				
Land Quality/Land Characteristics	S1 - S2 (80% x Y _{optim})	S2 – S3 (60% x Y _{optim})	S3 – N (40% x Y _{optim})	S1	82	S 3	N	
Rooting condition (rc)								
Coarse material (%)	8.17	6.05	4.04	0 – 13.51	13.51 – 27.48	27.48 – 52.41	> 52.41	
Effective depth (cm)	8.46	6.37	4.29	≥69.66	49.36 – 69.65	33.29 – 49.35	< 33.29	
Nutrient retention (nr) Organic carbon (%)	8.46	6.37	4.29	≥ 0.61	0.52 - 0.60	0.34 - 0.51	< 0.34	
Nutrient availability (na) Total N (%)	8.54	6.43	4.33	≥ 0.11	0.08 - 0.10	0.06 - 0.07	< 0.06	
K Exchangeable (cmol(+)/kg)	5.58	4.42	2.98	≥ 0.25	0.14 - 0.24	0.05 - 0.13	< 0.05	
Erosion hazard (eh)								
Slopes (%)	8.54	6.43	4.33	0- 7.70	7.71 – 11.84	11.85 – 18.25	> 18.25	
Soil erosion (ton/ha/year)	8.17	6.05	4.04	≤ 55.32	55.32 – 195.29	195.30 – 605.57	> 605.57	
Land preparation (lp)								
Rock outcrops (%)	7.41	5.69	3.97	0 – 4.46	4.47 – 13.10	13.11 – 31.89	> 31.89	
Surface rock (%)	7.41	5.69	3.97	0 - 4.46	4.47 – 13.10	13.11 – 31.89	> 31.89	

 Table 8: Yield limits of hybrid maize and values obtained in each land suitability class interval by land quality and characteristics.

438 S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, and N = not suitable.

Based on the relationship between the quality and characteristics of the selected land with optimum results, the criteria for hybrid maize land suitability were obtained as shown in Table 8. These criteria described the actual state of achieving optimum, moderate, and minimum yields of hybrid maize in the field with values of 80%, 60%, and 40%, respectively. According to Sukarman et al. [101], the parameters used in the land suitability assessment must describe the actual conditions. This is due to the significant positive correlation between maize yield and land suitability class [102].

446 The land suitability criteria for the new hybrid maize are fewer and have referred to the optimum yield. Meanwhile, the land quality and characteristics in this new criterion are less 447 because it only consists of root conditions with characteristics of coarse material and effective 448 depth, nutrient retention with organic C, and nutrient availability with total N and K 449 450 exchangeable. It also consists of erosion hazards with characteristics of slopes and soil erosion, 451 as well as land preparation with surface rocks and rock outcrops only. The land qualities 452 selected and maize yields consistent with the land potential are the basis for developing suitability criteria. This will reduce the land characteristics and make the evaluation process 453 454 faster, cheaper, and easier with accurate results [26]. Some characteristics and land quality 455 criteria were not made because they did not significantly affect the yield of hybrid maize. The number and distribution of the data were still limited and the diversity of values was small or 456 457 not measurable in the field [72].

458 Compared to Wahyunto et al. [47], the new land suitability criteria for hybrid maize plants in 459 Table 9 is more realistic in value with the conditions in the field and is based on the 460 achievement of optimum yields. The current land suitability criteria are still general and not specific to maize yields [26], although the agronomic and yield potential of each maize variety differ, based on the diversity of characteristics and land quality in the field. There are still limitations on the use of these results for the development of hybrid maize in the Boalemo Regency because the setting is only based on land characteristics and optimum yields in this regency. Therefore, further investigation to expand the scope of the research area nationally with more diverse and contrasting land characteristic values is recommended to determine the effect on hybrid maize production.

1		U	5					
Land Quality/Land Characteristics	Ne	w Land Suita Hybri	bility Criterio d Maize	Land Suitability Criterion of General Maize [47]				
Characteristics	S1	S2	S3	Ν	S1	S2	S3	Ν
Rooting condition (rc)								
Coarse material (%)	0 -	13.51 -	27.48 -	>	< 15	15 –	35 –	>55
Coarse material (70)	13.51	27.48	52.41	52.41		35	55	
Effective depth (cm)	\geq	49.36 -	33.29 -	<	> 60	60 –	40 –	< 25
Effective depth (effi)	69.66	69.65	49.35	33.29		40	25	
Nutrient retention (nr)								
Organic carbon (%)	\geq	0.52 0.60	0.34 - 0.51	< 0.34	>	0.8 -	< 0.8	-
6	0.61	0.32 - 0.00	0.34 - 0.31	< 0.34	1.20	1.2		
Nutrient availability (na)								
Total N (%)	≥ 0.11	0.08 - 0.10	0.06 - 0.07	< 0.06	Mo	Lo	VLo	-
K Exchangeable	\geq	0.14 0.24	0.05 0.12	< 0.05	Mo-	Lo	VLo	-
(cmol(+)/kg)	0.25	0.14 - 0.24	0.05 - 0.13	< 0.05	Hi			
Erosion hazard (eh)								
Slopes (%)	0 -	7.71 -	11.85 -	>	< 8	8 - 15	15 –	> 25
Slopes (78)	7.70	11.84	18.25	18.25			25	
Soil erosion	\leq	55.32 -	195.30 -	>	-	VLi	Li-	He-
(ton/ha/year)	55.32	195.29	605.57	605.57			Mo	VHe
Land preparation (lp)								
Rock outcrops (%)	0 -	4.47 –	13.11 -	>	< 5	5 - 15	15 –	> 40
Rock outcrops (70)	4.46	13.10	31.89	31.89			40	
Surface rock (%)	0 -	4.47 –	13.11 -	>	< 5	5 - 15	15 –	> 40
Surface fock (70)	4.46	13.10	31.89	31.89			40	

468 Table 9: Comparison of new and general land suitability criteria with land quality and characteristics.

469 S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable, Hi = high, Mo =
470 moderate, Lo = low, VLo = very low, He = heavy, Li = light, VLi = very light, VHe = very heavy.

471 Conclusions

472 Land suitability criteria for the new hybrid maize are determined by land qualities, namely root conditions, nutrient retention, available nutrients, erosion hazard, as well as land preparation, 473 and land characteristics, including coarse material, effective depth, organic C, total N, 474 475 exchangeable K, slopes, soil erosion, rock outcrops, and surface rocks. The highest optimum yield of 8.54 ton/ha was achieved by the total N and slopes for a very suitable class (S1), while 476 the lowest value of 5.58 ton/ha was attained by exchangeable K for class S1. These results 477 showed that the combination of the PLS-SEM and boundary line analysis can be an alternative 478 approach to establishing new land suitability criteria for crops based on optimum yields and 479 480 selected land quality.

481 Data Availability

482 All data can be obtained from the corresponding author upon request.

483 **Conflicts of Interest**

484 The authors declared that there is no conflict of interest regarding the publication of this paper.

485 **Funding Statement**

This study was funded by the Directorate of Research, Technology and Community Service,
Directorate General of Higher Education, Research and Technology, Ministry of Education,
Culture, Research and Technology of the Republic of Indonesia, grant number
B/105/UN47.D1/PT.01.03/2022.

490 Acknowledgments

491 The authors are grateful to the Ministry of Education, Culture, Research and Technology of

- 492 the Republic of Indonesia, and the Institute Research and Community Service of Universitas
- 493 Negeri Gorontalo for their financial and administrative support.

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Article Type Research Article	
Journal Applied and Environmental Soil Science	
Academic Editor Turjaman Maman	Submitted on 2022-12-29 (5 days ago)
> Abstract	
> Author Declaration	
> Files 2	
- Editorial Comments	
Recommendation	Maman Turjaman AE 03.01.2023
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Legend

Soil Sampling

Tile Box

	Soli Sali	ping		The Box		
SPT	Slopes (%)	Relief	Land Use	Soil Types	Elevation (m asl)	Area (Ha)
1	0-3	Flat	Plantation	Typic Endoaquepts	100 - 250	156.78
2	0 - 3	Flat	Plantation	Vertic Haplustepts	100 - 250	26.92
3	3 - 8	Waw	Plantation	Typic Haplustalfs	0 - 100	4,756.57
4	3 - 8	Waw	Plantation	Aquic Haplustepts	100 - 250	48.15
5	3 - 8	Wawy	Upland	Typic Haplustepts	100 - 250	91.77
6	3 - 8	Waw	Plantation	Typic Haplustults	0 - 100	684.95
7	3 - 8	Waw	Upland	Typic Haplustepts	100 - 250	249.07
8	3 - 8	Wawy	Plantation	Typic Haplustults	100 - 250	129.12
9	3-8	Waw	Plantation	Aquic Haplustepts	0 - 100	3.51
10	8 - 15	Wavy	Plantation	Typic Rhodustalfs	100 - 250	65.54
11 12	8 - 15 8 - 15	Wavy Wavy	Upland Upland	Typic Haplustalfs Lithic Haplustolls	100 - 250 0 - 100	471.97 302.43
12	8 - 15	Wavy Wavy	Plantation	Typic Haplustults	0 - 100	1,412.81
14	8 - 15	Wavy	Upland	Typic Haplustepts	0 - 100	1,412.01
15	8 - 15	Wavy	Plantation	Typic Haplustalfs	100 - 250	297.87
16	8 - 15	Wawy	Scrub	Typic Haplustepts	100 - 250	254.62
17	8 - 15	Waw	Upland	Typic Haplustalfs	250 - 500	853.23
18	8 - 15	Wawy	Plantation	Lithic Haplustepts	100 - 250	3,304.32
19	8 - 15	Wawy	Scrub	Typic Haplustults	100 - 250	793.13
20	8 - 15	Waw	Upland	Typic Haplustepts	100 - 250	3,293.28
21	8 - 15	Wawy	Plantation	Typic Haplustults	250 - 500	364.88
22	8 - 15	Wawy	Scrub	Typic Haplustalfs	100 - 250	165.87
23	8 - 15	Wawy	Upland	Typic Haplustults	100 - 250	2,038.84
24	8 - 15	Wawy	Plantation	Aquic Haplustepts	0 - 100	169.98
25	8 - 15	Waw	Upland	Typic Haplustalfs	100 - 250	349.74
26	15 - 30	Hilly	Scrub	Lithic Haplustolls	100 - 250	749.22
27	15 - 30	Hilly	Upland	Typic Haplustalfs	250 - 500	1,528.98
28	15 - 30	Hilly	Upland	Typic Haplustults	100 - 250	3,748.72
29	15 - 30	Hilly	Upland	Lithic Haplustolls	100 - 250	434.63
30	15 - 30	Hilly	Upland	Lithic Haplustalfs	250 - 500	3,908.31
31	15 - 30	Hilly	Scrub	Typic Haplustepts	250 - 500	154.35
32	15 - 30	Hilly	Scrub	Lithic Haplustalfs	250 - 500	1,474.02
33	> 45	Mountainous	Scrub	Lithic Haplustolls	100 - 250	229.51
34	> 45	Mountainous	Upland	Lithic Haplustalfs	100 - 250	853.11
35	> 45	Mountainous	Scrub	Typic Rhodustalfs	0 - 100	86.40
36	8 - 15	Hilly	Plantation	Typic Haplustalfs	0 - 100	254.52
37	> 45	Mountainous	Scrub	Fluventic Ustropepts	0 - 100	286.81
38	> 45	Mountainous	Scrub	Typic Haplustalfs	250 - 500	27.33
39	> 45	Mountainous	Upland	Fluventic Ustropepts	250 - 500	101.55
40	0 - 3	Flat	Plantation	Pluventic Haplustepts	0 - 100	3,052.35
41	0 - 3	Flat	Upland	Pluventic Haplustepts	0 - 100	3,834.11
42	0 - 3	Flat	Upland	Typic Argiustolls	0 - 100	1,072.70
43	0 - 3	Flat	Upland	Typic Tropaquepts	100 - 250	65.04
44	15 - 30	Hilly	Plantation	Fluventic Ustropepts	250 - 500	1,043.31
45	15 - 30	Hilly	Scrub	Typic Argiustolls	100 - 250	791.23
46	15 - 30	Hilly	Scrub	Typic Haplustalfs	0 - 100	53.32
47	15 - 30	Hilly	Upland	Fluventic Ustropepts	100 - 250	336.36
48	15 - 30	Hilly	Upland	Pluventic Haplustepts	250 - 500	705.51
49	15 - 30	Hilly	Upland	Typic Argiustolls	250 - 500	2,196.41
50 51	15 - 30 15 - 30	Hilly Hilly	Upland Upland	Typic Haplustalfs Typic Haplustalfs	0 - 100 250 - 500	104.35 871.02
52	15 - 30	Hilly	Upland		100 - 250	
52	15 - 30	Hilly	Upland	Typic Haplusteps Typic Tropaquepts	0 - 100	28.16 89.21
53	3 -8	Wavy	Plantation	Pluventic Haplustepts	0 - 100	
54 55	3-8	Wavy	Plantation	Typic Argiustolls	100 - 250	1,442.70 1,475.90
56	3-8	Wavy	Scrub	Typic Haplustalfs	250 - 500	413.33
57	3-8	Wavy	Upland	Pluventic Haplustepts	250 - 500	3,864.27
58	3-8	Wavy	Upland	Typic Argiustolls	0 - 100	151.63
59	3-8	Wavy	Upland	Typic Dystrudepts	0 - 100	63.14
60	3-8	Wavy	Upland	Typic Haplustalfs	250 - 500	2,054.29
61	30 - 45	Mountainous	Plantation	Typic Haplustalfs	100 - 250	52.44
62	30 - 45	Mountainous	Scrub	Typic Haplustalfs	100 - 250	63.05
63	30 - 45	Mountainous	Upland	Typic Haplustalfs	0 - 100	48.35
64	30 - 45	Mountainous	Upland	Typic Haplustalfs	100 - 250	171.54
65	8 - 15	Hilly	Upland	Typic Argiustolls	0 - 100	136.96
66	8 - 15	Hilly	Upland	Typic Haplustalfs	250 - 500	1,063.61
	8 - 15	Hilly	Upland	Typic Haplusteps	250 - 500	79.96
67	0 - 15		Opiana	i j pie i iapiaetope	200 000	60,518.81





Figure 2: Research framework



CEC = cation exchage capacity; BS = base saturation;

P = phospate; K = potassium; ESP = exchangeable sodium percentage

* = sig. 5%; ** = sig.1%; $R^2 = 53.70\%$

Figure 3: Path Coefficient of land quality on hybrid maize yield.



Figure 4: Scatter diagram relationship among maize yield and land characteristics

Lat	ent variables		Indicators	
Notation	Land quality	Notation	Land characteristics	- Data Sources
X1	Temperature (t)	X1.1	Temperature	[45]
X2	Water availability	X2.1	Rainfall	[45]
	(wa)	X2.2	Wet month	Rainfall $> 200 \text{ mm}$
		X2.3	Dry month	Rainfall < 100 mm
		X2.4	Long growth period	Water balance (Thornwhite
			(LGP)	method), soil moisture
				storage (Gravimetric
				method), water surplus and
				defisit days
X3	Oxygen availability	X3.1	Drainage	Soil survey and land
	(oa)			observation
X4	Rooting condition	X4.1	Texture	
	(rc)	X4.1.1	Sand fraction	Pipet method
		X4.1.2	Silt fraction	1
		X4.1.3	Clay	
		X4.2	Coarse material	Soil survey and land observation
X5	Nutrient retention	X4.3 X5.1	Effective depth	observation
AS	(nr)	X5.2	pH H ₂ O pH KCl	pH meter (1 : 2.5)
	(111)	X5.2 X5.3	Organic C	Walkley and Black method
		X5.5 X5.4	Cation exchange	1N NH ₄ OAc pH 7.0
		110.4	capacity (CEC)	Extracted
		X5.5	Base saturation	Calculation
X6	Nutrient	X6.1	Total N	Kjeldahl method
-	availability (na)	X6.2	P availability	Olsen method
	2 ()	X6.3	K exchangeable	1N NH₄OAc pH 7.0
			U	Extracted
X7	Sodicity (xn)	X7.1	Exchangeable sodium	Calculation
			percentage (ESP)	Calculation
X8	Erosion hazard (eh)	X8.1	Slopes	Soil survey and land
		X8.2	Soil erosion	observation
X9	Flooding hazard	X9.1	Inundation height	Soil survey and land
	(fh)	X9.2	Inundation period	observation
X10	Land preparation	X10.1	Rock outcrops	Soil survey and land
	(lp)	X10.2	Surface rock	observation
Y	Hybrid maize yield	Y.1	Hybrid maize yield	Tile box methods

Table 1: Latent variables and indicators used in this study

	Table 2. Biler statistics of faile quality and characteristics.									
Latent variables /	Unit	n	Min	Median	Mean	Max	SD			
Indicators										
X1 (Temperature)	20		26 70	27.00	20.01	00.10	0.62			
X1.1 (Temperature)	°C	67	26.79	27.80	28.01	28.19	0.63			
X2 (Water availability)										
X2.1 (Rainfall)	mm	67	1,246.00	1,533.42	1,478.00	1,849.00	232.69			
X2.2 (Wet month)	month	67	0.00	1.03	1.00	3.00	0.85			
X2.3 (Dry month)	month	67	2.00	3.39	4.00	5.00	1.06			
X2.4 (LGP)	day	67	211.00	246.00	214.00	304.00	44.54			
X3 (Oxygen availability)										
X3.1 (Drainage)	class	67	0.00	3.76	4.00	6.00	1.82			
X4 (Rooting conditions)										
X4.1 (texture)	class	67	1.00	2.21	2.00	5.00	0.99			
X4.1.1 (Sand fraction)	%	67	5.00	41.58	43.00	81.33	18.51			
X4.1.2 (Silt fraction)	%	67	7.33	27.31	24.50	51.50	11.54			
X4.1.3 (Clay)	%	67	11.33	31.90	30.00	56.33	12.72			
X4.2 (Coarse material)	%	67	5.00	17.27	10.00	70.00	16.58			
X4.3 (Effective depth)	cm	67	10.00	74.55	74.00	160.00	36.40			
X5 (Nutrient retention)										
X5.1 (pH H ₂ O)		67	5.00	5.92	5.90	7.15	0.52			
X5.2 (pH KCl)		67	4.35	5.24	5.17	6.60	0.56			
X5.3 (Organic C)	%	67	0.41	0.85	0.77	2.35	0.39			
X5.4 (CEC)	cmol(+)/kg	67	8.94	24.89	22.43	59.57	11.41			
X5.5 (Base saturation)	%	67	45.03	56.22	52.85	81.89	9.76			
X6 (Nutrient availability)										
X6.1 (Total N)	%	67	0.04	0.09	0.08	0.27	0.04			
X6.2 (P availability)	mg/kg	67	0.73	8.62	3.77	58.67	12.61			
X6.3 (K exchangeable)	cmol(+)/kg	67	0.07	0.39	0.24	1.92	0.42			
X7 (Sodicity)										
X7.1 (ESP)	%	67	0.76	7.06	6.20	24.17	5.62			
X8 (Erosion hazard)										
X8.1 (Slopes)	%	67	1.00	9.58	6.00	25.00	7.29			
X8.2 (Soil erosion)	ton/ha/year	67	3.66	334.51	110.27	1772.43	439.08			
X9 (Flooding hazard)	<u> </u>		•							
X9.1 (Inundation height)	cm	67	0.00	7.58	0.00	50.00	17.10			
X9.2 (Inundation period)	day	67	0.00	0.64	0.00	5.00	1.52			
X10 (Land preparation)		~ /	0.00	0.01	0.00	2.00	1.02			
X10 (Land preparation) X10.1 (Rock outcrops)	%	67	0.00	6.64	0.00	45.00	11.56			
X10.2 (Surface rock)	%	67	0.00	6.58	0.00	45.00	11.50			
Y (Hybrid maize yield)	ton/ha	67	2.85	4.95	4.68	8.07	1.15			
	1011/11a	07	2.05	4.73	4.00	0.07	1.13			

Table 2: Brief statistics of land quality and characteristics.

n = the number of the land unit, min = minimum, max is maximum, SD = standard deviations, LGP = long growth periods, CEC = cation exchange capacity, and ESP = exchangeable sodium percentage.

Indicators		Latent Variables	Loading	t-Stat	Status	AVE	
(land characteristic	<i>,</i>	(land quality)	Factors	• ~ •			
X1.1 (Temperature)	\rightarrow	X1 (Temperature)	1.000**	11.192	Valid	1.000	
X2.1 (Rainfall)	\rightarrow		0.838	0.085	Valid		
X2.2 (Wet month)	\rightarrow	X2 (Water availability)	0.989	0.999	Valid	0.006	
X2.3 (Dry month)	\rightarrow	A2 (water availability)	0.850	0.428	Valid	0.906	
X2.4 (LGP)	\rightarrow		0.993*	1.431	Valid		
X3.1 (Drainage)	\rightarrow	X3 (Oxygen availability)	1.000	0.000	Valid	1.000	
X4.1 (Texture)	\rightarrow		0.013	0.066	Invalid		
X4.2 (Coarse	\rightarrow		0.021	1.096	V-1:4		
material)		X4 (Rooting condition)	0.921	1.086	Valid	0.573	
X4.3 (Effective	\rightarrow		-0.899	1 047	Valid		
depth)			-0.899	1.047	vand		
X5.1 (pH H ₂ O)	\rightarrow		0.647	0.857	Valid		
X5.2 (pH KCl)	\rightarrow		0.570**	1.973	Valid		
X5.3 (Organic C)	\rightarrow	X5 (Nutrient retention)	0.831**	3.135	Valid	0.360	
X5.4 (CEC)	\rightarrow	AS (Nutrient retention)	0.436*	1.381	Invalid	(invalid)	
X5.5 (Base	\rightarrow		0.265	0.945	T		
saturation)			0.365	0.845	Invalid		
X6.1 (Total N)	\rightarrow		0.760**	3.226	Valid		
X6.2 (P availability)	\rightarrow	X6 (Nutrient	0.587*	1.385	Valid	0.585	
X6.3 (K	\rightarrow	availability)	0.897**	6.007	V-1:4	0.385	
exchangeable)			0.89/***	6.907	Valid		
X7.1 (ESP)	\rightarrow	X7 (Sodicity)	1.000	0.000	Valid	1.000	
X8.1 (Slopes)	\rightarrow	V9 (Energiese homenal)	0.954**	21.438	Valid	0.022	
X8.2 (Soil erosion)	\rightarrow	X8 (Erosion hazard)	0.941**	18.308	Valid	0.932	
X9.1 (Inundation	\rightarrow		0.984**	4 212	Valid		
height)		VO (Else din a herend)	0.984	4.213	vand	0.094	
X9.2 (Inundation	\rightarrow	X9 (Flooding hazard)	0 005**	2 0 1 9	Valid	0.984	
period)			0.985**	3.918	Valid		
X10.1 (Rock	\rightarrow		0.998**	189.133	Valid		
outcrops)		V10 (I and propagation)	0.998	109.133	vand	0.995	
X10.2 (Surface	\rightarrow	X10 (Land preparation)	0.998**	320.273	Valid	0.993	
rock)			0.998	320.273	v allu		

Table 3: Outer loading (loading factor) and the average variance extracted from study variables.

 \overline{AVE} = average variance extracted, LGP = long growth periods, CEC = cation exchange capacity, and ESP = exchangeable sodium percentage.

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Y
X1	1.000										
X2	0.940	0.952									
X3	0.059	0.149	1.000								
X4	0.082	0.030	-0.162	0.757							
X5	-0.360	-0.239	-0.103	-0.368	0.600						
X6	-0.069	0.021	0.012	-0.518	0.694	0.765					
X7	0.382	0.429	0.084	0.228	-0.030	-0.217	1.000				
X8	0.019	-0.082	-0.501	0.285	-0.317	-0.370	-0.009	0.966			
X9	-0.104	-0.033	0.237	-0.204	0.073	0.090	0.202	-0.250	0.992		
X10	0.198	0.093	-0.223	0.873	-0.303	-0.538	0.362	0.304	-0.126	0.998	
Y	0.018	0.152	0.169	-0.578	0.387	0.456	-0.016	-0.517	0.164	-0.568	1.000

Table 4: Fornell-Larker criterion test

X1 = temperature, X2 = water availability, X3 = oxygen availability, X4 = rooting condition, X5 = nutrient retention, X6 = nutrient availability, X7 = sodicity, X8 = erosion hazard, X9 = flooding hazard, X10 = land preparation, Y = maize hybrid yield.

Indiastans					Lat	ent Variab	les				
Indicators	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Y
X1.1	1	0.8300	0.0312	0.0240	-0.2959	-0.0592	0.3270	0.0195	-0.0837	0.1680	-0.0204
X2.1	0.9783	0.8379	-0.0035	-0.0063	-0.2488	-0.0320	0.3555	-0.0017	-0.0539	0.1552	0.0155
X2.2	0.8534	0.9887	0.1938	-0.0557	-0.1257	0.0988	0.4025	-0.1435	-0.0279	-0.0178	0.1748
X2.3	0.5223	0.8497	0.1523	0.2464	-0.2505	-0.1161	0.4641	-0.1494	0.0144	0.2154	0.0592
X2.4	0.8293	0.9928	0.1721	-0.0334	-0.1524	0.0833	0.4440	-0.1713	-0.0383	-0.0031	0.1331
X3.1	0.0312	0.1785	1	-0.1541	-0.1091	-0.0375	0.0843	-0.4964	0.2530	-0.2229	0.2156
X4.1	-0.0058	-0.0006	-0.1696	0.0126	0.2127	0.1013	0.2173	0.1761	0.0055	-0.0225	0.0050
X4.2	-0.0728	-0.1082	-0.0829	0.9212	-0.2754	-0.5494	0.1845	0.2891	-0.2674	0.7910	-0.5276
X4.3	-0.1289	-0.1240	0.2071	-0.8990	0.2046	0.3209	-0.2633	-0.1587	0.0730	-0.7693	0.4666
X5.1	-0.2975	-0.4140	-0.3824	-0.3027	0.6470	0.3024	-0.1283	0.1730	-0.0342	-0.1190	0.0718
X5.2	-0.2033	-0.2939	-0.4480	-0.2791	0.5701	0.3176	-0.0273	0.1935	0.0801	-0.1829	0.1445
X5.3	-0.2440	-0.0158	0.1276	-0.1134	0.8308	0.5651	0.0728	-0.5076	0.0545	-0.1147	0.3501
X5.4	0.0537	0.1002	0.0033	0.0110	0.4360	0.4081	0.3732	-0.0504	0.1426	-0.0137	0.1395
X5.5	-0.2717	-0.2512	-0.1053	-0.4382	0.3650	0.4343	-0.6008	-0.0619	-0.1498	-0.4876	0.0825
X6.1	-0.0256	0.1778	0.0335	-0.1950	0.7028	0.7604	0.0453	-0.3878	-0.0809	-0.2162	0.2623
X6.2	-0.1201	-0.2238	-0.4256	-0.2590	0.4149	0.5865	-0.2829	-0.0389	-0.0267	-0.2860	0.1025
X6.3	-0.0437	0.0283	0.0310	-0.5607	0.5145	0.8974	-0.3341	-0.2613	0.2133	-0.6520	0.3892
X7.1	0.3270	0.4411	0.0843	0.2420	0.0290	-0.2417	1	-0.0286	0.2142	0.3621	0.0487
X8.1	-0.0226	-0.2234	-0.5132	0.2998	-0.2625	-0.3475	-0.0481	0.9537	-0.3383	0.3031	-0.5274
X8.2	0.0649	-0.0590	-0.4223	0.1646	-0.2942	-0.2950	-0.0035	0.9409	-0.0988	0.2516	-0.4682
X9.1	-0.0996	-0.0225	0.2254	-0.1949	0.1126	0.1483	0.1939	-0.2440	0.9835	-0.1342	0.2278
X9.2	-0.0658	-0.0305	0.2717	-0.1860	0.0271	0.0449	0.2271	-0.2252	0.9849	-0.0901	0.2380
X10.1	0.1848	0.0403	-0.2340	0.8480	-0.2309	-0.5544	0.3760	0.3058	-0.1188	0.9977	-0.5424
X10.2	0.1503	0.0225	-0.2107	0.8629	-0.2274	-0.5592	0.3464	0.2812	-0.1076	0.9976	-0.5365
Y.1	-0.0204	0.1413	0.2156	-0.5479	0.3425	0.3790	0.0487	-0.5271	0.2367	-0.5408	1

Table 5: Cross-Loading of latent variables to indicators

X1 = temperature, X2 = water availability, X3 = oxygen availability, X4 = rooting condition, X5 = nutrient retention, X6 = nutrient availability, X7 = sodicity, X8 = erosion hazard, X9 = flooding hazard, X10 = land preparation, Y = hybrid maize yield, X1.1 = temperature, X2.1 = rainfall, X2.2 = the wet month, X2.3 = the dry month, X2.3 = long growth period, X3.1 = drainage, X4.1 = texture, X4.2 = coarse material, X4.3 = effective depth, X5.1 = organic C, X5.2 = cation exchanges capacity, X5.3 = base saturation, X6.1 = total N, X6.2 = P availability, X6.3 = K exchangeable, X7.1 = the exchange sodium percentage, X8.1 = slopes, X8.2 = soil erosion, X9.1 = inundation height, X9.2 = inundation period, X10.1 = rock outcrops, X10.2 = surface rock, Y.1 = hybrid maize yield.

Indicators (land characteristics)	Cronbach's Alpha	Composite Reliability
X1.1 (Temperature)	1.000	1.000
X2.1 (Rainfall)		
X2.2 (Wet month)	0.975	0.965
X2.3 (Dry month)	0.975	0.905
X2.4 (Long growth periods)		
X3.1 (Drainage)	1.000	1.000
X4.1 (Texture)		
X4.2 (Coarse material)	0.002^{nor}	-1.055 ^{nor}
X4.3 (Effective depth)		
X5.1 (pH H ₂ O)		
X5.2 (pH KCl)		
X5.3 (Organic C)	0.718	0.628
X5.4 (Cation exchange capacity)		
X5.5 (Base saturation)		
X6.1 (Total N)		
X6.2 (P availability)	0.805	0.681
X6.3 (K exchangeable)		
X7.1 (Exchangeable sodium percentage)	1.000	1.000
X8.1 (Slopes)	0.965	0.928
X8.2 (Soil erosion)	0.705	0.720
X9.1 (Inundation height)	0.992	0.984
X9.2 (Inundation period)	0.772	0.704
X10.1 (Rock outcrops)	0.998	0.995
X10.2 (Surface rock)	0.770	0.775

Table 6: Composite Reliability and Cronbach's Alpha test.

nor = not reliable.

Land Quality/Land Characteristics	Optimum Yield (ton/ha)	Yield Equation	R ²
Rooting condition (rc)			
Coarse material	8.17	$Y = 0.0025900x^2 - 0.2568578x + 11.9093576$	0.96
Effective depth	8.46	$\begin{split} Y &= -0.0008354 x^2 + 0.29100569 x - \\ 1.3957496 \end{split}$	0.97
Nutrient retention (nr)			
Organic carbon	8.46	$Y = -25.492979x^2 + 47.9575089X - 8.9895067$	0.97
Nutrient availability (na)			
Total N	8.54	$Y = -305.5574654X^2 + 155.8690907X - 2.7439640$	1.00
K Exchangeable	5.58	$Y = -10.6697409X^2 + 18.5239943X + 2.3179289$	0.95
Erosion hazard (eh)			
Slopes	8.54	$Y = 0.0183X^2 - 0.9559X + 14.806$	0.92
Soil erosion	8.17	$y = 0.0000184X^2 - 0.0198647X + 9.0537569$	0.89
Land preparation (lp)			
Rock outcrops	7.41	$\begin{split} Y &= 0.0057496X^2 - 0.3845867X + \\ 8.6269785 \end{split}$	0.92
Surface rock	7.41	$\begin{split} Y &= 0.0057496X^2 - 0.3945867X + \\ 8.6269785 \end{split}$	0.92

Table 7: The optimum hybrid maize yield by the land quality and land characteristics

characteristics.									
	Yield Limits (ton/ha)			Value of Land Suitability Criterion Obtained					
Land Quality/Land Characteristics	S1 - S2 (80% x Y _{optim})	S2 – S3 (60% x Y _{optim})	S3 – N (40% x Y _{optim})	S1	S2	S3	Ν		
Rooting condition (rc)									
Coarse material (%)	8.17	6.05	4.04	0 – 13.51	13.51 – 27.48	27.48 – 52.41	> 52.41		
Effective depth (cm)	8.46	6.37	4.29	≥69.66	49.36 – 69.65	33.29 – 49.35	< 33.29		
Nutrient retention (nr) Organic carbon (%)	8.46	6.37	4.29	≥ 0.61	0.52 - 0.60	0.34 - 0.51	< 0.34		
Nutrient availability (na) Total N (%)	8.54	6.43	4.33	≥ 0.11	0.08 - 0.10	0.06 - 0.07	< 0.06		
K Exchangeable (cmol(+)/kg)	5.58	4.42	2.98	\geq 0.25	0.14 - 0.24	0.05 - 0.13	< 0.05		
Erosion hazard (eh)									
Slopes (%)	8.54	6.43	4.33	0 - 7.70	7.71 – 11.84	11.85 – 18.25	> 18.25		
Soil erosion (ton/ha/year)	8.17	6.05	4.04	≤ 55.32	55.32 – 195.29	195.30 – 605.57	> 605.57		
Land preparation (lp)									
Rock outcrops (%)	7.41	5.69	3.97	0 - 4.46	4.47 - 13.10	13.11 – 31.89	> 31.89		
Surface rock (%)	7.41	5.69	3.97	0 - 4.46	4.47 - 13.10	13.11 – 31.89	> 31.89		

 Table 8: Yield limits of hybrid maize and values obtained in each land suitability class interval by land quality and characteristics.

S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, and N = not suitable.

Land Quality/Land Characteristics	New Land Suitability Criterion of Hybrid Maize				Land Suitability Criterion of General Maize [47]			
	S1	S2	S3	Ν	S1	S2	S3	Ν
Rooting condition (rc)								
Coarse material (%)	0 – 13.51	13.51 – 27.48	27.48 – 52.41	> 52.41	< 15	15 – 35	35 – 55	>55
Effective depth (cm)	≥ 69.66	49.36 – 69.65	33.29 – 49.35	< 33.29	> 60	60 - 40	40 – 25	< 25
Nutrient retention (nr)								
Organic carbon (%)	≥ 0.61	0.52 - 0.60	0.34 - 0.51	< 0.34	> 1.20	0.8 – 1.2	< 0.8	-
Nutrient availability (na)								
Total N (%)	≥ 0.11	0.08 - 0.10	0.06 - 0.07	< 0.06	Mo	Lo	VLo	-
K Exchangeable (cmol(+)/kg)	\geq 0.25	0.14 - 0.24	0.05 - 0.13	< 0.05	Mo- Hi	Lo	VLo	-
Erosion hazard (eh)								
Slopes (%)	$\begin{array}{c} 0-\\ 7.70 \end{array}$	7.71 – 11.84	11.85 – 18.25	> 18.25	< 8	8-15	15 – 25	> 25
Soil erosion	\leq	55.32 -	195.30 -	>	-	VLi	Li-	He-
(ton/ha/year)	55.32	195.29	605.57	605.57			Mo	VHe
Land preparation (lp)								
Rock outcrops (%)	0 – 4.46	4.47 – 13.10	13.11 – 31.89	> 31.89	< 5	5 – 15	15 – 40	>40
Surface rock (%)	0 – 4.46	4.47 – 13.10	13.11 – 31.89	> 31.89	< 5	5 – 15	15 - 40	> 40

Table 9: Comparison of new and general land suitability criteria with land quality and characteristics.

S1 = very suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable, Hi = high, Mo = moderate, Lo = low, VLo = very low, He = heavy, Li = light, VLi = very light, VHe = very heavy.



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Soil Science

ind Suitability Criteria for Maize Hybrid in Boalemo Regency Yield and Selected Land Quality

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Received 22 October 2022; Revised 29 December 2022; Accepted 3 January 2023

Academic Editor: Maman Turjaman

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Abstract

The significant effect of land quality on maize production has not been fully considered in the existing land suitability criteria. Therefore, this study aims to determine land suitability criteria for hybrid maize in Boalemo Regency based on the optimum yield and land quality. It was carried out in Boalemo Regency, Indonesia, where the land unit of 67 units was surveyed to obtain land characteristics data. A partial least square of structural equation model (PLS-SEM) with SmartPLS 8.0 was used to select a robust land quality controlling hybrid maize yield, while the boundary line method was used to determine optimum yield and differentiating of land suitability criteria. The result showed that land qualities that define the optimum yield of hybrid maize were root conditions, nutrient availability, nutrient retentions, land preparation, and erosion hazard. The soil characteristics were effective depth, coarse material, organic C, total N, K exchangeable, slopes, soil erosion, rock outcrops, and surface rocks. Furthermore, the highest optimum yield of 8.54 ton/ha was achieved by the total N and slopes for a very suitable class (S1), while the lowest of 5.58 ton/ha was obtained by exchangeable K for class S1. This showed that the combination of PLS-SEM and boundary line analysis was a better approach to developing new land suitability criteria for hybrid maize.

1. Introduction

Food security and farmer prosperity are global concerns; this makes every country increase crop production as well as farmers' income. An important issue for countries with developing economies is ensuring food security, where the agricultural sector plays a strategic role in increasing food availability [1]. Although the global food system has placed maize (Zea mays L.) as the leading cereal crop [2], its productivity is being disrupted by land degradation, water scarcity, and climate change [3].

In Indonesia, the wet tropical climate with rainfall and high temperatures tends to reduce the quality of land and agricultural products [4]. This country ranked 8th among the maize-producing nations with a contribution of 2.19% and 2.42% of the world's total harvested area [5]. However, the main problem is the relatively low level of yield in several regions because the achievement of maize production has not been followed by an increase in yield per unit area [6]. This is indicated by the average yield in 2020, which was up to 5.57 ton/ha [5]. According to a previous investigation, maize production in Indonesia can reach between 10 and 12 ton/ha [7, 8], thereby making the country the 21st leading importer in the world.

In Indonesia, Gorontalo Province is one of the centers of maize production, where the hybrid type is the most widely grown species [9]. The maize production in the province reached 1.8 million tons in 2021 [10], with several export advantages and competitiveness [11]. Furthermore, the planting of hybrid, composite, and local maize types has reached more than 98.90%, 0.68%, and 0.41% only, respectively [12], including Boalemo Regency.

Boalemo Regency ranks third as a maize-producing center in Gorontalo Province with a contribution of 18.90% [13]. The maize plant dominates the use of agricultural land in this district by 37.43% [14]; therefore, the commodity has competitive and comparative advantages with a PCR value of 0.80 and 0.91 DRC. This is because maize plant is supported by land area, climatic conditions, production facilities, as well as market guarantees, and the basic price of buying corn from the government [15]. In 2021, the average hybrid and local maize yields in the regency reached 5.20 tons/ha [16] and 2.34–3.30 tons/ha, respectively [17]. This indicated

cultivated on land that does not meet the required qualities [6]. Therefore, there is a need to determine land quality-based hybrid maize land suitability criteria for site-specific land use planning in Boalemo District.

Maize is usually grown on land with low yield potential [21] and soil fertility, thereby causing low productivity [22]. Moreover, land productivity is determined by quality and characteristics [23, 24], while land quality has a close relationship with maize yields [25]. The land quality affecting the optimum yield of maize needs to be determined [26] and increased by using hybrid varieties that have high yields. This makes it necessary to evaluate the suitability of the hybrid maize in a region to ensure optimal production. The land suitability criteria for hybrid maize are not yet available because the current criterion is the general suitability of maize plants without distinguishing between hybrids and inbreds. Therefore, there is a need to make land suitability criteria for hybrid maize plants.

A previous study has shown that land quality has a significant effect on suitability for certain uses [27]. Meanwhile, land suitability is also important due to the continuous increase in the demand for agricultural land [28]. The land suitability criteria for existing maize fields are still general [29], and there are no specific criteria for hybrid maize varieties. The class assessment outcomes obtained using the existing criteria are relatively many and are not in line with the actual field results [30]. The current criteria consist of 3 components, namely, land quality, characteristics, and ranges of land characteristic values to determine its suitability. Therefore, the problem in developing criteria is choosing land quality, characteristics, and determining the range of land characteristic values associated with suitability classes, namely, suitable, somewhat suitable, marginally suitable, and not suitable.

The selection of land quality and characteristics can be carried out through the partial least square of the structural equation model (PLS-SEM), while the range limits are being determined by the boundary line method. Land qualities and characteristics in the current criteria can be used temporarily since structural equation model analysis with partial least squares produces better indicators and models than other multivariate analyses [31–35]. This is because the variant-based PLS-SEM has a higher level of flexibility and the size of the sample used is relatively small ranging from 30 to 100 [36–39]. The use of PLS-SEM to determine land characteristics and qualities that control maize crop yields is still relatively rare, except for Syaf [40] on older cocoa plants, maize composite [41], and on local varieties [6]. The boundary line method can help determine nutrient adequacy concentrations and the optimum yield range of a plant that affects nutrients, as well as other land characteristics [42, 43]. Currently, the land suitability criteria for maize plants have not been determined using the boundary line method, except by Ridayanti et al. [44], although the investigation was not specific to hybrid maize.

After obtaining the quality and characteristics of land affecting maize yields with PLS-SEM, the boundary line method can be used to determine the optimum yield as well as land suitability criteria simultaneously. This is carried out by drawing the intersection of the boundary line at the yield and projecting with the land characteristics [29]. Therefore, this study aims to determine land suitability criteria for hybrid maize in Boalemo Regency based on the optimum yield and land quality.

2. Materials and Methods

2.1. Study Area

The study area extends from $0^{\circ}28'5.6''-0''57'30.02''$ N to $122^{\circ}8'34.25''-122^{\circ}43'10.41''E$ (Figure 1) on a scale of 1 : 40,000, which is located in the agricultural land of Boalemo Regency, Gorontalo Province, Indonesia. The maximum air temperature was 28.19°C and the minimum was 26.79° C with an average of 28.01° C. Meanwhile, the maximum rainfall was 1,849 mm and the minimum was 1,246 mm with an average of 1,478 mm [45]. The wet and dry seasons last for 3 months and 5 months, respectively. The soil mapping carried out by Ritung et al. [46] at a scale of 1:50,000 become the initial reference for determining 35 soil units, where each unit has information on land characteristics, namely, effective depth, drainage, texture, pH, cation exchange capacity, base saturation, landform, parent material, relief, and land unit area. Meanwhile, the new soil unit is 1:40,000 in scale, and there has been a change in the agricultural land use existing. This indicated that the slope class of 8-15% or hilly is more dominant in the study area with a percentage of 29.77% and slopes >40% or mountainous which is only 2.67%. Furthermore, the dry land is dominant with a value of 59.86% and a little shrub which was only 9.21%, while the dominant Typic Haplustalfs of soil subgroup classification was 20.04% only (Figure 1).



2.2. Dataset Collection for Land Quality and Land Characteristics

The quality and characteristics of the land in this study refer to Wahyunto et al. [47], consisting of 10 land qualities and 24 characteristics. The set of temperature land quality is determined from the characteristics of the annual average air temperature, while the land quality water availability is determined from the characteristics of annual rainfall, wet months, dry months, and the length of the growth period (LGP). Land

determined from the characteristics of total N, P, and exchangeable K, the sodicity is obtained from the exchangeable sodium percentage (ESP), while erosion hazard is determined from slopes and soil erosion. The quality of the flood-hazard land is determined by identifying the height and the duration of the inundation, while preparation is carried out from the characteristics of outcrops and surface rocks. The selection of this set of land qualities and characteristics is based on the availability of data and their impact on maize production [26].

Data on average annual air temperature and rainfall for 10 years (2010–2021) were collected from different climate stations, namely, the Bandungrejo with 0°41' N–122°38' E, the elevation 40 m asl, while Harapan has 0°42' N–122°29' E and an elevation of 37 m asl. It also includes Lakeya Rain Post with 0°42.82' N–122°32.07' E, 32 m asl, Mohiyolo has 0°46.41' N–122°26.41' E and an elevation of 39 m asl, Saritani 0°46.45' N–122°20.40' E, with 26 m asl, Tangkobu 0°37.25' N–122°36.36' E, 25 m asl, Bubaa 0°31.36' N–122°33.39' E, 16 m asl, Wonggahu 0°38' N–122°33' E, 35 m asl, and Sambati Rain Post with 0°31.184' N–122°27.074' E, and an elevation of 9 m asl managed by BWS II Sulawesi. Furthermore, these data determined wet months (>200 mm) and dry months (<100 mm), which refers to the Oldeman and Darmiyati criteria [48]. The land water balance was determined using the Thornwaite and LGP methods based on the number of surplus and deficit rainy days [49].

Based on the previous soil unit [46], then these soil units were detailed again by adding 32 of soil units to be surveyed and observed, making up to 67 soil units in the area as shown in the legend Figure 1. Soil characteristics such as drainage, coarse material, effective soil depth, slope, inundation height and duration, rock outcrops, and surface rocks were determined by conducting soil profile descriptions and direct observation on 67 pedons referring to the description guidelines in the field [50]. Meanwhile, soil erosion was determined by the USLE method [51]. Other soil characteristics were further analyzed in the soil laboratory using samples from each pedon.

Soil samples were dried for 3 days and sieved through a 2-mesh sieve. The method of soil physics laboratory analysis was carried out according to the procedures by Kurnia et al. [52]. Based on this procedure, soil texture was analyzed in terms of sand, clay, and silt fractions using the pipette method, while soil moisture storage was evaluated using the gravimetric method that can be applied in water balance analysis. The method of soil chemistry laboratory analysis was carried out according to the procedures by Eviyati and Sulaiman [53]. The soil pH was determined with a pH meter in a 1:2.5 soil and water solution, while the organic C content was assessed using the Walkley and Black method. The total N was assessed using the Kjeldahl method, while the available P content was measured using the Olsen method. The basic cations and CEC were extracted with 1N NH₄OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C. The base saturation was determined by calculating the percentage of basic cations number with CEC, and ESP was evaluated using the percentage ratio of sodium to CEC [54, 55]. Subsequently, the data from the chemical analysis were averaged to a depth of 0–30 cm using the weighted averaging technique. The framework of this study is presented in Figure 2.



2.3. Dataset Collection for Hybrid Maize Yield

The areas currently planted with hybrid maize were identified and blocks with a size of $2.5 \text{ m} \times 2.5 \text{ m}$ were made in each map unit (Figure 1). Maize plants in each block passed through standardized management according to farmers' technology. After harvesting, weighting was carried out to obtain hybrid maize yield data from the results of tiles on each land unit. Subsequently, the results were calculated using the following formula [56]:

$$Y(t) = H x \frac{A}{6.25 m^2}.$$
 (1)

Meanwhile, productivity is calculated using the following formula [56]:

$$Y(tha^{-1}) = \frac{Hx1.64x56.73}{100},$$
(2)

where Y is the hybrid maize yield, H is the tile yield (kg), A is the maize area 1 per hectare (ha), and 1.64 and 56.73 are the constants.

2.4. Selection of Land Quality and Land Characteristics

The quality and characteristics of the land in the suitability criteria are used as presented in Tables 1 and 2, which show brief statistics. Generally, most data are relatively homogenous, except for coarse material, available P, slopes, soil erosion, height and inundation, as well as rock outcrops and surface rocks. The selection used the partial least squares of the structural equation model (PLS-SEM) refers to Hair et al. [38] with tools SmartPLS, where land quality and characteristics were selected as the latent and manifest variables, respectively. The analysis in PLS-SEM has 2 main steps, namely, the measurement model (outer model) and the structural model test (inner model).



Step 1 consists of validity and reliability tests, wherein the validity test is conducted with convergent and discriminant validity. The convergent validity is in form of outer loadings (loading factor) and average variance extracted (AVE), while discriminant validity is in form of cross-loading and the Fornell–Larcker criterion. Meanwhile, the reliability test uses composite reliability and Cronbach's alpha.

Convergent validity was observed from the magnitude of the outer loading and the AVE value of each indicator on the latent variable. The validity was calculated according to the following equation [57–60]:

$$\begin{aligned} x_i &= \lambda x_i \xi_1 + \delta_i, \\ y_i &= \lambda y_i \eta_1 + \varepsilon_i, \end{aligned}$$

where x and y are the exogenous (ξ) and endogenous (η) latent variable indicators, λ_x and λ_y are the loading factors, δ and ε are the residual/measurement errors or noise.

Meanwhile, the average variance extracted (AVE) value was calculated using the following equation [61–65]:

$$AVE = \frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i \text{var}(\varepsilon_i)},$$
(4)

where λ_i^2 is the loading factor, var is the variance, and ε_i is the error variance.

The loading factor of an indicator with the highest value is the strongest or most important measure in reflecting the latent variable. In this study, the loading factor value is >0.70 for selecting best land characteristics, but values ranging from 0.50 to 0.60 can still be tolerated with a *t*-statistic >1.96 or a small *p* value of 0.05 [37, 66]. Meanwhile, the AVE value used was more than 0.50, showing that the convergent validity on the latent variable has been reached.

The discriminant validity test used the cross-loading value and the Fornell–Larker criterion to test discriminantly valid indicators in explaining or reflecting latent variables. When the correlation between the latent variables and the core measurement of each indicator is high, the latent variable can predict the indicator better and is considered valid. The discriminant validity is measured by the square root of the average variance extracted, which will be compared with the correlation value between variables. The value calculated based on the square root of AVE must be higher than the correlation between constructs [61]. The equation is expressed as follows [61, 63–65, 67]:

Square root of AVE =
$$\sqrt{\frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i \operatorname{var}(\varepsilon_i)}}$$
, (5)

where λ_i^2 is the loading factor, var is the variance, and ε_i is the error variance.

Furthermore, the composite reliability and Cronbach's alpha were used to test the reliability value between indicators of the latent variables. They are considered good and accepted when the value is >0.70 and has a minimum value of 0.60 [37]. The composite reliability value is calculated using the following equation [62, 65, 68, 69]:

$$oc = \frac{\left(\sum \lambda_i\right)^2}{\left(\sum \lambda_i\right)^2 + \sum i \operatorname{var}\left(\varepsilon_i\right)},\tag{6}$$

where λ_i is the loading factor, var is the variance, and ε_i is the error variance.

Meanwhile, the value of Cronbach's Alpha is calculated according to the following equation [65, 70]:

$$\alpha = \left(\frac{\sum p \neq p'^{\operatorname{cor}(X_{pq}, X_{p'q})}}{p_q + \sum p \neq p'^{\operatorname{cor}(X_{pq}, X_{p'q})}}\right) \left(\frac{p_q}{p_{q-1}}\right),\tag{7}$$

where P_q is the number of indicators or manifest variables and q is the indicator block.

For step 2, the structural model testing (inner model) was carried out after the relationship model was built in line with the observed data and the overall suitability, namely, goodness of fit. The structural equation (inner model) is as follows [59, 60, 62]:

$$\mathbf{H}_{i} = \gamma_{i}\xi_{1} + \gamma_{i}\xi_{2} + \dots \gamma_{i}\xi_{n} + \varsigma_{i},\tag{8}$$

Meanwhile, the determinant coefficient and goodness of fit (Q^2) were calculated using the following equation [62, 64, 70]:

$$Q^{2} (Predictive relevance) = 1 - (1 - R_{1}^{2}) (1 - R_{2}^{2}) \dots (1 - R_{p}^{2}), \qquad (9)$$

where $R_1^2, R_2^2, \dots, R_p^2 = R$ square of endogenous variables in the equation model [68].

The quantity of Q^2 has a value with a range of $0 < Q^2 < 1$, the closer the value to 1, the better the model [37]. It is also equivalent to the coefficient of total determination in path analysis. Furthermore, the effect and significance were tested based on the estimated value of the path coefficient and the critical point value (*t*-statistics or *p* value) at = 0.05. The relationship model between variables was measured by testing the direct correlation coefficient between variables. The results of testing the relationship between *X* and *Y* variables were indicated by the correlation coefficient, as well as t-statistics, and are also presented in the path diagram.

2.5. Class Assignment

To determine the class-required data for optimum results, class limits were calculated from the percentage of optimum results. After knowing the highest and lowest yields, the values were connected with the range of land characteristics values. The land suitability class and yield used referred to FAO [71], namely, class S1 (very suitable) when the values reach 80–100%, S2 was moderately suitable 60–80%, S3 marginally suitable 40–60%, and *N* not suitable <40% of the optimum capacity.

The optimum yield was determined using the boundary line method. This method is carried out by drawing a boundary line on the graph of the relationship between yield and land characteristics to obtain optimum results. In the boundary line method according to Widiatmaka et al. [72], each land characteristic is plotted on the *X*-axis, while hybrid maize yields are plotted on the *Y*-axis. Bhat and Sujatha [42] stated that the preparation of the hybrid maize yield boundary line includes the preparation of a scatter diagram between the *X* and the *Y* variable, division of the *X*-axis into several classes of intervals, determination of the highest data points in each class interval, preparation of boundary lines based on the highest data points from each class interval, and drawing a line parallel to the *X*-axis according to the percentage of the result class.

Furthermore, with the Microsoft Excel application tools, the boundary between classes S1 to S2, S2 to S3, and S3 to *N* were determined by the Data menu \rightarrow What-if-Analysis \rightarrow Goal Seek \rightarrow Set the cell at the location containing the regression equation \rightarrow to value fill with the result limit values S1 to S2, S2 to S3, and S3 to $N \rightarrow$ By changing cell \rightarrow the location where the value of the characteristics of the land will be sought \rightarrow Ok. On location "By changing cell," the number being searched will appear, and at the location, "set cell" will be equal to the limit value of the result.

3. Results and Discussion

3.1. Land Quality and Characteristics Controlling Hybrid Maize Yield

3.1.1. Validity Test Result

Table 3 shows the loading factor of the variables, where most indicators were more than the critical limit of 0.70 with a 95% confidence level (P > 1.960). Therefore, these variables are highly recommended and the indicators are considered convergently valid. In the soil texture indicator for the latent variable of root conditions as well as the cation exchange capacity (CEC) and base saturation (BS) indicators for nutrient retention, the loading factor was below the tolerance value of 0.50 at the 95% confidence level (P < 1.960); hence, it was not used. This implies that the indicators have not been established or explained properly because the standard value of the loading factor must be greater than or equal to 0.50 [37, 38, 66].



 Table 3: Outer loading (loading factor) and the average variance extracted from study variables.

The average variance extracted (AVE) value of almost all variables was greater than 0.50; therefore, it was considered convergently valid [61, 62]. The AVE value of the available nutrient variable was not valid due to the smaller value of the loading factor for the CEC and BS indicators of 0.50, leading to the removal of both indicators. A similar result was discovered in the root condition variable, although the AVE value was greater than 0.50, while the soil texture indicator was not used because the loading factor value is only 0.013.

The measurement of the Fornell–Larcker criterion and cross-loading was used as the basis for assessing the discriminant validity of the model. The calculation results on the Fornell–Larcker criterion in Table 4 show that the average of the tested variables has a higher square root of AVE than the correlation value; hence, the latent variable was considered discriminantly valid. The square root value of the AVE must be greater than its correlation value with other constructs to meet the discriminant validity requirements [69, 73]. The average loading factor value for the latent variable indicator was above that of others as shown in Table 5.

name and a second secon	Table 4: Fornell-Larker criterion test.
A construction of the second s	Table 5: Cross-loading of latent variables to indicators.

3.1.2. Reliability Test Result

The variables are considered reliable because composite reliability and Cronbach's alpha coefficient on average were more than 0.7 [61, 74], as shown in Table 6. However, certain indicators still had values less than 0.6, namely, soil texture, but the indicators used are reliable and adequate in forming the latent variables.

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Table 6: Composite reliability and Cronbach's alpha test.

The highest composite reliability and Cronbach's alpha coefficients were obtained for the variables of temperature, oxygen availability, and toxicity of 1 for the variables to be very reliable. The lowest coefficient was obtained on the root condition variable; therefore, the variable was not reliable. According to Bagozzi and Yi [75] and Hair et al. [74], variables are considered good and accepted when the value is >0.70.

The remaining variables are water availability, nutrient retention, available nutrients, erosion hazard, and land preparation variables. The coefficient of composite reliability and Cronbach's alpha >0.6; therefore, the variable is considered reliable. The minimum value of composite reliability and Cronbach's alpha coefficients was 0.60 [61, 74, 75].

3.1.3. Structural Model Test (Inner Models)

Land characteristics that have a significant correlation with hybrid maize yields show a high level of contribution to land quality in influencing hybrid maize yields as indicated in Figure 3. The figure shows a structural model of the relationship between indicator variables, namely, 24 land characteristics, rectangular yellow, and latent variables, including 10 land qualities maize yield and oval blue. It also shows a model for the relationship between latent variables such as land qualities and maize yield, as well as loading figures. The factor for each indicator and path coefficient for land qualities has a direct effect on the value of maize yields.



Figure 3: Path coefficient of land quality on hybrid maize yield.

For example, X8 (erosion hazard) significantly determines the hybrid maize yield with a path coefficient of -0.392. The negative sign indicates that the erosion hazard is negatively related to maize yield, where the higher the erosion hazard, the lower the maize yield. Furthermore, nutrient retention (X5) contributes to the diversity of hybrid maize yields with a path coefficient of 0.252. A positive sign indicates that nutrient retention is positively related to maize yield, where the higher the value of nutrient retention, followed by the maize yield.

The results of this path analysis indicated that the land quality that can be a predictor of maize yield diversity were oxygen availability (X3), nutrient retention (X5), nutrient availability (X6), erosion hazard (X8), and land preparation (X 10). Figure 2 indicates that only 8 of the 24 indicators explain latent variance at the 5% real test level. The 8 indicators were coarse material and effective soil depth as an indicator of rooting condition, organic carbon content as nutrient retention, exchangeable K as nutrient availability, soil erosion and slope as erosion hazard, as well as rock outcrop and surface rock as an indicator of land preparation. It was also indicated that the drainage loading factor was unable to explain the diversity of oxygen availability. Therefore, oxygen availability cannot be used as a land quality because there are no indicators that can represent it. Only the land qualities of nutrient retention (X5), nutrient availability (x6), erosion hazard (x8), and land preparation (X10) were used next.

The indicators of land characteristics for effective depth, organic C, total *N*, and exchangeable *K* have a fairly strong positive relationship and a very significant effect on hybrid maize yields. In this relationship, an increase in these parameters by 1% will be followed by a rise in hybrid maize yields of 39% to 57.7%. According to Wirosoedarmo et al. [4], effective depth affects root growth and development, making plants grow and develop properly. Moreover, the levels of organic C, total *N*, and CEC are influenced by soil organic matter [76], while potassium plays a role in the growth and development of maize [77].

Indicators of rough soil characteristics, slopes, soil erosion, as well as surface and rock outcrops, have a strong negative relationship with a very significant effect on hybrid maize yields. In this relationship, 1% decrease in coarse material slope soil erosion as well as surface and rock outcrop is followed by an increase in hybrid

Table 7 shows the mathematical equations for each land characteristic and also the optimum hybrid maize yield for the land equation. Figure 4 shows the diagram of the relationship between land characteristics as an independent variable (X) and maize yield as an independent variable Y. Model fitting indicates that the quadratic equation is sufficient to describe the condition of data distribution.

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Table 7: The optimum hybrid maize yield by the land quality and land characteristics.



Figure 4: Scatter diagram relationship among maize yield and land characteristics.

The optimum of hybrid maize yield ranged from 5.58 to 8.54 ton/ha, where the highest yield was obtained from total N and slopes of 8.54 ton/ha with an R^2 value of 100% and 92%. Sutardjo et al. (2012)showed that hybrid maize yields ranged from 7.43 to 9.2 ton/ha. This indicated that the optimum yield achieved is still within the range of hybrid maize yields that have been previously reported. Nitrogen is directly involved in the formation of amino acids, proteins, nucleic acids, enzymes, nucleoproteins, and alkaloids, which are needed in the plant growth process [78, 79]. An extremely high amount of N causes excessive vegetative growth, thereby making plants fall easily and increasing susceptibility to disease [80]. Meanwhile, the lack of N nutrients can limit cell division, enlargement [81], and the formation of chlorophyll, leading to stunted growth as well as yellowing of leaves [80].

The lowest optimum yield was obtained from exchangeable K, which was only 5.58 ton/ha with an R^2 value of 95%. This was presumably because the K content in the soil is very low, thereby affecting the hybrid maize yield. Potassium (K) is required by plants for physiological functions, including carbohydrate metabolism, enzyme activity, osmotic regulation, efficient water use, N uptake, protein synthesis, and assimilate translocation [82–85]. It also plays a role in improving the quality of crop yields [82, 86].

The optimum hybrid maize yield of the remaining is relatively diverse. This includes effective depth and organic carbon, which were both 8.46 ton/ha with an R^2 value of 97%. Furthermore, coarse material and soil erosion were 8.17 ton/ha with an R^2 value of 96% and 89%, while rock outcrops and surface rock were 7.41 ton/ha with an R^2 value of 92%. The absence of coarse material >2 mm in diameter indicated that plant roots can grow freely on the surface or deeper parts of the soil [88] because the deeper the roots of the maize, the greater the maize yield [89, 90]. The addition of organic matter will increase maize yield [91–93] and organic C content [94] because soil organic matter is a strong positive predictor of yield [95]. Kane et al. [95] also stated that the addition of more organic matter will improve water retention, thereby reducing maize yield losses due to drought. The slope has a significant effect on soil degradation [96]. According to a previous study, erosion and maize yield are negatively correlated; hence, increased erosion will reduce maize productivity [97]. Soil erosion on flat land is slower surface runoff [98]. It was also reported that surface rocks and outcrops are the limiting factors in the suitability of maize plantations [99]. Therefore, a high percentage of rock outcrops will complicate land cultivation and plant root growth.

3.3. Land Suitability Criteria for Hybrid Maize Crops

Table 8 shows the yield limit for each class from the calculation of the optimum yield, where the class range for each land characteristic is derived. Based on the optimum yield of the highest hybrid maize, there were 2 indicators, namely, the total N content and the slope. The total N indicator with a very suitable class (S1) was achieved when the value in the soil was greater than 0.11%, while in the moderately suitable class (S2), it was achieved when the total N in the soil ranges from 0.08 to 0.10%. In the marginally appropriate class (S3), the total N indicator was achieved when the total N in the soil ranges from 0.06 to 0.07%, while the not suitable class (N) was achieved when the content was less than 0.06%. On the slope indicator with class S1, it was obtained when the slope class ranges from 0 to 7.70%%, while class S2 was achieved when the slope class ranges from 11.85 to 18.25% and greater than 18.25%, respectively.



Table 8: Yield limits of hybrid maize and values obtained in each land suitability class interval by land quality and characteristics.

Based on the optimum yield of the lowest hybrid maize, only the exchangeable *K* was the indicator. In classes S1 and S2, it was achieved when the exchangeable *K* content in the soil was greater than 0.25 cmol(+)/kg and ranges from 0.14 to 0.24 cmol(+)/kg, respectively. Furthermore, class S3 was achieved when the exchangeable K content in the soil ranges from 0.05 to 0.13 cmol(+)/kg, while in class *N*, it was obtained when the exchangeable *K* content in the soil was less than 0.05 cmol(+)/kg. The remaining variables and indicators were relatively varied according to the optimum yield of hybrid maize and the range of land suitability classes obtained as presented in Table 8.

state of achieving optimum, moderate, and minimum yields of hybrid maize in the field with values of 80%, 60%, and 40%, respectively. According to Sukarman et al. [100], the parameters used in the land suitability assessment must describe the actual conditions. This is due to the significant positive correlation between maize yield and land suitability class [101].

The land suitability criteria for the new hybrid maize are fewer and have referred to the optimum yield. Meanwhile, the land quality and characteristics in this new criterion are less because it only consists of root conditions with characteristics of coarse material and effective depth, nutrient retention with organic C, and nutrient availability with total *N* and *K* exchangeable. It also consists of erosion hazards with characteristics of slopes and soil erosion, as well as land preparation with surface rocks and rock outcrops only. The land qualities selected and maize yields consistent with the land potential are the basis for developing suitability criteria. This will reduce the land characteristics and make the evaluation process faster, cheaper, and easier with accurate results [26]. Some characteristics and land quality criteria were not made because they did not significantly affect the yield of hybrid maize. The number and distribution of the data were still limited, and the diversity of values was small or not measurable in the field [72].

Compared to Wahyunto et al. [47], the new land suitability criteria for hybrid maize plants in Table 9 are more realistic in value with the conditions in the field and is based on the achievement of optimum yields. The current land suitability criteria are still general and not specific to maize yields [26], although the agronomic and yield potential of each maize variety differ, based on the diversity of characteristics and land quality in the field. There are still limitations on the use of these results for the development of hybrid maize in the Boalemo Regency because the setting is only based on land characteristics and optimum yields in this regency. Therefore, further investigation to expand the scope of the research area nationally with more diverse and contrasting land characteristic values is recommended to determine the effect on hybrid maize production.



Table 9: Comparison of new and general land suitability criteria with land quality and characteristics.

4. Conclusions

Land suitability criteria for the new hybrid maize are determined by land qualities, namely, root conditions, nutrient retention, available nutrients, erosion hazard, as well as land preparation, and land characteristics, including coarse material, effective depth, organic C, total N, exchangeable K, slopes, soil erosion, rock outcrops, and surface rocks. The highest optimum yield of 8.54 ton/ha was achieved by the total N and slopes for a very suitable class (S1), while the lowest value of 5.58 ton/ha was attained by exchangeable K for class S1. These results showed that the combination of the PLS-SEM and boundary line analysis can be an alternative approach to establishing new land suitability criteria for crops based on optimum yields and selected land quality.

7 Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors are grateful to the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia, and the Institute Research and Community Service of Universitas Negeri Gorontalo for their financial and administrative support. This study was funded by the Directorate of Research, Technology and Community Service, Directorate General of Higher Education, Research and Technology, Ministry of Education, Culture, Research and Technology of the Republic of Indonesia, grant number B/105/UN47.D1/PT.01.03/2022.

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Research Article

Determination of Land Suitability Criteria for Maize Hybrid in Boalemo Regency Based on Optimum Yield and Selected Land Quality

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Received 22 October 2022; Revised 29 December 2022; Accepted 3 January 2023; Published 18 January 2023

Academic Editor: Maman Turjaman

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The significant effect of land quality on maize production has not been fully considered in the existing land suitability criteria. Therefore, this study aims to determine land suitability criteria for hybrid maize in Boalemo Regency based on the optimum yield and land quality. It was carried out in Boalemo Regency, Indonesia, where the land unit of 67 units was surveyed to obtain land characteristics data. A partial least square of structural equation model (PLS-SEM) with SmartPLS 8.0 was used to select a robust land quality controlling hybrid maize yield, while the boundary line method was used to determine optimum yield and differentiating of land suitability criteria. The result showed that land qualities that define the optimum yield of hybrid maize were root conditions, nutrient availability, nutrient retentions, land preparation, and erosion hazard. The soil characteristics were effective depth, coarse material, organic C, total N, K exchangeable, slopes, soil erosion, rock outcrops, and surface rocks. Furthermore, the highest optimum yield of 8.54 ton/ha was achieved by the total N and slopes for a very suitable class (S1), while the lowest of 5.58 ton/ha was obtained by exchangeable K for class S1. This showed that the combination of PLS-SEM and boundary line analysis was a better approach to developing new land suitability criteria for hybrid maize.

1. Introduction

Food security and farmer prosperity are global concerns; this makes every country increase crop production as well as farmers' income. An important issue for countries with developing economies is ensuring food security, where the agricultural sector plays a strategic role in increasing food availability [1]. Although the global food system has placed maize (*Zea mays* L.) as the leading cereal crop [2], its productivity is being disrupted by land degradation, water scarcity, and climate change [3].

In Indonesia, the wet tropical climate with rainfall and high temperatures tends to reduce the quality of land and agricultural products [4]. This country ranked 8th among the maize-producing nations with a contribution of 2.19% and 2.42% of the world's total harvested area [5]. However, the main problem is the relatively low level of yield in several regions because the achievement of maize production has not been followed by an increase in yield per unit area [6]. This is indicated by the average yield in 2020, which was up to 5.57 ton/ha [5]. According to a previous investigation, maize production in Indonesia can reach between 10 and 12 ton/ha [7, 8], thereby making the country the 21st leading importer in the world.

In Indonesia, Gorontalo Province is one of the centers of maize production, where the hybrid type is the most widely grown species [9]. The maize production in the province reached 1.8 million tons in 2021 [10], with several export

advantages and competitiveness [11]. Furthermore, the planting of hybrid, composite, and local maize types has reached more than 98.90%, 0.68%, and 0.41% only, respectively [12], including Boalemo Regency.

Boalemo Regency ranks third as a maize-producing center in Gorontalo Province with a contribution of 18.90% [13]. The maize plant dominates the use of agricultural land in this district by 37.43% [14]; therefore, the commodity has competitive and comparative advantages with a PCR value of 0.80 and 0.91 DRC. This is because maize plant is supported by land area, climatic conditions, production facilities, as well as market guarantees, and the basic price of buying corn from the government [15]. In 2021, the average hybrid and local maize yields in the regency reached 5.20 tons/ha [16] and 2.34-3.30 tons/ha, respectively [17]. This indicated that the productivity of hybrid maize is still higher than local maize [18], but with lower achievement compared to the national maize production of 5.57 tons/ha [5], and has not yet reached the target of 5.60 tons/ha in 2021 [19]. The production of hybrid maize in Gorontalo can reach 9.78-13.11 tons/ha [20] because it is often cultivated on land that does not meet the required qualities [6]. Therefore, there is a need to determine land quality-based hybrid maize land suitability criteria for site-specific land use planning in Boalemo District.

Maize is usually grown on land with low yield potential [21] and soil fertility, thereby causing low productivity [22]. Moreover, land productivity is determined by quality and characteristics [23, 24], while land quality has a close relationship with maize yields [25]. The land quality affecting the optimum yield of maize needs to be determined [26] and increased by using hybrid varieties that have high yields. This makes it necessary to evaluate the suitability of the hybrid maize in a region to ensure optimal production. The land suitability criteria for hybrid maize are not yet available because the current criterion is the general suitability of maize plants without distinguishing between hybrids and inbreds. Therefore, there is a need to make land suitability criteria for hybrid maize plants.

A previous study has shown that land quality has a significant effect on suitability for certain uses [27]. Meanwhile, land suitability is also important due to the continuous increase in the demand for agricultural land [28]. The land suitability criteria for existing maize fields are still general [29], and there are no specific criteria for hybrid maize varieties. The class assessment outcomes obtained using the existing criteria are relatively many and are not in line with the actual field results [30]. The current criteria consist of 3 components, namely, land quality, characteristics, and ranges of land characteristic values to determine its suitability. Therefore, the problem in developing criteria is choosing land quality, characteristics, and determining the range of land characteristic values associated with suitability classes, namely, suitable, somewhat suitable, marginally suitable, and not suitable.

The selection of land quality and characteristics can be carried out through the partial least square of the structural equation model (PLS-SEM), while the range limits are being determined by the boundary line method. Land qualities and characteristics in the current criteria can be used temporarily

since structural equation model analysis with partial least squares produces better indicators and models than other multivariate analyses [31-35]. This is because the variantbased PLS-SEM has a higher level of flexibility and the size of the sample used is relatively small ranging from 30 to 100 [36-39]. The use of PLS-SEM to determine land characteristics and qualities that control maize crop yields is still relatively rare, except for Syaf [40] on older cocoa plants, maize composite [41], and on local varieties [6]. The boundary line method can help determine nutrient adequacy concentrations and the optimum yield range of a plant that affects nutrients, as well as other land characteristics [42, 43]. Currently, the land suitability criteria for maize plants have not been determined using the boundary line method, except by Ridayanti et al. [44], although the investigation was not specific to hybrid maize.

After obtaining the quality and characteristics of land affecting maize yields with PLS-SEM, the boundary line method can be used to determine the optimum yield as well as land suitability criteria simultaneously. This is carried out by drawing the intersection of the boundary line at the yield and projecting with the land characteristics [29]. Therefore, this study aims to determine land suitability criteria for hybrid maize in Boalemo Regency based on the optimum yield and land quality.

2. Materials and Methods

Study Area. The study area extends from 2.1. 0°28′5.6″-0″57′30.02″ N to 122°8′34.25″-122°43′10.41″E (Figure 1) on a scale of 1:40,000, which is located in the agricultural land of Boalemo Regency, Gorontalo Province, Indonesia. The maximum air temperature was 28.19°C and the minimum was 26.79°C with an average of 28.01°C. Meanwhile, the maximum rainfall was 1,849 mm and the minimum was 1,246 mm with an average of 1,478 mm [45]. The wet and dry seasons last for 3 months and 5 months, respectively. The soil mapping carried out by Ritung et al. [46] at a scale of 1:50,000 become the initial reference for determining 35 soil units, where each unit has information on land characteristics, namely, effective depth, drainage, texture, pH, cation exchange capacity, base saturation, landform, parent material, relief, and land unit area. Meanwhile, the new soil unit is 1:40,000 in scale, and there has been a change in the agricultural land use existing. This indicated that the slope class of 8-15% or hilly is more dominant in the study area with a percentage of 29.77% and slopes >40% or mountainous which is only 2.67%. Furthermore, the dry land is dominant with a value of 59.86% and a little shrub which was only 9.21%, while the dominant Typic Haplustalfs of soil subgroup classification was 22.47%; then, the Fluventic Haplustepts was 21.31% and very little Vertic Haplustepts of soil subgroup classification was 0.04% only (Figure 1).

2.2. Dataset Collection for Land Quality and Land Characteristics. The quality and characteristics of the land in this study refer to Wahyunto et al. [47], consisting of 10 land qualities and 24 characteristics. The set of temperature land



Tile Box

FIGURE 1: Study area.

quality is determined from the characteristics of the annual average air temperature, while the land quality water availability is determined from the characteristics of annual rainfall, wet months, dry months, and the length of the growth period (LGP). Land quality oxygen availability is determined from soil drainage characteristics, rooting conditions are determined from the soil texture, coarse material, and soil effective depth, and nutrient retention is identified from the pH value, C-organic, cation exchange capacity (CEC), and base saturation. Furthermore, the available nutrient is determined from the characteristics of total N, P, and exchangeable K, the sodicity is obtained from the exchangeable sodium percentage (ESP), while erosion hazard is determined from slopes and soil erosion. The quality of the flood-hazard land is determined by identifying the height and the duration of the inundation, while preparation is carried out from the characteristics of outcrops and surface rocks. The selection of this set of land qualities and characteristics is based on the availability of data and their impact on maize production [26].

Data on average annual air temperature and rainfall for 10 years (2010–2021) were collected from different climate stations, namely, the Bandungrejo with $0^{\circ}41' \text{ N}-122^{\circ}38' \text{ E}$, the elevation 40 m asl, while Harapan has $0^{\circ}42' \text{ N}-122^{\circ}29' \text{ E}$ and an elevation of 37 m asl. It also includes Lakeya Rain Post with $0^{\circ}42.82' \text{ N}-122^{\circ}32.07' \text{ E}$, 32 m asl, Mohiyolo has

 $0^{\circ}46.41' \text{ N}-122^{\circ}26.41' \text{ E}$ and an elevation of 39 m asl, Saritani $0^{\circ}46.45' \text{ N}-122^{\circ}20.40' \text{ E}$, with 26 m asl, Tangkobu $0^{\circ}37.25' \text{ N}-122^{\circ}36.36' \text{ E}$, 25 m asl, Bubaa $0^{\circ}31.36' \text{ N}-122^{\circ}33.39' \text{ E}$, 16 m asl, Wonggahu $0^{\circ}38' \text{ N}-122^{\circ}33' \text{ E}$, 35 m asl, and Sambati Rain Post with $0^{\circ}31.184' \text{ N}-122^{\circ}27.074' \text{ E}$, and an elevation of 9 m asl managed by BWS II Sulawesi. Furthermore, these data determined wet months (>200 mm) and dry months (<100 mm), which refers to the Oldeman and Darmiyati criteria [48]. The land water balance was determined using the Thornwaite and LGP methods based on the number of surplus and deficit rainy days [49].

Based on the previous soil unit [46], then these soil units were detailed again by adding 32 of soil units to be surveyed and observed, making up to 67 soil units in the area as shown in the legend Figure 1. Soil characteristics such as drainage, coarse material, effective soil depth, slope, inundation height and duration, rock outcrops, and surface rocks were determined by conducting soil profile descriptions and direct observation on 67 pedons referring to the description guidelines in the field [50]. Meanwhile, soil erosion was determined by the USLE method [51]. Other soil characteristics were further analyzed in the soil laboratory using samples from each pedon.

Soil samples were dried for 3 days and sieved through a 2-mesh sieve. The method of soil physics laboratory analysis was carried out according to the procedures by Kurnia et al. [52]. Based on this procedure, soil texture was analyzed in terms of sand, clay, and silt fractions using the pipette method, while soil moisture storage was evaluated using the gravimetric method that can be applied in water balance analysis. The method of soil chemistry laboratory analysis was carried out according to the procedures by Eviyati and Sulaiman [53]. The soil pH was determined with a pH meter in a 1:2.5 soil and water solution, while the organic C content was assessed using the Walkley and Black method. The total N was assessed using the Kjeldahl method, while the available P content was measured using the Olsen method. The basic cations and CEC were extracted with 1N NH₄OAc pH 7.0 (ammonium acetate) on a dry sample of 105°C. The base saturation was determined by calculating the percentage of basic cations number with CEC, and ESP was evaluated using the percentage ratio of sodium to CEC [54, 55]. Subsequently, the data from the chemical analysis were averaged to a depth of 0-30 cm using the weighted averaging technique. The framework of this study is presented in Figure 2.

2.3. Dataset Collection for Hybrid Maize Yield. The areas currently planted with hybrid maize were identified and blocks with a size of $2.5 \text{ m} \times 2.5 \text{ m}$ were made in each map unit (Figure 1). Maize plants in each block passed through standardized management according to farmers' technology. After harvesting, weighting was carried out to obtain hybrid maize yield data from the results of tiles on each land unit. Subsequently, the results were calculated using the following formula [56]:

$$Y(t) = H x \frac{A}{6.25 m^2}.$$
 (1)

Meanwhile, productivity is calculated using the following formula [56]:

$$Y(tha^{-1}) = \frac{H \ x \ 1.64 \ x \ 56.73}{100},\tag{2}$$

where *Y* is the hybrid maize yield, *H* is the tile yield (kg), *A* is the maize area 1 per hectare (ha), and 1.64 and 56.73 are the constants.

2.4. Selection of Land Quality and Land Characteristics. The quality and characteristics of the land in the suitability criteria are used as presented in Tables 1 and 2, which show brief statistics. Generally, most data are relatively homogenous, except for coarse material, available P, slopes, soil erosion, height and inundation, as well as rock outcrops and surface rocks. The selection used the partial least squares of the structural equation model (PLS-SEM) refers to Hair et al. [38] with tools SmartPLS, where land quality and characteristics were selected as the latent and manifest variables, respectively. The analysis in PLS-SEM has 2 main steps, namely, the measurement model (outer model) and the structural model test (inner model).

Step 1 consists of validity and reliability tests, wherein the validity test is conducted with convergent and discriminant validity. The convergent validity is in form of outer loadings (loading factor) and average variance extracted (AVE), while discriminant validity is in form of cross-loading and the Fornell–Larcker criterion. Meanwhile, the reliability test uses composite reliability and Cronbach's alpha.

Convergent validity was observed from the magnitude of the outer loading and the AVE value of each indicator on the latent variable. The validity was calculated according to the following equation [57–60]:

$$\begin{aligned} x_i &= \lambda x_i \xi_1 + \delta_i, \\ y_i &= \lambda y_i \eta_1 + \varepsilon_i, \end{aligned}$$
 (3)

where x and y are the exogenous (ξ) and endogenous (η) latent variable indicators, λ_x and λ_y are the loading factors, δ and ε are the residual/measurement errors or noise.

Meanwhile, the average variance extracted (AVE) value was calculated using the following equation [61–65]:

AVE =
$$\frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i \operatorname{var}(\varepsilon_i)}$$
, (4)

where λ_i^2 is the loading factor, var is the variance, and ε_i is the error variance.

The loading factor of an indicator with the highest value is the strongest or most important measure in reflecting the latent variable. In this study, the loading factor value is >0.70 for selecting best land characteristics, but values ranging from 0.50 to 0.60 can still be tolerated with a *t*-statistic >1.96 or a small *p* value of 0.05 [37, 66]. Meanwhile, the AVE value used was more than 0.50, showing that the convergent validity on the latent variable has been reached.

The discriminant validity test used the cross-loading value and the Fornell–Larker criterion to test discriminantly valid indicators in explaining or reflecting latent variables. When the correlation between the latent variables and the core measurement of each indicator is high, the latent variable can predict the indicator better and is considered valid. The discriminant validity is measured by the square root of the average variance extracted, which will be compared with the correlation value between variables. The value calculated based on the square root of AVE must be higher than the correlation between constructs [61]. The equation is expressed as follows [61, 63–65, 67]:

Square root of AVE =
$$\sqrt{\frac{\sum \lambda^2 i}{\sum \lambda^2 i + \sum i \operatorname{var}(\varepsilon_i)}}$$
, (5)

where λ_i^2 is the loading factor, var is the variance, and ε_i is the error variance.

Furthermore, the composite reliability and Cronbach's alpha were used to test the reliability value between indicators of the latent variables. They are considered good and accepted when the value is >0.70 and has a minimum value of 0.60 [37]. The composite reliability value is calculated using the following equation [62, 65, 68, 69]:



FIGURE 2: Research framework.

	للمفسط متعشية أمالي			
	Latent variables		Indicators	
Notation	Land quality	Notation	Land characteristics	Lata sources
X1	Temperature (t)	X1.1	Temperature	[45]
		X2.1	Rainfall	[45]
		X2.2	Wet month	Rainfall >200 mm
X2	Water availability (wa)	X2.3	Dry month	Rainfall <100 mm
		X2.4	Long growth period (LGP)	Water balance (Thornwaite method), soil moisture storage (gravimetric method), water surplus, and deficit days
X3	Oxygen availability (oa)	X3.1	Drainage	Soil survey and land observation
		X4.1	Texture	
		X4.1.1	Sand fraction	[- ·]·······
~~	Destine and divise (m)	X4.1.2	Silt fraction	Prpet method
$\Lambda 4$	ROOLING CONDUCTION (FC)	X4.1.3	Clay	
		X4.2 X4.3	Coarse material Effective depth	Soil survey and land observation
		X5.1	pH, H_2O	nH meter (1·25)
		X5.2	pH, KCl	
X5	Nutrient retention (nr)	X5.3	Organic C	Walkley and Black method
		X5.4	Cation exchange capacity (CEC)	1N NH4OAc, pH 7.0, extracted
		X5.5	Base saturation	Calculation
		X6.1	Total N	Kjeldahl method
X6	Nutrient availability (na)	X6.2	P availability	Olsen method
		X6.3	K exchangeable	1N NH4OAc, pH 7.0, extracted
X7	Sodicity (xn)	X7.1	Exchangeable sodium percentage (ESP)	Calculation
X8	Erosion hazard (eh)	X8.1	Slopes	Soil survey and land observation
0.07		X8.2	Soil erosion	
6X	Flooding hazard (fh)	1.9X X9.2	Inundation height Inundation period	Soil survey and land observation
			source of monoments	
X10	Land preparation (lp)	X10.1 X10.2	Rock outcrops Surface rock	Soil survey and land observation
Υ	Hybrid maize yield	Y.1	Hybrid maize yield	Tile box methods

TABLE 1: Latent variables and indicators used in this study.

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TABLE 2: Brief statistics of land quality and characteristics.

Latent variables/indicators	Unit	п	Min	Median	Mean	Max	SD
X1 (temperature)							
X1.1 (temperature)	°C	67	26.79	27.80	28.01	28.19	0.63
X2 (water availability)							
X2.1 (rainfall)	Mm	67	1,246.00	1,533.42	1,478.00	1,849.00	232.69
X2.2 (wet month)	Month	67	0.00	1.03	1.00	3.00	0.85
X2.3 (dry month)	Month	67	2.00	3.39	4.00	5.00	1.06
X2.4 (LGP)	Day	67	211.00	246.00	214.00	304.00	44.54
X3 (oxygen availability)							
X3.1 (drainage)	Class	67	0.00	3.76	4.00	6.00	1.82
X4 (rooting conditions)							
X4.1 (texture)	Class	67	1.00	2.21	2.00	5.00	0.99
X4.1.1 (sand fraction)	%	67	5.00	41.58	43.00	81.33	18.51
X4.1.2 (silt fraction)	%	67	7.33	27.31	24.50	51.50	11.54
X4.1.3 (clay)	%	67	11.33	31.90	30.00	56.33	12.72
X4.2 (coarse material)	%	67	5.00	17.27	10.00	70.00	16.58
X4.3 (effective depth)	Cm	67	10.00	74.55	74.00	160.00	36.40
X5 (nutrient retention)							
X5.1 (pH, H ₂ O)		67	5.00	5.92	5.90	7.15	0.52
X5.2 (pH, KCl)		67	4.35	5.24	5.17	6.60	0.56
X5.3 (organic C)	%	67	0.41	0.85	0.77	2.35	0.39
X5.4 (CEC)	Cmol(+)/kg	67	8.94	24.89	22.43	59.57	11.41
X5.5 (base saturation)	%	67	45.03	56.22	52.85	81.89	9.76
X6 (nutrient availability)							
X6.1 (total N)	%	67	0.04	0.09	0.08	0.27	0.04
X6.2 (P availability)	Mg/kg	67	0.73	8.62	3.77	58.67	12.61
X6.3 (K exchangeable)	Cmol(+)/kg	67	0.07	0.39	0.24	1.92	0.42
X7 (sodicity)	_						
X7.1 (ESP)	%	67	0.76	7.06	6.20	24.17	5.62
X8 (erosion hazard)							
X8.1 (slopes)	%	67	1.00	9.58	6.00	25.00	7.29
X8.2 (soil erosion)	Tons/ha/year	67	3.66	334.51	110.27	1772.43	439.08
X9 (flooding hazard)							
X9.1 (inundation height)	Cm	67	0.00	7.58	0.00	50.00	17.10
X 9.2 (inundation period)	Day	67	0.00	0.64	0.00	5.00	1.52
X10 (land preparation)							
X10.1 (rock outcrops)	%	67	0.00	6.64	0.00	45.00	11.56
X10.2 (surface rock)	%	67	0.00	6.58	0.00	45.00	11.59
Y (hybrid maize yield)	Ton/ha	67	2.85	4.95	4.68	8.07	1.15

n, the number of the land unit; min, minimum; max, maximum; SD, standard deviation; LGP, long growth period; CEC, cation exchange capacity; ESP, exchangeable sodium percentage.

$$\rho c = \frac{\left(\sum \lambda_i\right)^2}{\left(\sum \lambda_i\right)^2 + \sum i \operatorname{var}(\varepsilon_i)},\tag{6}$$

where λ_i is the loading factor, var is the variance, and ε_i is the error variance.

Meanwhile, the value of Cronbach's Alpha is calculated according to the following equation [65, 70]:

$$\alpha = \left(\frac{\sum p \neq p'^{\operatorname{cor}\left(X_{pq}, X_{p'q}\right)}}{p_q + \sum p \neq p'^{\operatorname{cor}\left(X_{pq}, X_{p'q}\right)}}\right) \left(\frac{p_q}{p_{q-1}}\right),\tag{7}$$

where P_q is the number of indicators or manifest variables and q is the indicator block.

For step 2, the structural model testing (inner model) was carried out after the relationship model was built in line with the observed data and the overall suitability, namely,

goodness of fit. The structural equation (inner model) is as follows [59, 60, 62]:

$$\mathbf{H}_{j} = \gamma_{j}\xi_{1} + \gamma_{j}\xi_{2} + \dots \gamma_{j}\xi_{n} + \varsigma_{j}, \tag{8}$$

where η_j is the endogenous variable vector (dependent), $\gamma_j \xi_1 + \gamma_j \xi_2 + \dots + \gamma_j \xi_n$ is the exogenous latent variable vector, and ς_j is the residual vector (error).

Meanwhile, the determinant coefficient and goodness of fit (Q^2) were calculated using the following equation [62, 64, 70]:

$$Q^{2}$$
 (Predictive relevance) = $1 - (1 - R_{1}^{2})(1 - R_{2}^{2}) \dots (1 - R_{p}^{2}),$
(9)

where $R_1^2, R_2^2, \dots, R_p^2 = R$ square of endogenous variables in the equation model [68].

The quantity of Q^2 has a value with a range of $0 < Q^2 < 1$, the closer the value to 1, the better the model [37]. It is also equivalent to the coefficient of total determination in path analysis. Furthermore, the effect and significance were tested based on the estimated value of the path coefficient and the critical point value (*t*-statistics or *p* value) at = 0.05. The relationship model between variables was measured by testing the direct correlation coefficient between variables. The results of testing the relationship between *X* and *Y* variables were indicated by the correlation coefficient, as well as t-statistics, and are also presented in the path diagram.

2.5. Class Assignment. To determine the class-required data for optimum results, class limits were calculated from the percentage of optimum results. After knowing the highest and lowest yields, the values were connected with the range of land characteristics values. The land suitability class and yield used referred to FAO [71], namely, class S1 (very suitable) when the values reach 80–100%, S2 was moderately suitable 60–80%, S3 marginally suitable 40–60%, and *N* not suitable <40% of the optimum capacity.

The optimum yield was determined using the boundary line method. This method is carried out by drawing a boundary line on the graph of the relationship between yield and land characteristics to obtain optimum results. In the boundary line method according to Widiatmaka et al. [72], each land characteristic is plotted on the X-axis, while hybrid maize yields are plotted on the Y-axis. Bhat and Sujatha [42] stated that the preparation of the hybrid maize yield boundary line includes the preparation of a scatter diagram between the X and the Y variable, division of the Xaxis into several classes of intervals, determination of the highest data points in each class interval, preparation of boundary lines based on the highest data points from each class interval, and drawing a line parallel to the X-axis according to the percentage of the result class.

Furthermore, with the Microsoft Excel application tools, the boundary between classes S1 to S2, S2 to S3, and S3 to N were determined by the Data menu \longrightarrow What-if-Analysis \longrightarrow Goal Seek \longrightarrow Set the cell at the location containing the regression equation \longrightarrow to value fill with the result limit values S1 to S2, S2 to S3, and S3 to $N \longrightarrow$ By changing cell \longrightarrow the location where the value of the characteristics of the land will be sought \longrightarrow Ok. On location "By changing cell," the number being searched will appear, and at the location, "set cell" will be equal to the limit value of the result.

3. Results and Discussion

3.1. Land Quality and Characteristics Controlling Hybrid Maize Yield

3.1.1. Validity Test Result. Table 3 shows the loading factor of the variables, where most indicators were more than the critical limit of 0.70 with a 95% confidence level (P > 1.960). Therefore, these variables are highly recommended and the indicators are considered convergently valid. In the soil texture indicator for the latent variable of root conditions as

well as the cation exchange capacity (CEC) and base saturation (BS) indicators for nutrient retention, the loading factor was below the tolerance value of 0.50 at the 95% confidence level (P < 1.960); hence, it was not used. This implies that the indicators have not been established or explained properly because the standard value of the loading factor must be greater than or equal to 0.50 [37, 38, 66].

The average variance extracted (AVE) value of almost all variables was greater than 0.50; therefore, it was considered convergently valid [61, 62]. The AVE value of the available nutrient variable was not valid due to the smaller value of the loading factor for the CEC and BS indicators of 0.50, leading to the removal of both indicators. A similar result was discovered in the root condition variable, although the AVE value was greater than 0.50, while the soil texture indicator was not used because the loading factor value is only 0.013.

The measurement of the Fornell–Larcker criterion and cross-loading was used as the basis for assessing the discriminant validity of the model. The calculation results on the Fornell–Larcker criterion in Table 4 show that the average of the tested variables has a higher square root of AVE than the correlation value; hence, the latent variable was considered discriminantly valid. The square root value of the AVE must be greater than its correlation value with other constructs to meet the discriminant validity requirements [69, 73]. The average loading factor value for the latent variable indicator was above that of others as shown in Table 5.

3.1.2. Reliability Test Result. The variables are considered reliable because composite reliability and Cronbach's alpha coefficient on average were more than 0.7 [61, 74], as shown in Table 6. However, certain indicators still had values less than 0.6, namely, soil texture, but the indicators used are reliable and adequate in forming the latent variables.

The highest composite reliability and Cronbach's alpha coefficients were obtained for the variables of temperature, oxygen availability, and toxicity of 1 for the variables to be very reliable. The lowest coefficient was obtained on the root condition variable; therefore, the variable was not reliable. According to Bagozzi and Yi [75] and Hair et al. [74], variables are considered good and accepted when the value is >0.70.

The remaining variables are water availability, nutrient retention, available nutrients, erosion hazard, and land preparation variables. The coefficient of composite reliability and Cronbach's alpha >0.6; therefore, the variable is considered reliable. The minimum value of composite reliability and Cronbach's alpha coefficients was 0.60 [61, 74, 75].

3.1.3. Structural Model Test (Inner Models). Land characteristics that have a significant correlation with hybrid maize yields show a high level of contribution to land quality in influencing hybrid maize yields as indicated in Figure 3. The figure shows a structural model of the relationship between indicator variables, namely, 24 land characteristics, rectangular yellow, and latent variables, including 10 land qualities maize yield and oval blue. It also shows a model for

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Indicators (land character	istics)	Latent variables (land quality)	Loading factors	t stat	Status	AVE
X1.1 (temperature)	\longrightarrow	X1 (temperature)	1.000**	11.192	Valid	1.000
X2.1 (rainfall)	\longrightarrow	-	0.838	0.085	Valid	
X2.2 (wet month)	\longrightarrow	V2 (mater availability)	0.989	0.999	Valid	0.906
X2.3 (dry month)	\longrightarrow	X2 (water availability)	0.850	0.428	Valid	0.906
X2.4 (LGP)	\longrightarrow		0.993*	1.431	Valid	
X3.1 (drainage)	\longrightarrow	X3 (oxygen availability)	1.000	0.000	Valid	1.000
X4.1 (texture)	\longrightarrow		0.013	0.066	Invalid	
X4.2 (coarse material)	\longrightarrow	X4 (rooting condition)	0.921	1.086	Valid	0.573
X4.3 (effective depth)	\longrightarrow	C C	-0.899	1.047	Valid	
X5.1 (pH, H ₂ O)	\longrightarrow		0.647	0.857	Valid	
X5.2 (pH, KCl)	\longrightarrow		0.570**	1.973	Valid	
X5.3 (organic C)	\longrightarrow	X5 (nutrient retention)	0.831**	3.135	Valid	0.360 (invalid)
X5.4 (CEC)	\longrightarrow		0.436*	1.381	Invalid	
X5.5 (base saturation)	\longrightarrow		0.365	0.845	Invalid	
X6.1 (total N)	\longrightarrow		0.760**	3.226	Valid	
X6.2 (P availability)	\longrightarrow	X6 (nutrient availability)	0.587*	1.385	Valid	0.585
X6.3 (K exchangeable)	\longrightarrow	-	0.897**	6.907	Valid	
X7.1 (ESP)	\longrightarrow	X7 (sodicity)	1.000	0.000	Valid	1.000
X8.1 (slopes)	\longrightarrow	VQ (anasian harand)	0.954**	21.438	Valid	0.022
X8.2 (soil erosion)	\longrightarrow	X8 (erosion hazard)	0.941**	18.308	Valid	0.932
X9.1 (inundation height)	\longrightarrow	VO (flooding barand)	0.984**	4.213	Valid	0.094
X9.2 (inundation period)	\longrightarrow	X9 (flooding hazard)	0.985**	3.918	Valid	0.984
X10.1 (rock outcrops)	\longrightarrow	X10 (land preparation)	0.998**	189.133	Valid	0.995
X10.2 (surface rock)	\longrightarrow	ATO (land preparation)	0.998**	320.273	Valid	0.995

TABLE 3: Outer loading (loading factor) and the average variance extracted from study variables.

AVE, average variance extracted; LGP, long growth period; CEC, cation exchange capacity; ESP, exchangeable sodium percentage.

TABLE 4:	Fornell-	-Larker	criterion	test.	
TABLE 4:	romen-	-Laikei	criterion	test.	

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Y
X1	1.000										
X2	0.940	0.952									
X3	0.059	0.149	1.000								
X4	0.082	0.030	-0.162	0.757							
X5	-0.360	-0.239	-0.103	-0.368	0.600						
X6	-0.069	0.021	0.012	-0.518	0.694	0.765					
X7	0.382	0.429	0.084	0.228	-0.030	-0.217	1.000				
X8	0.019	-0.082	-0.501	0.285	-0.317	-0.370	-0.009	0.966			
X9	-0.104	-0.033	0.237	-0.204	0.073	0.090	0.202	-0.250	0.992		
X10	0.198	0.093	-0.223	0.873	-0.303	-0.538	0.362	0.304	-0.126	0.998	
Y	0.018	0.152	0.169	-0.578	0.387	0.456	-0.016	-0.517	0.164	-0.568	1.000

X1, temperature; X2, water availability; X3, oxygen availability; X4, rooting condition; X5, nutrient retention; X6, nutrient availability; X7, sodicity; X8, erosion hazard; X9, flooding hazard; X10, land preparation; *Y*, maize hybrid yield.

the relationship between latent variables such as land qualities and maize yield, as well as loading figures. The factor for each indicator and path coefficient for land qualities has a direct effect on the value of maize yields.

For example, X8 (erosion hazard) significantly determines the hybrid maize yield with a path coefficient of -0.392. The negative sign indicates that the erosion hazard is negatively related to maize yield, where the higher the erosion hazard, the lower the maize yield. Furthermore, nutrient retention (X5) contributes to the diversity of hybrid maize yields with a path coefficient of 0.252. A positive sign indicates that nutrient retention is positively related to maize yield, where the higher the value of nutrient retention, followed by the maize yield. The results of this path analysis indicated that the land quality that can be a predictor of maize yield diversity were oxygen availability (X3), nutrient retention (X5), nutrient availability (X6), erosion hazard (X8), and land preparation (X 10). Figure 2 indicates that only 8 of the 24 indicators explain latent variance at the 5% real test level. The 8 indicators were coarse material and effective soil depth as an indicator of rooting condition, organic carbon content as nutrient retention, exchangeable K as nutrient availability, soil erosion and slope as erosion hazard, as well as rock outcrop and surface rock as an indicator of land preparation. It was also indicated that the drainage loading factor was unable to explain the diversity of oxygen availability. Therefore, oxygen availability cannot be used as a land

T 1. (Latent Variables										
Indicators	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Υ
X1.1	1	0.8300	0.0312	0.0240	-0.2959	-0.0592	0.3270	0.0195	-0.0837	0.1680	-0.0204
X2.1	0.9783	0.8379	-0.0035	-0.0063	-0.2488	-0.0320	0.3555	-0.0017	-0.0539	0.1552	0.0155
X2.2	0.8534	0.9887	0.1938	-0.0557	-0.1257	0.0988	0.4025	-0.1435	-0.0279	-0.0178	0.1748
X2.3	0.5223	0.8497	0.1523	0.2464	-0.2505	-0.1161	0.4641	-0.1494	0.0144	0.2154	0.0592
X2.4	0.8293	0.9928	0.1721	-0.0334	-0.1524	0.0833	0.4440	-0.1713	-0.0383	-0.0031	0.1331
X3.1	0.0312	0.1785	1	-0.1541	-0.1091	-0.0375	0.0843	-0.4964	0.2530	-0.2229	0.2156
X4.1	-0.0058	-0.0006	-0.1696	0.0126	0.2127	0.1013	0.2173	0.1761	0.0055	-0.0225	0.0050
X4.2	-0.0728	-0.1082	-0.0829	0.9212	-0.2754	-0.5494	0.1845	0.2891	-0.2674	0.7910	-0.5276
X4.3	-0.1289	-0.1240	0.2071	-0.8990	0.2046	0.3209	-0.2633	-0.1587	0.0730	-0.7693	0.4666
X5.1	-0.2975	-0.4140	-0.3824	-0.3027	0.6470	0.3024	-0.1283	0.1730	-0.0342	-0.1190	0.0718
X5.2	-0.2033	-0.2939	-0.4480	-0.2791	0.5701	0.3176	-0.0273	0.1935	0.0801	-0.1829	0.1445
X5.3	-0.2440	-0.0158	0.1276	-0.1134	0.8308	0.5651	0.0728	-0.5076	0.0545	-0.1147	0.3501
X5.4	0.0537	0.1002	0.0033	0.0110	0.4360	0.4081	0.3732	-0.0504	0.1426	-0.0137	0.1395
X5.5	-0.2717	-0.2512	-0.1053	-0.4382	0.3650	0.4343	-0.6008	-0.0619	-0.1498	-0.4876	0.0825
X6.1	-0.0256	0.1778	0.0335	-0.1950	0.7028	0.7604	0.0453	-0.3878	-0.0809	-0.2162	0.2623
X6.2	-0.1201	-0.2238	-0.4256	-0.2590	0.4149	0.5865	-0.2829	-0.0389	-0.0267	-0.2860	0.1025
X6.3	-0.0437	0.0283	0.0310	-0.5607	0.5145	0.8974	-0.3341	-0.2613	0.2133	-0.6520	0.3892
X7.1	0.3270	0.4411	0.0843	0.2420	0.0290	-0.2417	1	-0.0286	0.2142	0.3621	0.0487
X8.1	-0.0226	-0.2234	-0.5132	0.2998	-0.2625	-0.3475	-0.0481	0.9537	-0.3383	0.3031	-0.5274
X8.2	0.0649	-0.0590	-0.4223	0.1646	-0.2942	-0.2950	-0.0035	0.9409	-0.0988	0.2516	-0.4682
X9.1	-0.0996	-0.0225	0.2254	-0.1949	0.1126	0.1483	0.1939	-0.2440	0.9835	-0.1342	0.2278
X9.2	-0.0658	-0.0305	0.2717	-0.1860	0.0271	0.0449	0.2271	-0.2252	0.9849	-0.0901	0.2380
X10.1	0.1848	0.0403	-0.2340	0.8480	-0.2309	-0.5544	0.3760	0.3058	-0.1188	0.9977	-0.5424
X10.2	0.1503	0.0225	-0.2107	0.8629	-0.2274	-0.5592	0.3464	0.2812	-0.1076	0.9976	-0.5365
Y.1	-0.0204	0.1413	0.2156	-0.5479	0.3425	0.3790	0.0487	-0.5271	0.2367	-0.5408	1

TABLE 5: Cross-loading of latent variables to indicators.

X1, temperature; X2, water availability; X3, oxygen availability; X4, rooting condition; X5, nutrient retention; X6, nutrient availability; X7, sodicity; X8, erosion hazard; X9, flooding hazard; X10, land preparation; Y, hybrid maize yield; X1.1, temperature; X2.1, rainfall; X2.2, the wet month; X2.3, the dry month; X2.3, long growth period; X3.1, drainage; X4.1, texture; X4.2, coarse material; X4.3, effective depth; X5.1, organic C; X5.2, cation exchanges capacity; X5.3, base saturation; X6.1, total *N*; X6.2, *P* availability; X6.3, *K* exchangeable; X7.1, the exchange sodium percentage; X8.1, slopes; X8.2, soil erosion; X9.1, inundation height; X9.2, inundation period; X10.1, rock outcrops; X10.2, surface rock; Y.1, hybrid maize yield. The yellow color shows the loading factor value for the indicators of the latent variables above the loading factor values for other latent variable indicators (>0.5), while the red color indicates the opposite (<0.5).

TABLE 6: Composite reliability and Cronbach's alpha test.

Indicators	Crophoch's alpha	Composito reliability		
(land characteristics)	Cronbach's alpha	Composite reliability		
X1.1 (temperature)	1.000	1.000		
X2.1 (rainfall)				
X2.2 (wet month)	0.975	0.965		
X2.3 (dry month)	0.973	0.905		
X2.4 (long growth periods)				
X3.1 (drainage)	1.000	1.000		
X4.1 (texture)				
X4.2 (coarse material)	0.002 ^{nor}	-1.055^{nor}		
X4.3 (effective depth)				
X5.1 (pH, H ₂ O)				
X5.2 (pH, KCl)				
X5.3 (organic C)	0.718	0.628		
X5.4 (cation exchange capacity)				
X5.5 (base saturation)				
X6.1 (total <i>N</i>)				
X6.2 (P availability)	0.805	0.681		
X6.3 (K exchangeable)				
X7.1 (exchangeable sodium percentage)	1.000	1.000		
X8.1 (slopes)	0.965	0.928		
X8.2 (soil erosion)	0.905	0.928		
X9.1 (inundation height)	0.992	0.984		
X9.2 (inundation period)	0.772	0.984		
X10.1 (rock outcrops)	0.998	0.995		
X10.2 (surface rock)	0.770	0.225		

nor, not reliable.



FIGURE 3: Path coefficient of land quality on hybrid maize yield.

quality because there are no indicators that can represent it. Only the land qualities of nutrient retention (X5), nutrient availability (x6), erosion hazard (x8), and land preparation (X10) were used next.

The indicators of land characteristics for effective depth, organic C, total *N*, and exchangeable *K* have a fairly strong positive relationship and a very significant effect on hybrid maize yields. In this relationship, an increase in these parameters by 1% will be followed by a rise in hybrid maize yields of 39% to 57.7%. According to Wirosoedarmo et al. [4], effective depth affects root growth and development, making plants grow and develop properly. Moreover, the levels of organic C, total *N*, and CEC are influenced by soil organic matter [76], while potassium plays a role in the growth and development of maize [77].

Indicators of rough soil characteristics, slopes, soil erosion, as well as surface and rock outcrops, have a strong negative relationship with a very significant effect on hybrid maize yields. In this relationship, 1% decrease in coarse material, slope, soil erosion, as well as surface, and rock outcrop is followed by an increase in hybrid maize yields by 39–57.7%.

3.2. Optimum Hybrid Maize Yield by the Land Quality and Land Characteristics. Table 7 shows the mathematical equations for each land characteristic and also the optimum hybrid maize yield for the land equation. Figure 4 shows the diagram of the relationship between land characteristics as an independent variable (X) and maize yield as an independent variable Y. Model fitting indicates that the

quadratic equation is sufficient to describe the condition of data distribution.

The optimum of hybrid maize yield ranged from 5.58 to 8.54 ton/ha, where the highest yield was obtained from total N and slopes of 8.54 ton/ha with an R^2 value of 100% and 92%. Sutardjo et al. [78] showed that hybrid maize yields ranged from 7.43 to 9.2 ton/ha. This indicated that the optimum yield achieved is still within the range of hybrid maize yields that have been previously reported. Nitrogen is directly involved in the formation of amino acids, proteins, nucleic acids, enzymes, nucleoproteins, and alkaloids, which are needed in the plant growth process [79, 80]. An extremely high amount of N causes excessive vegetative growth, thereby making plants fall easily and increasing susceptibility to disease [81]. Meanwhile, the lack of N nutrients can limit cell division, enlargement [82], and the formation of chlorophyll, leading to stunted growth as well as yellowing of leaves [81].

The lowest optimum yield was obtained from exchangeable K, which was only 5.58 ton/ha with an R^2 value of 95%. This was presumably because the K content in the soil is very low, thereby affecting the hybrid maize yield. Potassium (K) is required by plants for physiological functions, including carbohydrate metabolism, enzyme activity, osmotic regulation, efficient water use, N uptake, protein synthesis, and assimilate translocation [83–86]. It also plays a role in improving the quality of crop yields [87, 83, 88].

The optimum hybrid maize yield of the remaining is relatively diverse. This includes effective depth and organic carbon, which were both 8.46 ton/ha with an R^2 value of 97%. Furthermore, coarse material and soil erosion were

Land	Optimum yield (ton/ha)	Yield equation	R^2	
quality/land characteristics	Optimum yield (ton/na)	Tield equation	K	
Rooting condition (rc)				
Coarse material	8.17	$Y = 0.0025900x^2 - 0.2568578x + 11.9093576$	0.96	
Effective depth	8.46	$Y = -0.0008354x^2 + 0.29100569x - 1.3957496$	0.97	
Nutrient retention (nr)				
Organic carbon	8.46	$Y = -25.492979x^2 + 47.9575089X - 8.9895067$	0.97	
Nutrient availability (na)				
Total N	8.54	$Y = -305.5574654X^2 + 155.8690907X - 2.7439640$	1.00	
K exchangeable	5.58	$Y = -10.6697409X^2 + 18.5239943X + 2.3179289$	0.95	
Erosion hazard (eh)				
Slopes	8.54	$Y = 0.0183X^2 - 0.9559X + 14.806$	0.92	
Soil erosion	8.17	$y = 0.0000184X^2 - 0.0198647X + 9.0537569$	0.89	
Land preparation (lp)				
Rock outcrops	7.41	$Y = 0.0057496X^2 - 0.3845867X + 8.6269785$	0.92	
Surface rock	7.41	$Y = 0.0057496X^2 - 0.3945867X + 8.6269785$	0.92	

TABLE 7: The optimum hybrid maize yield by the land quality and land characteristics.

8.17 ton/ha with an R^2 value of 96% and 89%, while rock outcrops and surface rock were 7.41 ton/ha with an R^2 value of 92%. The absence of coarse material >2 mm in diameter indicated that plant roots can grow freely on the surface or deeper parts of the soil [89] because the deeper the roots of the maize, the greater the maize yield [90, 91]. The addition of organic matter will increase maize yield [92-94] and organic C content [95] because soil organic matter is a strong positive predictor of yield [96]. Kane et al. [96] also stated that the addition of more organic matter will improve water retention, thereby reducing maize yield losses due to drought. The slope has a significant effect on soil degradation [97]. According to a previous study, erosion and maize yield are negatively correlated; hence, increased erosion will reduce maize productivity [98]. Soil erosion on flat land is slower surface runoff [99]. It was also reported that surface rocks and outcrops are the limiting factors in the suitability of maize plantations [100]. Therefore, a high percentage of rock outcrops will complicate land cultivation and plant root growth.

3.3. Land Suitability Criteria for Hybrid Maize Crops. Table 8 shows the yield limit for each class from the calculation of the optimum yield, where the class range for each land characteristic is derived. Based on the optimum yield of the highest hybrid maize, there were 2 indicators, namely, the total N content and the slope. The total N indicator with a very suitable class (S1) was achieved when the value in the soil was greater than 0.11%, while in the moderately suitable class (S2), it was achieved when the total N in the soil ranges from 0.08 to 0.10%. In the marginally appropriate class (S3), the total N indicator was achieved when the total N in the soil ranges from 0.06 to 0.07%, while the not suitable class (N) was achieved when the content was less than 0.06%. On the slope indicator with class S1, it was obtained when the slope class ranges from 0 to 7.70%%, while class S2 was achieved when the slope class ranges from 7.71 to 11.84%. Furthermore, in classes S3 and N, it was obtained when the slope class ranged from 11.85 to 18.25% and greater than 18.25%, respectively.

Based on the optimum yield of the lowest hybrid maize, only the exchangeable K was the indicator. In classes S1 and S2, it was achieved when the exchangeable K content in the soil was greater than 0.25 cmol(+)/kg and ranges from 0.14 to 0.24 cmol(+)/kg, respectively. Furthermore, class S3 was achieved when the exchangeable K content in the soil ranges from 0.05 to 0.13 cmol(+)/kg, while in class N, it was obtained when the exchangeable K content in the soil was less than 0.05 cmol(+)/kg. The remaining variables and indicators were relatively varied according to the optimum yield of hybrid maize and the range of land suitability classes obtained as presented in Table 8.

Based on the relationship between the quality and characteristics of the selected land with optimum results, the criteria for hybrid maize land suitability were obtained as shown in Table 8. These criteria described the actual state of achieving optimum, moderate, and minimum yields of hybrid maize in the field with values of 80%, 60%, and 40%, respectively. According to Sukarman et al. [101], the parameters used in the land suitability assessment must describe the actual conditions. This is due to the significant positive correlation between maize yield and land suitability class [102].

The land suitability criteria for the new hybrid maize are fewer and have referred to the optimum yield. Meanwhile, the land quality and characteristics in this new criterion are less because it only consists of root conditions with characteristics of coarse material and effective depth, nutrient retention with organic C, and nutrient availability with total N and K exchangeable. It also consists of erosion hazards with characteristics of slopes and soil erosion, as well as land preparation with surface rocks and rock outcrops only. The land qualities selected and maize yields consistent with the land potential are the basis for developing suitability criteria. This will reduce the land characteristics and make the evaluation process faster, cheaper, and easier with accurate results [26]. Some characteristics and land quality criteria were not made because they did not significantly affect the yield of hybrid maize. The number and distribution of the data were still limited, and the diversity of values was small or not measurable in the field [72].



FIGURE 4: Scatter diagram relationship among maize yield and land characteristics.

Compared to Wahyunto et al. [47], the new land suitability criteria for hybrid maize plants in Table 9 are more realistic in value with the conditions in the field and is based on the achievement of optimum yields. The current land suitability criteria are still general and not specific to maize yields [26], although the agronomic and yield potential of each maize variety differ, based on the diversity of characteristics and land quality in the field. There are still

TABLE 8: Yield limits of hybrid maize and values obtained in each land suitability class interval by land quality and characteristics.

Land quality/land	Yield limits (ton/ha)				Value of land suitability criterion obtained				
Land quality/land characteristics	$\frac{S1 - S2}{(80\% \times Y_{\text{optim}})}$	$\frac{S2 - S3}{(60\% \times Y_{optim})}$	$\frac{S3 - N}{(40\% \times Y_{\text{optim}})}$) S1 S2		S3	Ν		
Rooting condition (rc)									
Coarse material (%)	8.17	6.05	4.04	0-13.51	13.51-27.48	27.48-52.41	>52.41		
Effective depth (cm)	8.46	6.37	4.29	≥69.66	49.36-69.65	33.29-49.35	<33.29		
Nutrient retention (nr)									
Organic carbon (%)	8.46	6.37	4.29	≥0.61	0.52-0.60	0.34-0.51	< 0.34		
Nutrient availability (na)									
Total N (%)	8.54	6.43	4.33	≥0.11	0.08 - 0.10	0.06-0.07	< 0.06		
<i>K</i> exchangeable (cmol(+)/kg)	5.58	4.42	2.98	≥0.25	0.14-0.24	0.05-0.13	< 0.05		
Erosion hazard (eh)									
Slopes (%)	8.54	6.43	4.33	0 - 7.70	7.71-11.84	11.85-18.25	>18.25		
Soil erosion (ton/ha/year)	8.17	6.05	4.04	≤55.32	55.32-195.29	195.30-605.57	>605.57		
Land preparation (lp)									
Rock outcrops (%)	7.41	5.69	3.97	0 - 4.46	4.47-13.10	13.11-31.89	>31.89		
Surface rock (%)	7.41	5.69	3.97	0 - 4.46	4.47-13.10	13.11-31.89	>31.89		

S1, very suitable; S2, moderately suitable; S3, marginally suitable; N, not suitable.

TABLE 9: Comparison of new and general land suitability criteria with land quality and characteristics.

Land	New land suitability criterion of hybrid maize					Land suitability criterion of general maize [47]			
quality/land characteristics	S1	S2	\$3	N	S1	S2	S3	N	
Rooting condition (rc)									
Coarse material (%)	0-13.51	13.51-27.48	27.48-52.41	>52.41	<15	15-35	35-55	>55	
Effective depth (cm)	≥69.66	49.36-69.65	33.29-49.35	<33.29	>60	60-40	40-25	<25	
Nutrient retention (nr)									
Organic carbon (%)	≥0.61	0.52-0.60	0.34-0.51	< 0.34	>1.20	0.8-1.2	< 0.8	_	
Nutrient availability (na)									
Total N (%)	≥0.11	0.08-0.10	0.06-0.07	< 0.06	Мо	Lo	VLo	_	
<i>K</i> exchangeable (cmol(+)/kg)	≥0.25	0.14-0.24	0.05-0.13	< 0.05	Mo-Hi	Lo	VLo	_	
Erosion hazard (eh)									
Slopes (%)	0 - 7.70	7.71-11.84	11.85-18.25	>18.25	<8	8-15	15-25	>25	
Soil erosion (ton/ha/year)	≤55.32	55.32-195.29	195.30-605.57	>605.57	_	VLi	Li-Mo	He-VHe	
Land preparation (lp)									
Rock outcrops (%)	0 - 4.46	4.47-13.10	13.11-31.89	>31.89	<5	5-15	15 - 40	>40	
Surface rock (%)	0 - 4.46	4.47-13.10	13.11-31.89	>31.89	<5	5-15	15-40	>40	

S1, very suitable; S2, moderately suitable; S3, marginally suitable; *N*, not suitable; Hi, high; M, moderate; Lo, low; VLo, very low; He, heavy; Li, light; VLi, very light; VHe, very heavy.

limitations on the use of these results for the development of hybrid maize in the Boalemo Regency because the setting is only based on land characteristics and optimum yields in this regency. Therefore, further investigation to expand the scope of the research area nationally with more diverse and contrasting land characteristic values is recommended to determine the effect on hybrid maize production.

4. Conclusions

Land suitability criteria for the new hybrid maize are determined by land qualities, namely, root conditions, nutrient retention, available nutrients, erosion hazard, as well as land preparation, and land characteristics, including coarse material, effective depth, organic C, total *N*, exchangeable *K*, slopes, soil erosion, rock outcrops, and surface rocks. The highest optimum yield of 8.54 ton/ha was achieved by the total N and slopes for a very suitable class (S1), while the lowest value of 5.58 ton/ha was attained by exchangeable K for class S1. These results showed that the combination of the PLS-SEM and boundary line analysis can be an alternative approach to establishing new land suitability criteria for crops based on optimum yields and selected land quality.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors are grateful to the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia, and the Institute Research and Community Service of Universitas Negeri Gorontalo for their financial and administrative support. This study was funded by the Directorate of Research, Technology and Community Service, Directorate General of Higher Education, Research and Technology, Ministry of Education, Culture, Research and Technology of the Republic of Indonesia, grant number B/ 105/UN47.D1/PT.01.03/2022.

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