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Dear Dr. Nurdin,

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.

We will confirm this submission with all authors of the manuscript, but you will be the primary recipient of communications from the journal. As submitting author, you will be responsible for responding to editorial queries and making updates to the manuscript.

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Kind regards,
Karlo Lalap

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.

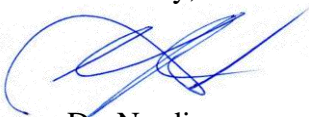
We believe that this manuscript is appropriate for publication by Applied and Environmental Soil Science because this manuscript is relevant to the aim and scope of the journal.

We have no conflicts of interest to disclose.

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

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
 14 existing land suitability criteria. Therefore, this study aims to determine the hybrid maize land
 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
 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 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**

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

35 In Indonesia, the wet tropical climate with rainfall and high temperatures tends to reduce the
 36 quality of land and agricultural products [4]. This country ranked 8th among the maize-
 37 producing nations with a contribution of 2.19% and 2.42% of the world's total harvested area
 38 [5]. However, the main problem is the relatively low level of yield in several regions because
 39 the achievement of maize production has not been followed by an increase in yield per unit
 40 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
44 low productivity [10]. Moreover, land productivity is determined by quality and characteristics
45 [11], [12], while land quality has a close relationship with maize yields [13]. The land quality
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
50 without distinguishing between hybrids and inbreds. Therefore, there is a need to make land
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,
58 characteristics, and ranges of land characteristic values to determine its suitability. Therefore,
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.

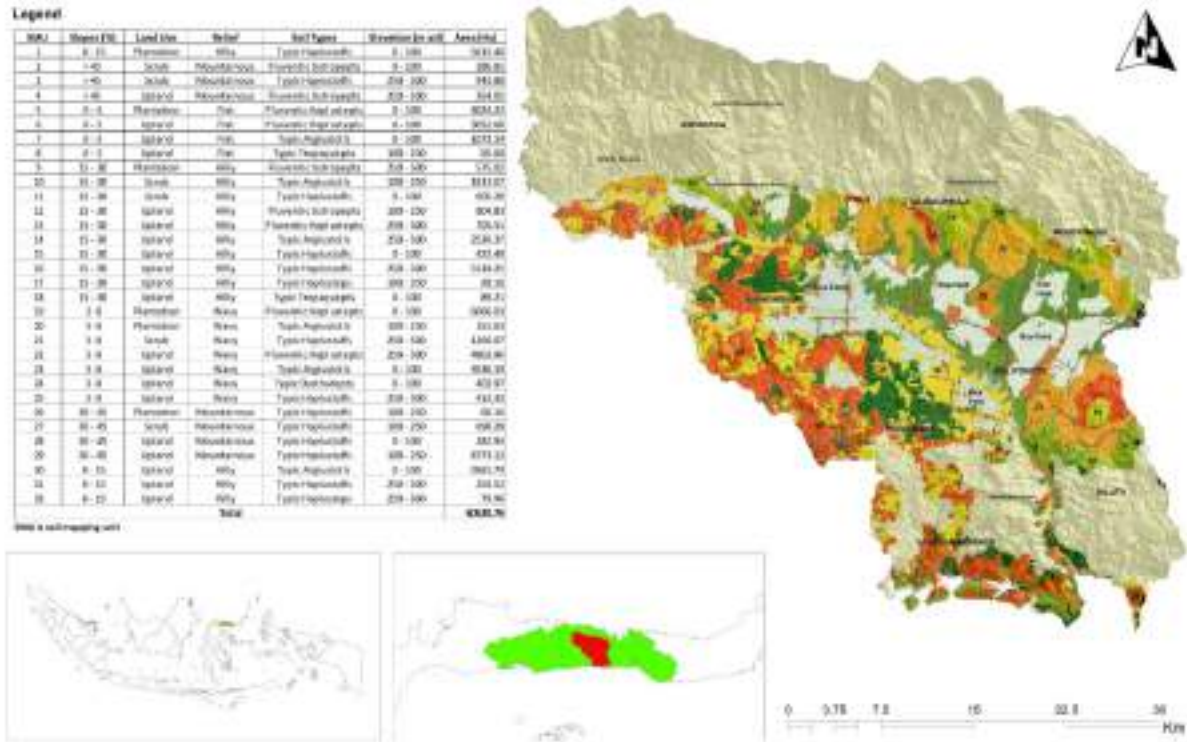
62 The selection of land quality and characteristics can be carried out through the partial least
63 square of the structural equation model (PLS-SEM), while the range limits is being determined
64 by the boundary line method. Land qualities and characteristics in the current criteria can be
65 used temporarily since structural equation model analysis with partial least squares produces
66 better indicators and models than other multivariate analyses [19]–[23]. This is because the
67 variant-based PLS-SEM has a higher level of flexibility and the size of the sample used is
68 relatively small ranging from 30 to 100 [24]–[27]. The use of PLS-SEM to determine land
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.

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

81 **2. Materials and Methods**

82 **2.1 Study area**

83 The study area extends from 0°28'5.6" - 0°57'30.02" N to 122°08'34.25" - 122°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
 86 average of 28.01°C. Meanwhile, the maximum rainfall was 1,849 mm and the minimum was
 87 1,246 mm with an average of 1,478 mm. The wet and dry seasons last for 3 months and 5
 88 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.



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
 96 a working map, where information on land characteristics, namely soil, climate, and terrain,
 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
 100 according to horizon boundaries were taken for analysis in the laboratory.

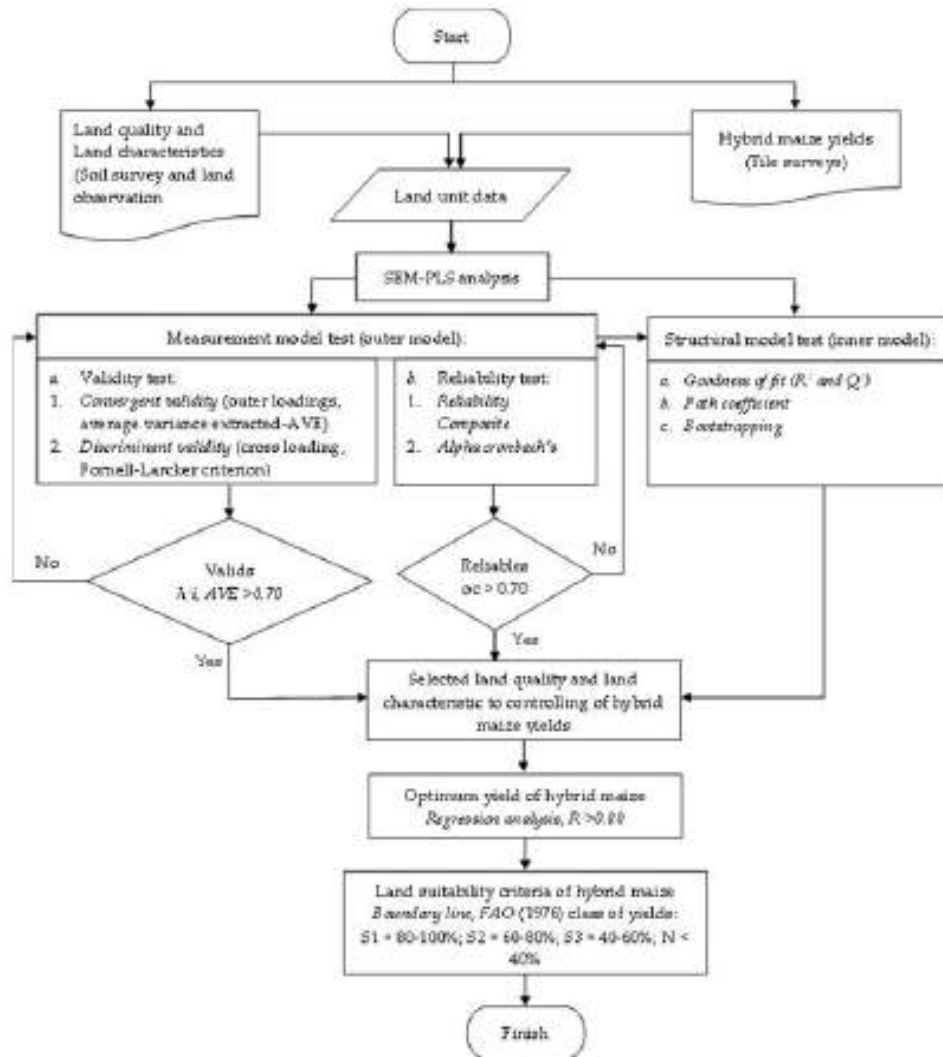


Figure 2: Research framework.

101
102

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
 105 pH was determined with a pH meter in a 1:2.5 soil and water solution, while the organic C
 106 content was assessed using the Walkley and Black method. The available P content was
 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
 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
 115 obtain hybrid maize yield data from the results of tiles on each land unit. Subsequently, the
 116 results were calculated using the formula, as expressed below:

$$117 Y(t) = H \times \frac{A}{6.25 \text{ m}^2} \quad (1)$$

118 Meanwhile, productivity is calculated using the formula below:

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

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

123 The quality and characteristics of the land in the suitability criteria were used as presented in
124 Tables 1 and 2, which show brief statistics. Generally, most data are relatively homogenous,
125 except for coarse material, available P, slopes, soil erosion, height and inundation, as well as
126 rock outcrops and surface rocks. The selection used the partial least squares of the structural
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
129 steps, namely (1) the measurement model (outer model) and (2) the structural model test (inner
130 model).

131 Table 1: Latent variables and indicators used in this study

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

132

133

134 Step 1 consists of validity and reliability tests, wherein the validity test is conducted with
 135 convergent and discriminant validity. The convergent validity is in form of outer loadings
 136 (loading factor) and average variance extracted (AVE), while discriminant validity is in form
 137 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:

$$142 \quad x_i = \lambda x_i \xi_l + \delta_i \quad (3)$$

$$143 \quad y_i = \lambda y_i \eta_l + \varepsilon_i \quad (4)$$

144 where x and y = exogenous (ξ) and endogenous (η) latent variable indicator, λ_x and λ_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	1.06
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)							
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:

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

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

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
154 selecting best land characteristics, but values ranging from 0.50-0.60 can still be tolerated with
155 a t-statistic > 1.96 or a small p-value of 0.05 [25], [35]. Meanwhile, the AVE value used was
156 more than 0.50, showing that the convergent validity on the latent variable has been reached.

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
159 correlation between the latent variables and the core measurement of each indicator is high, the
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
163 must be higher than the correlation between constructs [36]. The equation is expressed below

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

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

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

$$170 \quad \rho_c = \frac{(\sum \lambda_i)^2}{(\sum \lambda_i)^2 + \sum i \text{ var}(\varepsilon_i)} \quad (7)$$

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

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

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

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:

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

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 ζ_j = residual vector (error).

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

$$183 \quad Q^2 \text{ (Predictive relevance)} = 1 - (1 - R_1^2) (1 - R_2^2) \dots (1 - R_p^2) \quad (10)$$

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

185 The quantity of Q^2 has a value with a range of $0 < Q^2 < 1$, 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

193 To determine the class-required data for optimum results, class limits were calculated from the
194 percentage of optimum results. After knowing the highest and lowest yields, the values were
195 connected with the range of land characteristics values. The land suitability class and yield
196 used referred to FAO [37], namely class S1 (very suitable) when the values reach 80-100%, S2
197 was moderately suitable 60-80%, S3 marginally suitable 40-60%, and N not suitable <40% of
198 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
206 highest data points in each class interval, (4) preparation of boundary lines based on the highest
207 data points from each class interval, (5) draw a line parallel to the X-axis according to the
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 → What-if-Analysis → Goal
211 Seek → Set the cell at the location containing the regression equation → to value fill with the
212 result limit values S1 to S2, S2 to S3, and S3 to N → By changing cell → the location where

213 the value of the characteristics of the land will be sought → Ok. On location "By changing
214 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

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].

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

233 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)	→ X1 (Temperature)	1.000**	11.192	Valid	1.000
X2.1 (Rainfall)	→ X2 (Water availability)	0.838	0.085	Valid	0.906
X2.2 (Wet month)		0.989	0.999	Valid	
X2.3 (Dry month)		0.850	0.428	Valid	
X2.4 (LGP)		0.993*	1.431	Valid	
X3.1 (Drainage)	→ X3 (Oxygen availability)	1.000	0.000	Valid	1.000
X4.1 (Texture)	→ X4 (Rooting condition)	0.013	0.066	Invalid	0.573
X4.2 (Coarse material)		0.921	1.086	Valid	
X4.3 (Effective depth)		-0.899	1.047	Valid	
X5.1 (pH H ₂ O)	→ X5 (Nutrient retention)	0.647	0.857	Valid	0.360 (invalid)
X5.2 (pH KCl)		0.570**	1.973	Valid	
X5.3 (Organic C)		0.831**	3.135	Valid	
X5.4 (CEC)		0.436*	1.381	Invalid	
X5.5 (Base saturation)		0.365	0.845	Invalid	
X6.1 (Total N)	→	0.760**	3.226	Valid	0.585

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

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

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

243 3.1.2 Reliability test result

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

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

253 The remaining variables are water availability, nutrient retention, available nutrients, erosion
 254 hazard, and land preparation variables. The coefficient of composite reliability and cronbach's
 255 alpha > 0.6, there, the variable is considered reliable. The minimum value of composite
 256 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

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

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hazard, X9 = flooding hazard, X10 = land preparation, Y = maize hybrid yield.

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Table 5: Cross-Loading of latent variables to indicators

Indicators	Latent Variables										
	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

269 X1 = temperature, X2 = water availability, X3 = oxygen availability, X4 = rooting condition, X5 = nutrient retention, X6 = nutrient availability, X7 = sodicity, X8 = erosion
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 =
271 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
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.

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

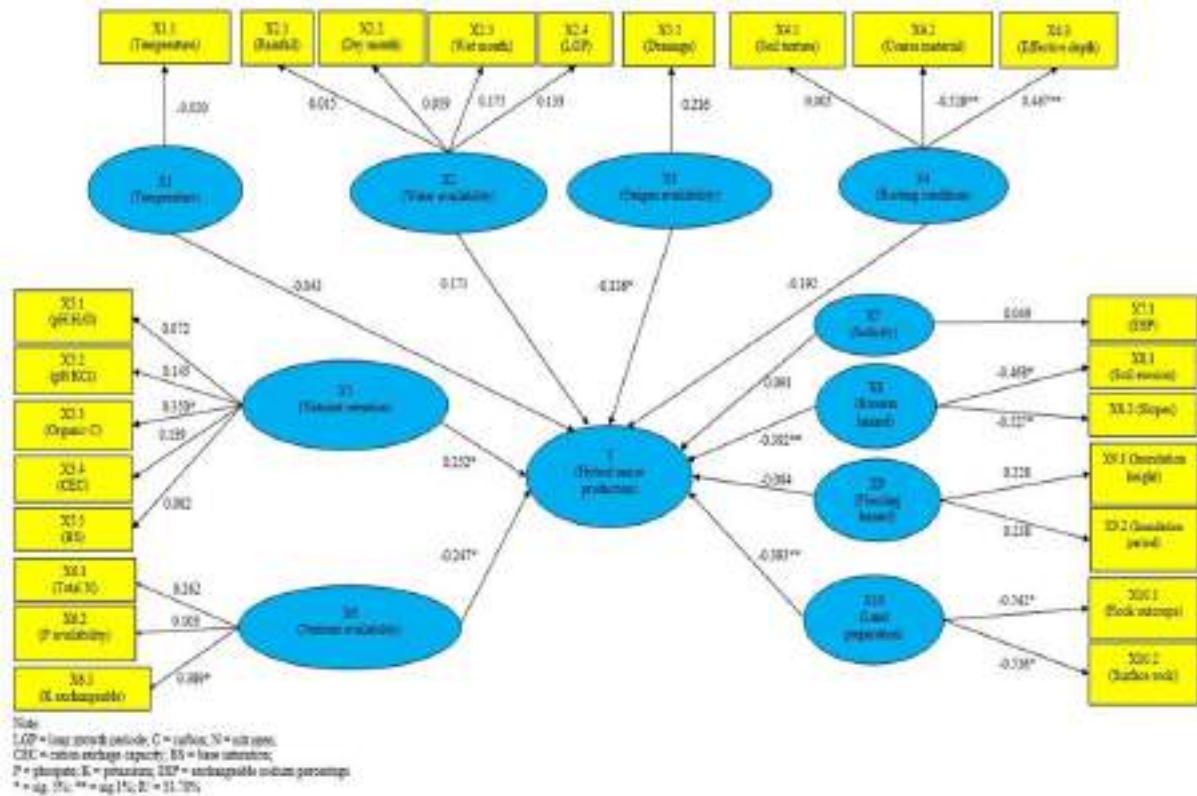
Indicators (land characteristics)	Cronbach's Alpha	Composite Reliability
X1.1 (Temperature)	1.000	1.000
X2.1 (Rainfall)		
X2.2 (Wet month)	0.975	0.965
X2.3 (Dry month)		
X2.4 (Long growth periods)		
X3.1 (Drainage)	1.000	1.000
X4.1 (Texture)		
X4.2 (Coarse material)	0.002 ^{nor}	-1.055 ^{nor}
X4.3 (Effective 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)		
X9.1 (Inundation height)	0.992	0.984
X9.2 (Inundation period)		
X10.1 (Rock outcrops)	0.998	0.995
X10.2 (Surface rock)		

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
 278 level of contribution to land quality in influencing hybrid maize yields as indicated in Figure
 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
 281 maize yield, and oval blue. It also shows a model for the relationship between latent variables
 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
 285 coefficient of -0.392. The negative sign indicates that the erosion hazard is negatively related
 286 to maize yield, where the higher the erosion hazard, the lower the maize yield. Furthermore,
 287 nutrient retention (X5) contributes to the diversity of hybrid maize yields with a path coefficient
 288 of 0.252. A positive sign indicates that nutrient retention is positively related to maize yield,
 289 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.

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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 (X10). 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.

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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].

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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, 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%.

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
 317 between land characteristics as an independent variable (X) and maize yield as an independent
 318 variable Y. Model fitting indicates that the quadratic equation is sufficient to describe the
 319 condition of data distribution.

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

Land Quality/Land Characteristics	Optimum Yield (ton/ha)	Yield Equation	R ²
Rooting condition (rc)			
Coarse material	8.06	$Y = 0.0024800x^2 - 0.2457487x + 10.9082465$	0.95
Effective depth	8.35	$Y = -0.0007242x^2 + 0.1890458x - 1.2946385$	0.96
Nutrient retention (nr)			
Organic carbon	8.35	$Y = -24.3891969x^2 + 46.8464078X - 8.8894056$	0.87
Nutrient availability (na)			
Total N	8.43	$Y = -304.4463543X^2 + 144.7590906X - 2.6328530$	1.00
K Exchangeable	5.74	$Y = -10.5596308X^2 + 17.4129832X + 2.2069179$	0.94
Erosion hazard (eh)			
Slopes	8.43	$Y = 0.0172X^2 - 0.8448X + 13.907$	0.91
Soil erosion	8.06	$y = 0.0000173X^2 - 0.0187536X + 9.0426459$	0.88
Land preparation (lp)			
Rock outcrops	7.30	$Y = 0.0046385X^2 - 0.2934756X + 8.5159674$	0.91
Surface rock	7.30	$Y = 0.0046385X^2 - 0.2934756X + 8.5159674$	0.91

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322 The optimum of hybrid maize yield ranged from 5.74 to 8.43 ton/ha, where the highest yield
 323 was obtained from total N and slopes of 8.43 ton/ha with an R² value of 100% and 91%.
 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,
 327 proteins, nucleic acids, enzymes, nucleoproteins, and alkaloids, which are needed in the plant
 328 growth process [44], [45]. An extremely high amount of N causes excessive vegetative growth,
 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].

332 The lowest optimum yield was obtained from exchangeable K, which was only 5.74 ton/ha
 333 with an R² 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
 335 functions, including carbohydrate metabolism, enzyme activity, osmotic regulation, efficient

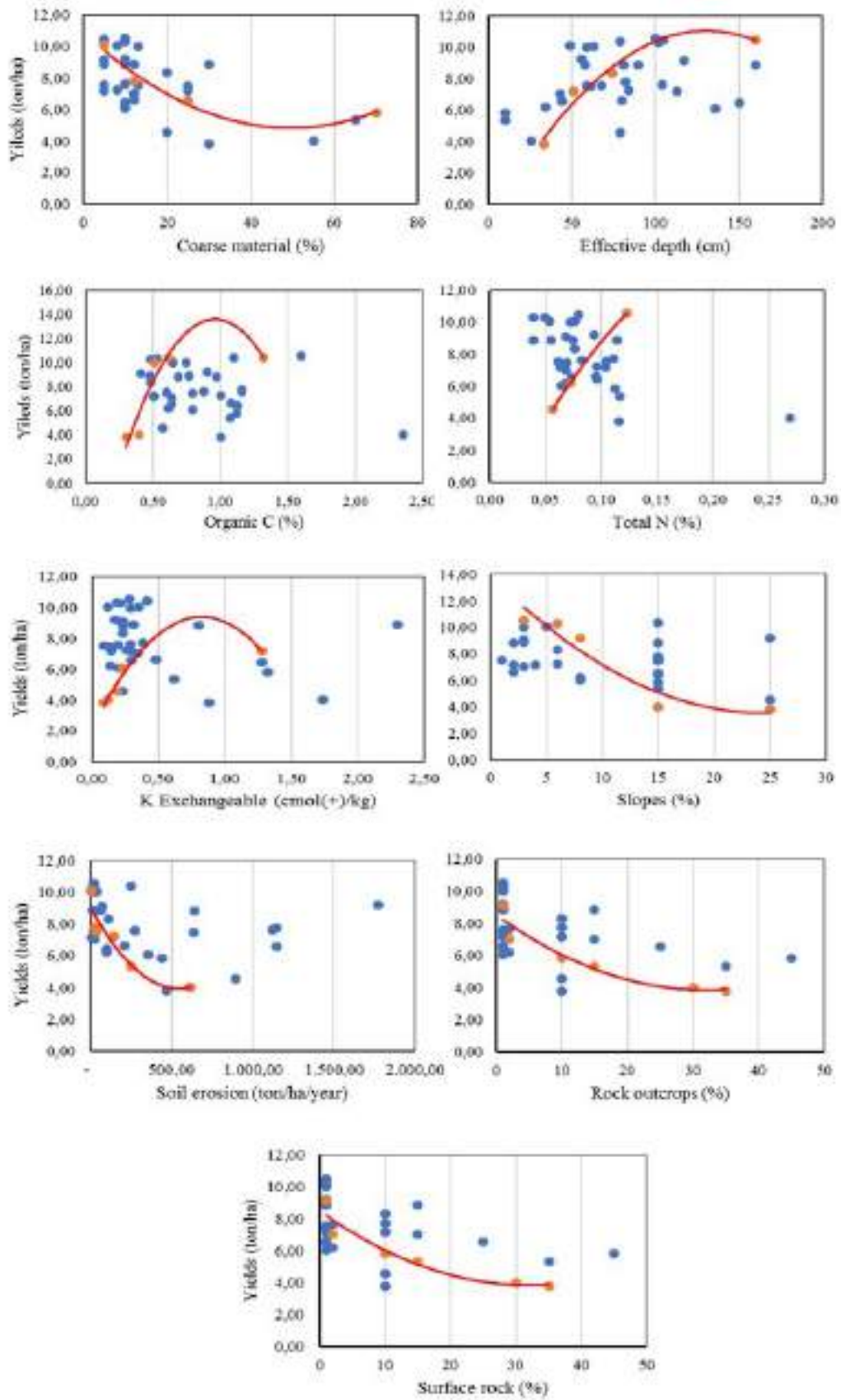
336 water use, N uptake, protein synthesis, and assimilate translocation [48]–[51]. It also plays a
337 role in improving the quality of crop yields (McKenzie, 2013, Subandi, 2013).

338 The optimum hybrid maize yield of the remaining is relatively diverse. This includes effective
339 depth and organic carbon, which were both 8.35 ton/ha with an R^2 value of 87%. Furthermore,
340 coarse material and soil erosion were 8.06 ton/ha with an R^2 value of 95% and 88%, while rock
341 outcrops and surface rock were 7.30 ton/ha with an R^2 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
345 content [60] because soil organic matter is a strong positive predictor of yield [61]. Kane et al.
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
349 correlated, hence, increased erosion will reduce maize productivity [63]. Soil erosion on flat
350 land is slower surface runoff [64]. It was also reported that surface rocks and outcrops are the
351 limiting factors in the suitability of maize plantations [65]. Therefore, a high percentage of rock
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
355 the class range for each land characteristic is derived. Based on the optimum yield of the highest
356 hybrid maize, there were 2 indicators, namely the total N content and the slope. The total N
357 indicator with a very suitable class (S1) was achieved when the value in the soil was greater
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
361 (N) was achieved when the content was less than 0.05%. On the slope indicator with class S1,
362 it was obtained when the slope class ranges from 0-7.69%, while class S2 was achieved when
363 the slope class ranges from 7.70-11.83%. Furthermore, in classes S3 and N, it was obtained
364 when the slope class ranged from 11.84-18.24% and greater than 18.24%, respectively.

365 Based on the optimum yield of the lowest hybrid maize, only the exchangeable K was the
366 indicator. In classes S1 and S2, it was achieved when the exchangeable K content in the soil
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
369 0.04-0.12 cmol(+)/kg, while in class N, it was obtained when the exchangeable K content in
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.



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

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

Land Quality/Land Characteristics	Yield Limits (ton/ha)			Value of Land Suitability Criterion Obtained			
	S1 - S2 (80% x Y _{optim})	S2 - S3 (60% x Y _{optim})	S3 - N (40% x Y _{optim})	S1	S2	S3	N
Rooting condition (rc)							
Coarse material (%)	8.06	6.04	4.03	0 – 13.40	13.41 – 27.37	27.38 – 52.39	> 52.39
Effective depth (cm)	8.35	6.26	4.18	≥ 69.55	49.25 – 69.54	33.18 – 49.24	< 33.18
Nutrient retention (nr)							
Organic carbon (%)	8.35	6.26	4.18	≥ 0.50	0.41 – 0.49	0.34 – 0.40	< 0.34
Nutrient availability (na)							
Total N (%)	8.43	6.32	4.22	≥ 0.10	0.07 – 0.09	0.05 – 0.06	< 0.05
K Exchangeable (cmol(+)/kg)	5.74	4.31	2.87	≥ 0.24	0.13 – 0.23	0.04 – 0.12	< 0.04
Erosion hazard (eh)							
Slopes (%)	8.43	6.32	4.22	0 – 7.69	7.70 – 11.83	11.84 – 18.24	> 18.24
Soil erosion (ton/ha/year)	8.06	6.04	4.03	≤ 55.21	195.29	605.56	> 605.56
Land preparation (lp)							
Rock outcrops (%)	7.30	5.47	3.85	0 – 4.45	4.46 – 13.09	13.10 – 31.78	> 31.78
Surface rock (%)	7.30	5.47	3.85	0 – 4.45	4.46 – 13.09	13.10 – 31.78	> 31.78

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

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

385 The land suitability criteria for the new hybrid maize are fewer and have referred to the
386 optimum yield. Meanwhile, the land quality and characteristics in this new criterion are less
387 because it only consists of root conditions with characteristics of coarse material and effective
388 depth, nutrient retention with organic C, and nutrient availability with total N and K
389 exchangeable. It also consists of erosion hazards with characteristics of slopes and soil erosion,
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
392 suitability criteria. This will reduce the land characteristics and make the evaluation process
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.

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

Land Quality/Land Characteristics	New Land Suitability Criterion of Hybrid Maize				Land Suitability Criterion of General Maize [68]			
	S1	S2	S3	N	S1	S2	S3	N
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	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	> 40
Surface rock (%)	0 – 4.45	4.46 – 13.09	13.10 – 31.78	> 31.78	< 5	5 – 15	15 – 40	> 40

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

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

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428 **References**

- 429 [1] K. Pawlak and M. Kołodziejczak, “The Role of Agriculture in Ensuring Food Security
430 in Developing Countries: Considerations in the Context of the Problem of Sustainable
431 Food Production,” *Sustainability*, vol. 12, no. 13, p. 5488, Jul. 2020, doi:
432 10.3390/su12135488.
- 433 [2] O. Erenstein, M. Jaleta, K. Sonder, K. Mottaleb, and B. M. Prasanna, “Global maize
434 production, consumption and trade: trends and R&D implications,” *Food Secur.* 2022,
435 pp. 1–25, May 2022, doi: 10.1007/S12571-022-01288-7.
- 436 [3] U. Grote, A. Fasse, T. T. Nguyen, and O. Erenstein, “Food Security and the Dynamics
437 of Wheat and Maize Value Chains in Africa and Asia,” *Front. Sustain. Food Syst.*, vol.
438 4, no. February, pp. 1–17, Feb. 2021, doi: 10.3389/fsufs.2020.617009.
- 439 [4] R. Wirosodarmo, A. T. Sutanhaji, and E. Kurniati, “Land Suitability Assessment Of
440 Corn (*Zea mays* L.) Using Spasial Analysis Method,” *agriTECH*, vol. 31, no. 1, pp.
441 71–78, 2012, doi: <https://doi.org/10.22146/agritech.9728>.
- 442 [5] B. Arifin, “High expectations on KSA maize production,” *Stat. Policy Br. Indones.*,
443 vol. 18, no. December, pp. 37–41, 2021, [Online]. Available:
444 <https://fmsindonesia.id/wp-content/uploads/2022/01/Buletin-17-FINAL.pdf>.
- 445 [6] Nurdin, M. L. Rayes, Soemarno, and Sudarto, “Analysis of Quality and Land
446 Characteristics That Control Local Maize Production in Gorontalo,” in *the*
447 *International Seminar on Promoting Local Resources for Sustainable Agriculture and*
448 *Development (ISPLRSAD 2020)*, 2021, vol. 13, no. Isplrsad 2020, pp. 438–446, doi:
449 10.2991/absr.k.210609.068.
- 450 [7] T. Kartika, “The Effect of Planting Distance on Growth and Production of Non Hybrid
451 Maize (*Zea Mays* L) in the Land of Integrated Technology Agro Center (ATP),”
452 *Sainmatika J. Ilm. Mat. dan Ilmu Pengetah. Alam*, vol. 15, no. 2, p. 129, Dec. 2018,
453 doi: 10.31851/sainmatika.v15i2.2378.
- 454 [8] Sutimawati, A. N. Aulia, and R. M. Muliastari, “Comparative Analysis of Hybrid Corn
455 Farming Based on Business Scale in Tempurejo Sub-District,” *J. Agribest*, vol. 3, no.
456 1, p. 61, Mar. 2019, doi: 10.32528/agribest.v3i1.1950.
- 457 [9] D. K. S. Swastika, “Corn Self-Sufficiency in Indonesia: The Past 30 years and Future
458 Prospects,” *J. Litbang Pertan.*, vol. 21, no. 3, pp. 75–83, 2002, [Online]. Available:
459 <https://agris.fao.org/agris-search/search.do?recordID=ID2005000155>.

- 460 [10] E. Kaya, A. Siregar, D. M. Y. Matulesy, and M. Hasan, "Growth and Yield of Corn
461 (Zea mays L.) due to The Granting of Sago Palm Waste Compost of Sago Palm Waste
462 Compost and Organic Liquid Fertilizer (OLF) in Ultisols," *J. Budid. Pertan.*, vol. 12,
463 no. 1, pp. 16–19, 2016, [Online]. Available:
464 <https://ojs3.unpatti.ac.id/index.php/bdp/article/view/42>.
- 465 [11] R. Yacoub, "Land Qualities as a Function to Estimate Land Productivity in the
466 Recently Reclaimed Calcareous Soils , Nubariya , Egypt .," *Egypt. J. Geosci.*, vol. 50,
467 no. 4, pp. 1–13, 2010, [Online]. Available:
468 https://www.researchgate.net/publication/327838295_Land_Qualities_as_a_Function_to_Estimate_Land_Productivity_in_the_Recently_Reclaimed_Calcareous_Soils_Nubariya_Egypt.
- 471 [12] M. Liyanda, A. Karim, and Y. Abubakar, "Analysis of Land Suitability Criteria for
472 Cocoa Production of Three Cluster Development in Pidie District," *Agrista*, vol. 16,
473 no. 2, pp. 62–79, 2012, [Online]. Available:
474 <http://jurnal.unsyiah.ac.id/agrista/article/view/289>.
- 475 [13] R. Neswati, S. Baja, and C. Lopulisa, "A modification of land suitability requirements
476 for maize in the humid tropics of South Sulawesi," *IOP Conf. Ser. Earth Environ. Sci.*,
477 vol. 921, no. 1, p. 012012, Nov. 2021, doi: 10.1088/1755-1315/921/1/012012.
- 478 [14] D. Subardja and Sudarsono, "The influence of Land Quality on Productivity of Maize
479 in Soils Derived from Volcanic and Sedimentary Rocks in the Bogor Area," *Soil Clim.*
480 *J.*, vol. 23, pp. 38–46, 2005, doi: <http://dx.doi.org/10.21082/jti.v0n23.2005.%25p>.
- 481 [15] G. O. Awe and T. P. Abegunrin, "Land Preparation Practices for Maize Production :
482 Short Term Effects on Some Hydro-Physical Properties of Analfisol and Crop
483 Performance," *Middle-East J. Sci. Res.*, vol. 25, no. 7, pp. 1420–1430, 2017, doi:
484 10.5829/idosi.mejsr.2017.1420.1430.
- 485 [16] J. Janků *et al.*, "An overview of a land evaluation in the context of ecosystem
486 services," *Soil Water Res.*, vol. 17, no. No. 1, pp. 1–14, Jan. 2022, doi:
487 10.17221/136/2021-SWR.
- 488 [17] D. Nadalia, A. Sutandi, and B. Nugroho, "Suitability criteria of land characteristics
489 related to Eucalyptus pellita production," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 694,
490 no. 1, p. 012053, Mar. 2021, doi: 10.1088/1755-1315/694/1/012053.
- 491 [18] N. Nurdin, F. Zakaria, M. A. Azis, Y. Rahim, R. Rahman, and M. Kasim,
492 "Comparison of land suitability class for endemic Coffea liberica Pinogu HP. acquired
493 using different methods and recommendations for land management in Pinogu Plateau,
494 Bone Bolango Regency, Indonesia," *SAINS TANAH - J. Soil Sci. Agroclimatol.*, vol.
495 19, no. 1, p. 42, May 2022, doi: 10.20961/stjssa.v19i1.56441.
- 496 [19] A. . Elisanti, W. Purnomo, and S. Melaniani, "Application of partial least square health
497 status of children under 5 years in indonesia," *J. Biometrika dan Kependud.*, vol. 2, no.
498 2, pp. 99–107, 2013, doi: 10.31227/osf.io/gtbq6.
- 499 [20] J.-M. Becker, C. M. Ringle, and M. Sarstedt, "Estimating Moderating Effects in PLS-
500 SEM and PLSC-SEM: Interaction Term Generation*Data Treatment," *J. Appl. Struct.*
501 *Equ. Model.*, vol. 2, no. 2, pp. 1–21, Jun. 2018, doi: 10.47263/JASEM.2(2)01.
- 502 [21] M. . Yim, "A Study on Factor Analytical Methods and Procedures for PLS-SEM
503 (Partial Least Squares Structural Equation Modeling)," *J. Ind. Distrib. Bus.*, vol. 10,
504 no. 5, pp. 7–20, 2019, doi: 10.13106/ijidb.2019.vol10.no5.7.
- 505 [22] R. Schlittgen, M. Sarstedt, and C. M. Ringle, "Data generation for composite-based

- 506 structural equation modeling methods,” *Adv. Data Anal. Classif.*, vol. 14, no. 4, pp.
507 747–757, 2020, doi: 10.1007/s11634-020-00396-6.
- 508 [23] S. Kono and M. Sato, “The potentials of partial least squares structural equation
509 modeling (PLS-SEM) in leisure research,” *J. Leis. Res.*, pp. 1–21, Jun. 2022, doi:
510 10.1080/00222216.2022.2066492.
- 511 [24] M. E. Civelek, “Comparison of Covariance-Based and Partial Least Square Structural
512 Equation Modeling Methods under Non-Normal Distribution and Small Sample Size
513 Limitations,” *Eurasian Econom. Stat. Emprical Econ. Journa*, vol. 10, no. 1, pp. 39–
514 50, 2018, doi: 10.17740/eas.stat.2018-V10-03.
- 515 [25] J. F. Hair, J. J. Risher, M. Sarstedt, and C. M. Ringle, “When to use and how to report
516 the results of PLS-SEM,” *Eur. Bus. Rev.*, vol. 31, no. 1, pp. 2–24, Jan. 2019, doi:
517 10.1108/EBR-11-2018-0203.
- 518 [26] J. F. Hair, C. M. Ringle, and M. Sarstedt, “Partial Least Squares Structural Equation
519 Modeling: Rigorous Applications, Better Results and Higher Acceptance,” *Long
520 Range Plann.*, vol. 46, no. 1–2, pp. 1–12, Feb. 2013, doi: 10.1016/j.lrp.2013.01.001.
- 521 [27] W. Reinartz, M. Haenlein, and J. Henseler, “An empirical comparison of the efficacy
522 of covariance-based and variance-based SEM,” *Int. J. Res. Mark.*, vol. 26, no. 4, pp.
523 332–344, Dec. 2009, doi: 10.1016/j.ijresmar.2009.08.001.
- 524 [28] H. Syaf, “The Relationship Evaluation Between Land Quality, Growth And Production
525 Of Advanced Age Cocoa In Kolaka East District, Southeast Sulawesi Province,”
526 *Bioedukasi*, vol. 3, no. 1, pp. 267–276, 2014, doi:
527 <http://dx.doi.org/10.33387/bioedu.v2i1.60>.
- 528 [29] Nurdin, M. L. Rayes, Soemarno, and Sudarto, “Study of Land Quality and Land
529 Characteristics that Determine the Productivity of Composite Maize Varieties in
530 Gorontalo,” *Syst. Rev. Pharm.*, vol. 11, no. 12, pp. 500–509, 2020, doi:
531 10.31838/srp.2020.12.81.
- 532 [30] R. Bhat and S. Sujatha, “stablishing leaf nutrient norms for arecanut by boundary line
533 approach,” *J. Plant Nutr.*, vol. 36, no. 6, pp. 849–862, Jan. 2013, doi:
534 10.1080/01904167.2013.770524.
- 535 [31] A. M. Ali, “Nutrient Sufficiency Ranges in Mango Using Boundary-Line Approach
536 and Compositional Nutrient Diagnosis Norms in El-Salhiya, Egypt,” *Commun. Soil
537 Sci. Plant Anal.*, vol. 49, no. 2, pp. 188–201, Jan. 2018, doi:
538 10.1080/00103624.2017.1421651.
- 539 [32] M. Ridayanti, M. L. Rayes, and C. Agustina, “Land Suitability Evaluation for Maize in
540 Dry Land Wagir District, Malang Regency,” *J. Tanah dan Sumberd. Lahan*, vol. 8, no.
541 1, pp. 149–160, Dec. 2020, doi: 10.21776/ub.jtsl.2021.008.1.18.
- 542 [33] S. Ritung, F. Lukman, and R. Purnanto, *Atlas Peta Tanah Semi Detail 1:50.000
543 Kabupaten Gorontalo Provinsi Gorontalo*, 2016th ed. Bogor: Badan Penelitian dan
544 Pengembangan Pertanian Kementerian Pertanian, 2016.
- 545 [34] Eviyati and Sulaeman, *Analysis of soil, chemical, plants, water, and fertilizer*. Bogor:
546 Indonesia Centre of Soil Research, 2009.
- 547 [35] K. K. Wong, “Partial Least Squares Structural Equation Modeling (PLS-SEM)
548 Techniques Using SmartPLS,” *Mark. Bull.*, vol. 24, no. 1, pp. 1–32, 2013, [Online].
549 Available: http://marketing-bulletin.massey.ac.nz/marketing_bulletin_articles.html#24.
- 550 [36] C. Fornell and D. F. Larcker, “Evaluating Structural Equation Models with

- 551 Unobservable Variables and Measurement Error;” *J. Mark. Res.*, vol. 18, no. 1, pp.
552 39–50, Nov. 1981, doi: 10.1177/002224378101800104.
- 553 [37] FAO, “A Framework for Innovation,” *FAO Soils Bull.*, vol. 32, no. 22, pp. 1–92, 1976,
554 doi: 10.1007/978-3-030-45139-4_4.
- 555 [38] Widiatmaka, A. Sutandi, A. Iswandi, U. Daras, M. Hikmat, and A. Krisnohadi,
556 “Establishing Land Suitability Criteria for Cashew (*Anacardium occidentale* L.) in
557 Indonesia,” *Appl. Environ. Soil Sci.*, vol. 2014, no. 743194, pp. 1–14, 2014, doi:
558 10.1155/2014/743194.
- 559 [39] R. . Darmawan, “Analysis of the Effect of Work-Family Conflict and Job Stress on the
560 Job Performance of Nurses at ‘X’ Hospital,” *Agora*, vol. 6, no. 2, pp. 1–6, 2018,
561 [Online]. Available: <https://www.neliti.com/id/publications/287084>.
- 562 [40] J. F. Hair, M. Sarstedt, C. M. Ringle, and J. A. Mena, “An assessment of the use of
563 partial least squares structural equation modeling in marketing research,” *J. Acad.*
564 *Mark. Sci.*, vol. 40, no. 3, pp. 414–433, 2012, doi: 10.1007/s11747-011-0261-6.
- 565 [41] R. P. Bagozzi and Y. Yi, “On the evaluation of structural equation models,” *J. Acad.*
566 *Mark. Sci.*, vol. 16, no. 1, pp. 74–94, Mar. 1988, doi: 10.1007/BF02723327.
- 567 [42] T. M. Basuki, D. R. Indrawati, and B. Haryadi, “The Use of Organic Matter to
568 Improve Productivity of Post Lime Mining Land,” *J. For. Nat. Conserv. Res.*, vol. 4,
569 no. 1, pp. 1–8, 2007, doi: 10.20886/jphka.2007.4.1.1-8.
- 570 [43] M. S. Alfian and H. Purnamawati, “Dose and Time of Potassium Fertilizer Application
571 on Growth and Sweet Corn Production at NATC Batangkaluku Gowa regency of
572 South Sulawesi,” *Bul. Agrohorti*, vol. 7, no. 1, pp. 8–15, 2019, doi:
573 10.29244/agrob.v7i1.24404.
- 574 [44] S. Nasreen, M. M. Haque, M. A. Hossain, and A. T. M. Farid, “Nutrient uptake and
575 yield of onion as influenced by nitrogen and sulphur fertilization,” *Bangladesh J.*
576 *Agric. Res.*, vol. 32, no. 3, pp. 413–420, Jan. 2008, doi: 10.3329/bjar.v32i3.543.
- 577 [45] Y. Abdissa, T. Tekalign, and L. M. Pant, “Growth, Bulb Yield and Quality of Onion
578 (*Allium cepa* L.) as Influenced by Nitrogen and Phosphorus Fertilization on Vertisol I.
579 Growth Attributes, Biomass Production and Bulb Yield,” *African J. Agric. Res.*, vol. 6,
580 no. 14, pp. 3252–3258, 2011, doi: 10.5897/AJAR10.1024.
- 581 [46] I. Firmansyah and N. Sumarni, “Effect of N Fertilizer Dosages and Varieties On Soil
582 pH, Soil Total-N, N Uptake, and Yield of Shallots (*Allium ascalonicum* L.) Varieties
583 On Entisols-Brebes Central Java,” *J. Hortik.*, vol. 23, no. 4, p. 358, May 2016, doi:
584 10.21082/jhort.v23n4.2013.p358-364.
- 585 [47] E. Sumiati and O. S. Gunawan, “Application of Mycorrhizal Biofertilizer to Increase
586 the Efficiency of NPK Uptake and its Effects on Yiled and Quality of Shallot Bulbs,”
587 *J. Hort*, vol. 17, no. 1, pp. 34–42, 2006, doi: 10.21082/jhort.v17n1.2007.p%p.
- 588 [48] H. R. McKenzie, “Potassium Fertilizer Application in Crop Production,” *Agri-Facts*,
589 vol. 542, no. 9, pp. 1–7, 2013, [Online]. Available:
590 <https://open.alberta.ca/publications/6060438>.
- 591 [49] M. Dianawati, “Rates and application time of K₂SO₄ on production of G₀ potato
592 seed,” *J. Kultiv.*, vol. 17, no. 1, pp. 531–536, 2018, [Online]. Available:
593 <http://jurnal.unpad.ac.id/kultivasi/article/viewFile/15499/7786>.
- 594 [50] N. Gunadi, “The Use of Potassium Sulphate as an Alternative Source of Potassium
595 Fertilizer in Potato,” *J. Hort*, vol. 17, no. 1, pp. 52–60, 2019, [Online]. Available:

- 596 <http://repository.pertanian.go.id/handle/123456789/7798>.
- 597 [51] I. S. Rahmawan, A. Z. Arifin, and Sulistyawati, "The effect of potassium (K) fertilizer
598 on growth and yield of cabbage (*Brassica oleraceae* var. *capitata*, L.)," *J.*
599 *Agroteknologi Merdeka Pasuruan*, vol. 3, no. 1, pp. 17–23, 2019.
- 600 [52] Subandi, "Role and Management of Potassium Nutrient for Food Production in
601 Indonesia," *Agric. Innov. Dev.*, vol. 6, no. 1, pp. 1–10, 2013, [Online]. Available:
602 [https://www.neliti.com/publications/30881/role-and-management-of-potassium-](https://www.neliti.com/publications/30881/role-and-management-of-potassium-nutrient-for-food-production-in-indonesia)
603 [nutrient-for-food-production-in-indonesia](https://www.neliti.com/publications/30881/role-and-management-of-potassium-nutrient-for-food-production-in-indonesia).
- 604 [53] IIED, "Potash Case Study: Information supplied by the International Fertilizer Industry
605 Association," *Mining, Miner. Sustain. Dev.*, vol. 65, no. February, p. 9, 2002, [Online].
606 Available: http://www.agritrade.org/documents/Biofuels_Sub_Web_Final.pdf.
- 607 [54] N. Nursjahbani, O. Rusdiana, and . D., "Suitability of *Durio zibethinus* Murr. and
608 *Nephelium lappaceum* L. on the Utilization Block at Menumbing Mountain Grand
609 Forest Park, West Bangka," *J. Trop. Silv.*, vol. 9, no. 1, pp. 1–6, May 2018, doi:
610 10.29244/j-siltrop.9.1.1-6.
- 611 [55] I. W. Nyakudya and L. Stroosnijder, "Effect of rooting depth, plant density and
612 planting date on maize (*Zea mays* L.) yield and water use efficiency in semi-arid
613 Zimbabwe: Modelling with AquaCrop," *Agric. Water Manag.*, vol. 146, pp. 280–296,
614 Dec. 2014, doi: 10.1016/j.agwat.2014.08.024.
- 615 [56] S. B. Wang *et al.*, "Effect of subsoiling depth on soil physical properties and summer
616 maize (*Zea mays* L.) yield," *Plant, Soil Environ.*, vol. 65 (2019), no. No. 3, pp. 131–
617 137, Mar. 2019, doi: 10.17221/703/2018-PSE.
- 618 [57] H. Z. Khan, M. A. Malik, and M. F. Saleem, "Effect of rate and source of organic
619 material on the production potential of spring maize (*Zea mays* L.)," *Pak. J. Agri. Sci.*,
620 vol. 45, no. 1, pp. 40–43, 2008, [Online]. Available:
621 <https://pakjas.com.pk/papers/222.pdf>.
- 622 [58] A. Jalal, K. Azeem, M. C. M. T. Filho, and A. Khan, "Enhancing Soil Properties and
623 Maize Yield through Organic and Inorganic Nitrogen and Diazotrophic Bacteria," in
624 *Sustainable Crop Production*, IntechOpen, 2020, pp. 1–14.
- 625 [59] E. E. Kandil, N. R. Abdelsalam, M. A. Mansour, H. M. Ali, and M. H. Siddiqui,
626 "Potentials of organic manure and potassium forms on maize (*Zea mays* L.) growth
627 and production," *Sci. Rep.*, vol. 10, no. 1, p. 8752, Dec. 2020, doi: 10.1038/s41598-
628 020-65749-9.
- 629 [60] Mulyati, A. B. Baharuddin, and R. S. Tejowulan, "Improving Maize (*Zea mays* L.)
630 growth and yield by the application of inorganic and organic fertilizers plus," *IOP*
631 *Conf. Ser. Earth Environ. Sci.*, vol. 712, no. 1, p. 012027, Mar. 2021, doi:
632 10.1088/1755-1315/712/1/012027.
- 633 [61] D. A. Kane, M. A. Bradford, E. Fuller, E. E. Oldfield, and S. A. Wood, "Soil organic
634 matter protects US maize yields and lowers crop insurance payouts under drought,"
635 *Environ. Res. Lett.*, vol. 16, no. 4, p. 044018, Apr. 2021, doi: 10.1088/1748-
636 9326/abe492.
- 637 [62] Mujiyo, W. Larasati, H. Widijanto, and A. Herawati, "The Effect of Slope Gradient of
638 land on the Soil Damage in Giritontro, Wonogiri.," *Agrotrop J. Agric. Sci.*, vol. 11,
639 no. 2, p. 115, 2021, doi: 10.24843/ajoas.2021.v11.i02.p02.
- 640 [63] D. O. Suparwata, Nurmi, and M. I. Bahua, "Using vertical mulch to upland for

- 641 reducing erosion, runoff and its responses to maize growth and yields,”
 642 *Agroteknotropika*, vol. 1, no. 3, pp. 138–145, 2012, doi: 10.31227/osf.io/5aek7.
- 643 [64] R. E. Christanto, Suryono, Mujiyo, and J. Winarno, “The Degree of Erosion Hazard
 644 Mapping in Dry Land at Jatipuro Sub District of Karanganyar with Geographic
 645 Information System (GIS,” *Sains Tanah - J. Soil Sci. Agroclimatol.*, vol. 7, no. 2, pp.
 646 114–119, 2013, doi: 10.15608/stjssa.v7i2.42.
- 647 [65] E. Elfayetti and H. Herdi, “Land Suitability Evaluation for Maize Crops in Saentis
 648 Village, Percut Sei Tuan,” *JUPIIS J. Pendidik. ILMU-ILMU Sos.*, vol. 7, no. 1, p. 33,
 649 Jul. 2015, doi: 10.24114/jupiis.v7i1.2295.
- 650 [66] Sukarman, A. Mulyani, and S. Purwanto, “The Modification of Land Evaluation
 651 Methods for Oriented Climate Change,” *J. Sumberd. Lahan*, vol. 12, no. 1, p. 1, Jun.
 652 2018, doi: 10.21082/jsdl.v12n1.2018.1-11.
- 653 [67] W. Chivasaa, O. Mutanga, and C. Biradarc, “Mapping land suitability for maize (*Zea*
 654 *mays L.*) production using GIS and AHP technique in Zimbabwe,” *South African J.*
 655 *Geomatics*, vol. 8, no. 2, pp. 265–281, Sep. 2022, doi: 10.4314/sajg.v8i2.11.
- 656 [68] Wahyunto, Hikmatullah, E. Suryani, C. Tafakresnanto, S. Ritung, A.
 657 Mulyani, Sukarman, K. Nugroho, Y. Sulaeman, Y. Apriyana, S. Suciantini, A.
 658 Pramudia, Suparto, R. E. Subandiono, T. Sutriadi, and D. Nursyamsi, *Technical*
 659 *Guidance Guidelines for Land Suitability Assessment for Strategic Agricultural*
 660 *Commodities Semi-Detailed Scale 1:50.000*. Bogor: Balai Besar Litbang Sumberdaya
 661 Lahan Pertanian, 2016.

662

INSTRUKSI REVISI 1

(Major Revision

12 Desember 2022)

3800877: Revision requested

3 pesan

Maman Turjaman <support@hindawi.com>
Balas Ke: Karlo Lalap <karlo.lalap@hindawi.com>
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12 Desember 2022 pukul 18.37



Dear Dr. Nurdin,

In order for your submission "Determination of Maize Hybrid Land Suitability Criteria Based on Optimum Yield and Selected Land Quality" to Applied and Environmental Soil Science to proceed to the review process, there needs to be a revision.

Reason & Details:

“

Major Revision

For more information about what is required, please click the link below.

MANUSCRIPT DETAILS

Kind regards,
Maman Turjaman

Applied and Environmental Soil Science

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12 Desember 2022 pukul 21.53

Thank you for the correction... Hopefully in the near future we will fix it according to the revisions from the reviewers

Regards
Nurdin
[Kutipan teks disembunyikan]

Karlo Lalap <phenom.emails@hindawi.com>

13 Desember 2022 pukul 09.25

Determination of Maize Hybrid Land Suitability Criteria Based on Optimum Yield and Selected Land Quality

VIEWING AN OLDER VERSION

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](#)

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— Editorial Comments

Recommendation

Maman Turjaman AE 12.12.2022

Major 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
 14 existing land suitability criteria. Therefore, this study aims to determine the hybrid maize land
 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
 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 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**

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

35 In Indonesia, the wet tropical climate with rainfall and high temperatures tends to reduce the
 36 quality of land and agricultural products [4]. This country ranked 8th among the maize-
 37 producing nations with a contribution of 2.19% and 2.42% of the world's total harvested area
 38 [5]. However, the main problem is the relatively low level of yield in several regions because
 39 the achievement of maize production has not been followed by an increase in yield per unit
 40 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
44 low productivity [10]. Moreover, land productivity is determined by quality and characteristics
45 [11], [12], while land quality has a close relationship with maize yields [13]. The land quality
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
50 without distinguishing between hybrids and inbreds. Therefore, there is a need to make land
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,
58 characteristics, and ranges of land characteristic values to determine its suitability. Therefore,
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.

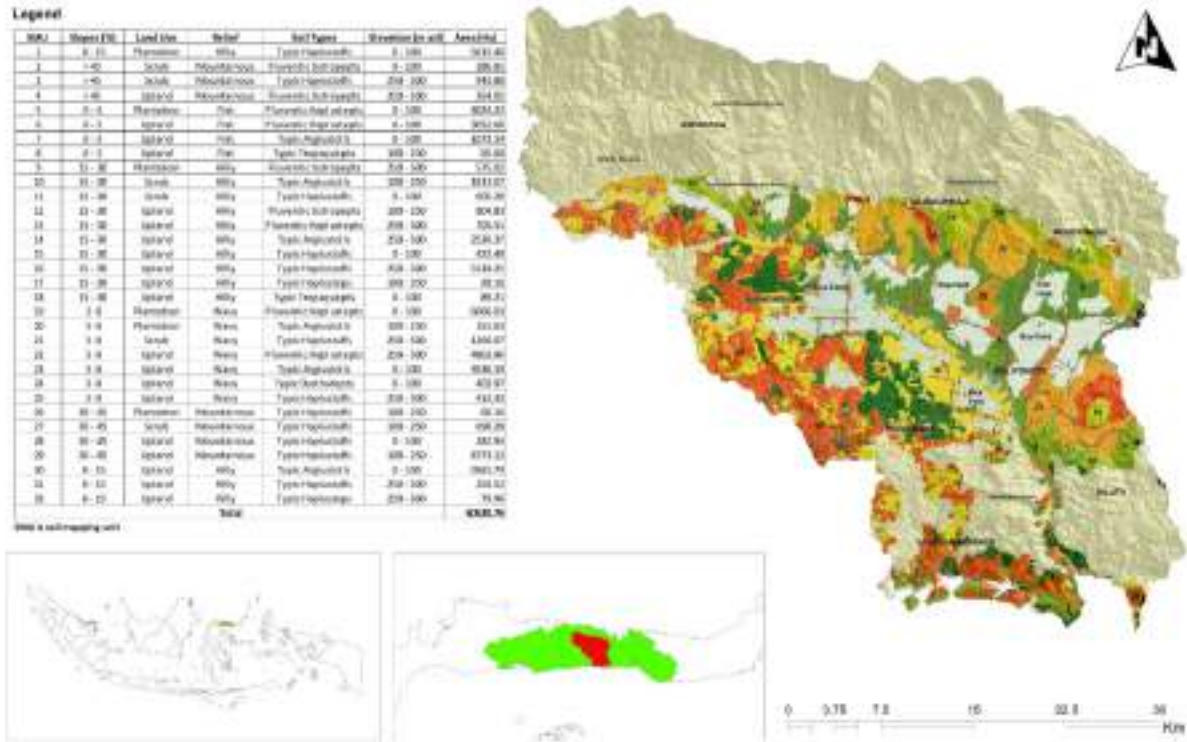
62 The selection of land quality and characteristics can be carried out through the partial least
63 square of the structural equation model (PLS-SEM), while the range limits is being determined
64 by the boundary line method. Land qualities and characteristics in the current criteria can be
65 used temporarily since structural equation model analysis with partial least squares produces
66 better indicators and models than other multivariate analyses [19]–[23]. This is because the
67 variant-based PLS-SEM has a higher level of flexibility and the size of the sample used is
68 relatively small ranging from 30 to 100 [24]–[27]. The use of PLS-SEM to determine land
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.

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

81 **2. Materials and Methods**

82 **2.1 Study area**

83 The study area extends from 0°28'5.6" - 0°57'30.02" N to 122°08'34.25" - 122°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
 86 average of 28.01°C. Meanwhile, the maximum rainfall was 1,849 mm and the minimum was
 87 1,246 mm with an average of 1,478 mm. The wet and dry seasons last for 3 months and 5
 88 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.



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
 96 a working map, where information on land characteristics, namely soil, climate, and terrain,
 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
 100 according to horizon boundaries were taken for analysis in the laboratory.

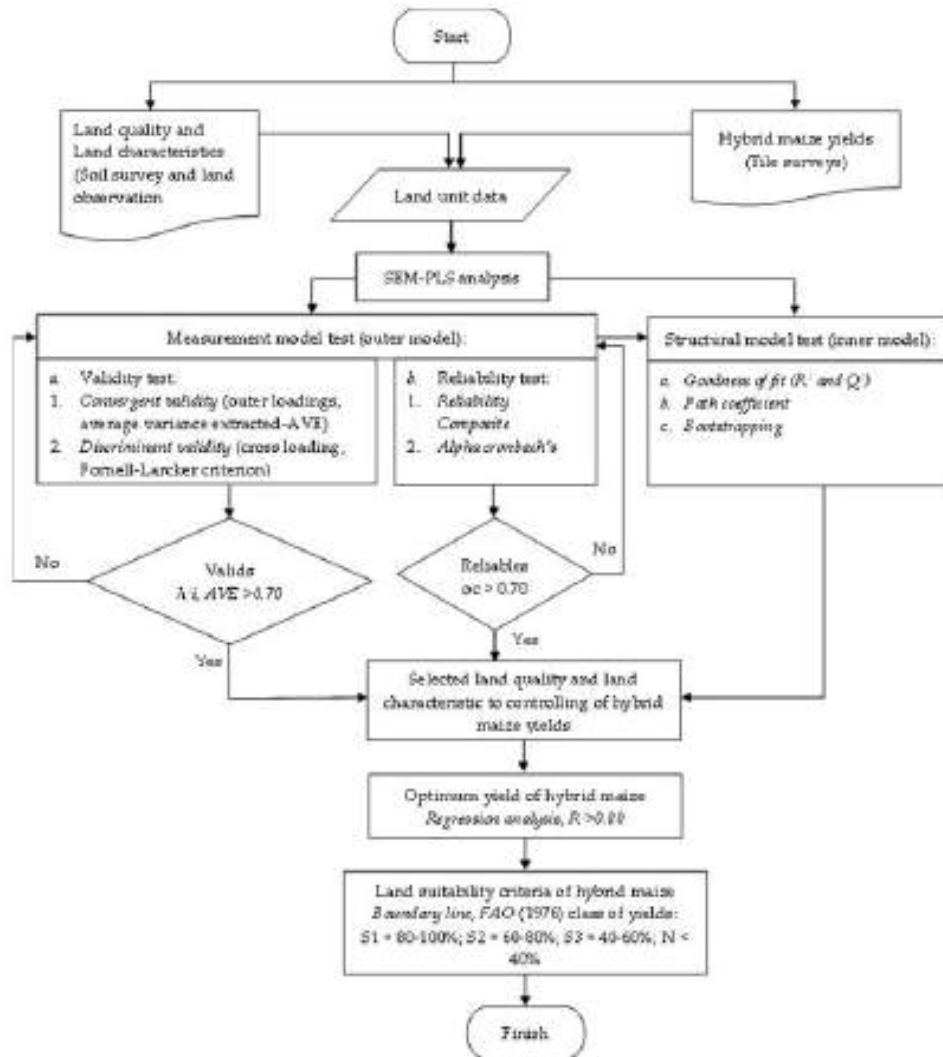


Figure 2: Research framework.

101
102

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
105 pH was determined with a pH meter in a 1:2.5 soil and water solution, while the organic C
106 content was assessed using the Walkley and Black method. The available P content was
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
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
115 obtain hybrid maize yield data from the results of tiles on each land unit. Subsequently, the
116 results were calculated using the formula, as expressed below:

$$117 Y(t) = H \times \frac{A}{6.25 \text{ m}^2} \quad (1)$$

118 Meanwhile, productivity is calculated using the formula below:

$$Y (t ha^{-1}) = \frac{H \times 1.64 \times 56.73}{100} \quad (2)$$

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

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 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) 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 structural model test (inner model).

Table 1: Latent variables and indicators used in this study

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

132

133

134 Step 1 consists of validity and reliability tests, wherein the validity test is conducted with
 135 convergent and discriminant validity. The convergent validity is in form of outer loadings
 136 (loading factor) and average variance extracted (AVE), while discriminant validity is in form
 137 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:

$$142 \quad x_i = \lambda x_i \xi_I + \delta_i \quad (3)$$

$$143 \quad y_i = \lambda y_i \eta_I + \varepsilon_i \quad (4)$$

144 where x and y = exogenous (ξ) and endogenous (η) latent variable indicator, λx and λy =
 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	1.06
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)							
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:

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

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

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
154 selecting best land characteristics, but values ranging from 0.50-0.60 can still be tolerated with
155 a t-statistic > 1.96 or a small p-value of 0.05 [25], [35]. Meanwhile, the AVE value used was
156 more than 0.50, showing that the convergent validity on the latent variable has been reached.

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
159 correlation between the latent variables and the core measurement of each indicator is high, the
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
163 must be higher than the correlation between constructs [36]. The equation is expressed below

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

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

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

$$170 \quad \rho_c = \frac{(\sum \lambda_i)^2}{(\sum \lambda_i)^2 + \sum i \text{ var}(\varepsilon_i)} \quad (7)$$

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

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

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

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:

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

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 ζ_j = residual vector (error).

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

$$183 \quad Q^2 \text{ (Predictive relevance)} = 1 - (1 - R_1^2) (1 - R_2^2) \dots (1 - R_p^2) \quad (10)$$

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

185 The quantity of Q^2 has a value with a range of $0 < Q^2 < 1$, 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

193 To determine the class-required data for optimum results, class limits were calculated from the
194 percentage of optimum results. After knowing the highest and lowest yields, the values were
195 connected with the range of land characteristics values. The land suitability class and yield
196 used referred to FAO [37], namely class S1 (very suitable) when the values reach 80-100%, S2
197 was moderately suitable 60-80%, S3 marginally suitable 40-60%, and N not suitable <40% of
198 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
206 highest data points in each class interval, (4) preparation of boundary lines based on the highest
207 data points from each class interval, (5) draw a line parallel to the X-axis according to the
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 → What-if-Analysis → Goal
211 Seek → Set the cell at the location containing the regression equation → to value fill with the
212 result limit values S1 to S2, S2 to S3, and S3 to N → By changing cell → the location where

213 the value of the characteristics of the land will be sought → Ok. On location "By changing
 214 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

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].

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

233 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)	→ X1 (Temperature)	1.000**	11.192	Valid	1.000
X2.1 (Rainfall)	→ X2 (Water availability)	0.838	0.085	Valid	0.906
X2.2 (Wet month)		0.989	0.999	Valid	
X2.3 (Dry month)		0.850	0.428	Valid	
X2.4 (LGP)		0.993*	1.431	Valid	
X3.1 (Drainage)	→ X3 (Oxygen availability)	1.000	0.000	Valid	1.000
X4.1 (Texture)	→ X4 (Rooting condition)	0.013	0.066	Invalid	0.573
X4.2 (Coarse material)		0.921	1.086	Valid	
X4.3 (Effective depth)		-0.899	1.047	Valid	
X5.1 (pH H ₂ O)	→ X5 (Nutrient retention)	0.647	0.857	Valid	0.360 (invalid)
X5.2 (pH KCl)		0.570**	1.973	Valid	
X5.3 (Organic C)		0.831**	3.135	Valid	
X5.4 (CEC)		0.436*	1.381	Invalid	
X5.5 (Base saturation)		0.365	0.845	Invalid	
X6.1 (Total N)	→	0.760**	3.226	Valid	0.585

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

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

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

243 3.1.2 Reliability test result

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

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

253 The remaining variables are water availability, nutrient retention, available nutrients, erosion
 254 hazard, and land preparation variables. The coefficient of composite reliability and cronbach's
 255 alpha > 0.6, there, the variable is considered reliable. The minimum value of composite
 256 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

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

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hazard, X9 = flooding hazard, X10 = land preparation, Y = maize hybrid yield.

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Table 5: Cross-Loading of latent variables to indicators

Indicators	Latent Variables										
	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

269 X1 = temperature, X2 = water availability, X3 = oxygen availability, X4 = rooting condition, X5 = nutrient retention, X6 = nutrient availability, X7 = sodicity, X8 = erosion
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 =
271 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
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.

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

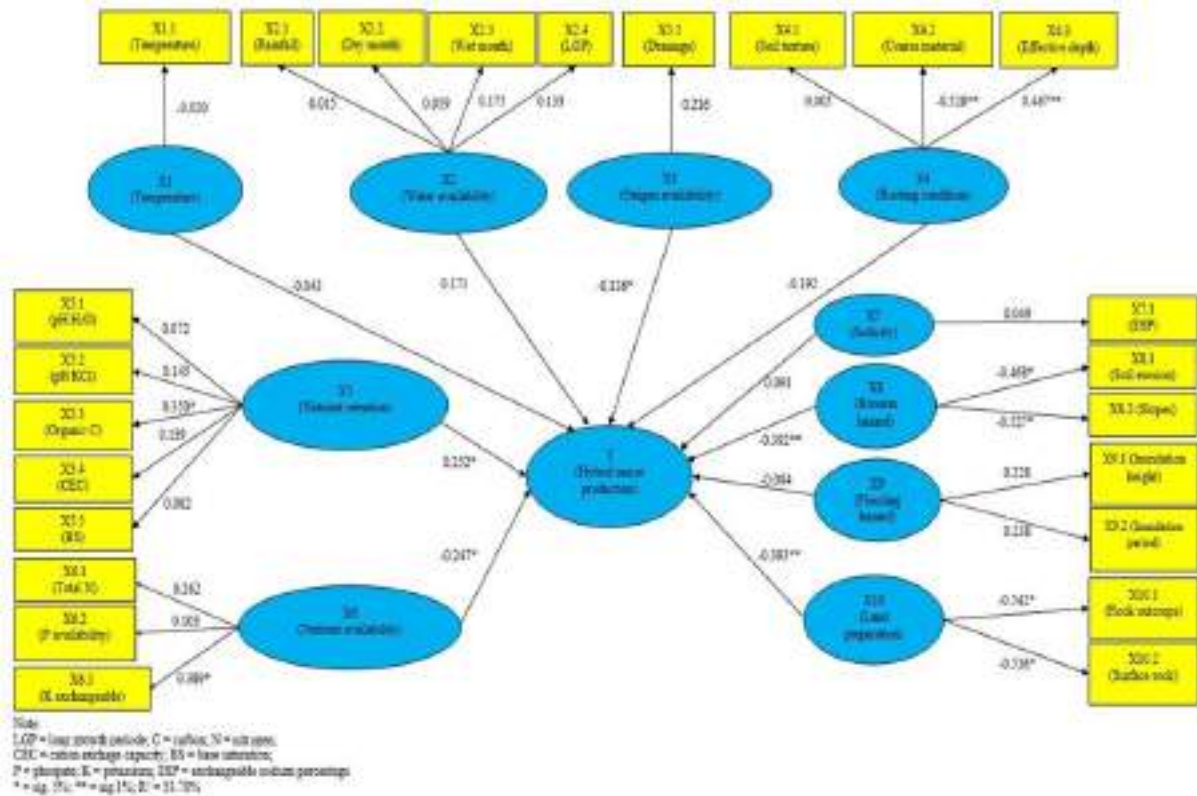
Indicators (land characteristics)	Cronbach's Alpha	Composite Reliability
X1.1 (Temperature)	1.000	1.000
X2.1 (Rainfall)		
X2.2 (Wet month)	0.975	0.965
X2.3 (Dry month)		
X2.4 (Long growth periods)		
X3.1 (Drainage)	1.000	1.000
X4.1 (Texture)		
X4.2 (Coarse material)	0.002 ^{nor}	-1.055 ^{nor}
X4.3 (Effective 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)		
X9.1 (Inundation height)	0.992	0.984
X9.2 (Inundation period)		
X10.1 (Rock outcrops)	0.998	0.995
X10.2 (Surface rock)		

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
 278 level of contribution to land quality in influencing hybrid maize yields as indicated in Figure
 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
 281 maize yield, and oval blue. It also shows a model for the relationship between latent variables
 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
 285 coefficient of -0.392. The negative sign indicates that the erosion hazard is negatively related
 286 to maize yield, where the higher the erosion hazard, the lower the maize yield. Furthermore,
 287 nutrient retention (X5) contributes to the diversity of hybrid maize yields with a path coefficient
 288 of 0.252. A positive sign indicates that nutrient retention is positively related to maize yield,
 289 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.

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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 (X10). 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.

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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].

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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, 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%.

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.

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

Land Quality/Land Characteristics	Optimum Yield (ton/ha)	Yield Equation	R ²
Rooting condition (rc)			
Coarse material	8.06	$Y = 0.0024800x^2 - 0.2457487x + 10.9082465$	0.95
Effective depth	8.35	$Y = -0.0007242x^2 + 0.1890458x - 1.2946385$	0.96
Nutrient retention (nr)			
Organic carbon	8.35	$Y = -24.3891969x^2 + 46.8464078X - 8.8894056$	0.87
Nutrient availability (na)			
Total N	8.43	$Y = -304.4463543X^2 + 144.7590906X - 2.6328530$	1.00
K Exchangeable	5.74	$Y = -10.5596308X^2 + 17.4129832X + 2.2069179$	0.94
Erosion hazard (eh)			
Slopes	8.43	$Y = 0.0172X^2 - 0.8448X + 13.907$	0.91
Soil erosion	8.06	$y = 0.0000173X^2 - 0.0187536X + 9.0426459$	0.88
Land preparation (lp)			
Rock outcrops	7.30	$Y = 0.0046385X^2 - 0.2934756X + 8.5159674$	0.91
Surface rock	7.30	$Y = 0.0046385X^2 - 0.2934756X + 8.5159674$	0.91

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The optimum of hybrid maize yield ranged from 5.74 to 8.43 ton/ha, where the highest yield was obtained from total N and slopes of 8.43 ton/ha with an R² value of 100% and 91%. 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 [44], [45]. An extremely high amount of N causes excessive vegetative growth, thereby making plants fall easily and increasing susceptibility to disease [46]. Meanwhile, the lack of N nutrients can limit cell division, enlargement [47], and the formation of chlorophyll, 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 with an R² value of 94%. 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

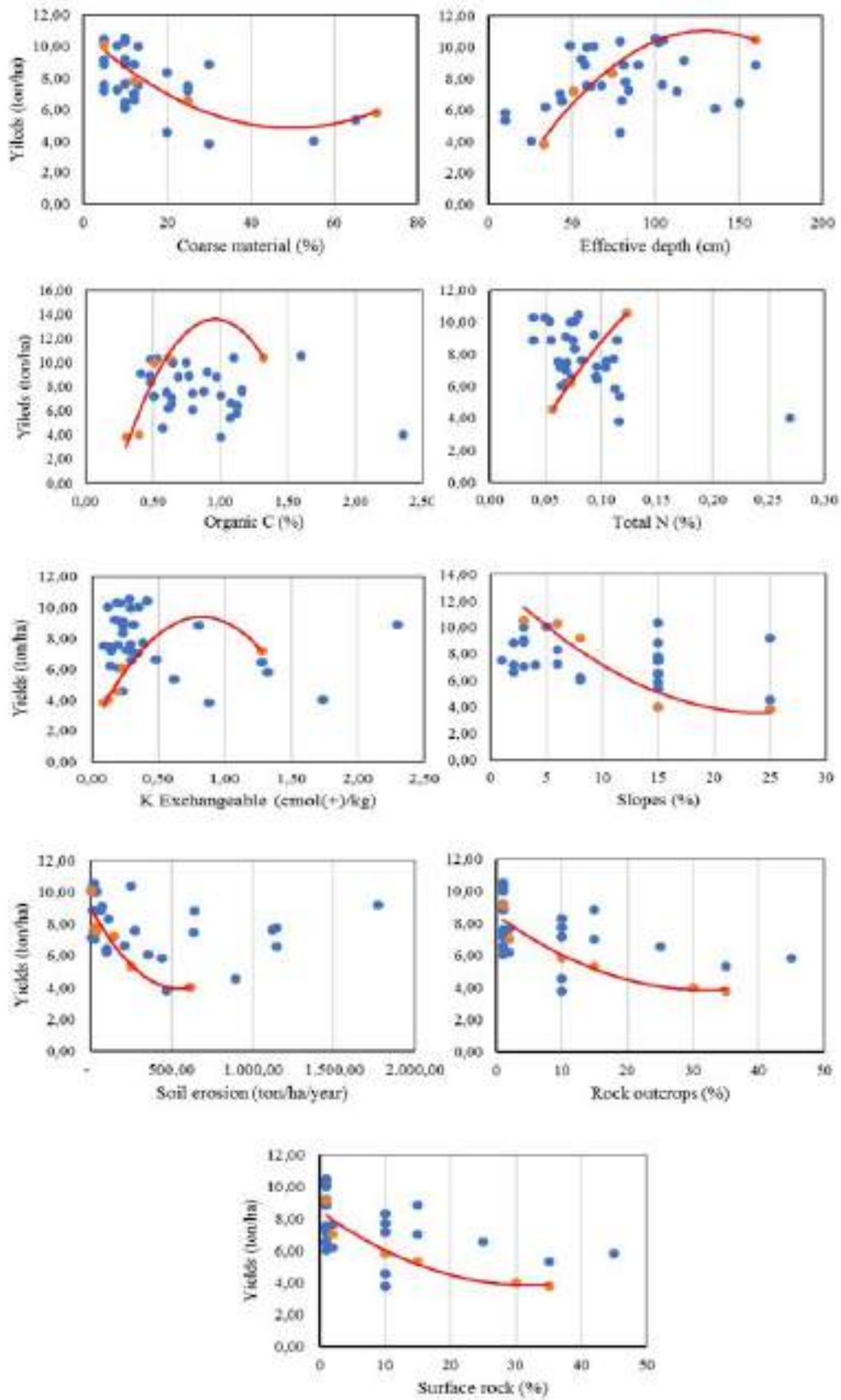
336 water use, N uptake, protein synthesis, and assimilate translocation [48]–[51]. It also plays a
337 role in improving the quality of crop yields (McKenzie, 2013, Subandi, 2013).

338 The optimum hybrid maize yield of the remaining is relatively diverse. This includes effective
339 depth and organic carbon, which were both 8.35 ton/ha with an R^2 value of 87%. Furthermore,
340 coarse material and soil erosion were 8.06 ton/ha with an R^2 value of 95% and 88%, while rock
341 outcrops and surface rock were 7.30 ton/ha with an R^2 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
345 content [60] because soil organic matter is a strong positive predictor of yield [61]. Kane et al.
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
349 correlated, hence, increased erosion will reduce maize productivity [63]. Soil erosion on flat
350 land is slower surface runoff [64]. It was also reported that surface rocks and outcrops are the
351 limiting factors in the suitability of maize plantations [65]. Therefore, a high percentage of rock
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
355 the class range for each land characteristic is derived. Based on the optimum yield of the highest
356 hybrid maize, there were 2 indicators, namely the total N content and the slope. The total N
357 indicator with a very suitable class (S1) was achieved when the value in the soil was greater
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
361 (N) was achieved when the content was less than 0.05%. On the slope indicator with class S1,
362 it was obtained when the slope class ranges from 0-7.69%, while class S2 was achieved when
363 the slope class ranges from 7.70-11.83%. Furthermore, in classes S3 and N, it was obtained
364 when the slope class ranged from 11.84-18.24% and greater than 18.24%, respectively.

365 Based on the optimum yield of the lowest hybrid maize, only the exchangeable K was the
366 indicator. In classes S1 and S2, it was achieved when the exchangeable K content in the soil
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
369 0.04-0.12 cmol(+)/kg, while in class N, it was obtained when the exchangeable K content in
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.



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

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

Land Quality/Land Characteristics	Yield Limits (ton/ha)			Value of Land Suitability Criterion Obtained			
	S1 - S2 (80% x Y _{optim})	S2 - S3 (60% x Y _{optim})	S3 - N (40% x Y _{optim})	S1	S2	S3	N
Rooting condition (rc)							
Coarse material (%)	8.06	6.04	4.03	0 – 13.40	13.41 – 27.37	27.38 – 52.39	> 52.39
Effective depth (cm)	8.35	6.26	4.18	≥ 69.55	49.25 – 69.54	33.18 – 49.24	< 33.18
Nutrient retention (nr)							
Organic carbon (%)	8.35	6.26	4.18	≥ 0.50	0.41 – 0.49	0.34 – 0.40	< 0.34
Nutrient availability (na)							
Total N (%)	8.43	6.32	4.22	≥ 0.10	0.07 – 0.09	0.05 – 0.06	< 0.05
K Exchangeable (cmol(+)/kg)	5.74	4.31	2.87	≥ 0.24	0.13 – 0.23	0.04 – 0.12	< 0.04
Erosion hazard (eh)							
Slopes (%)	8.43	6.32	4.22	0 – 7.69	7.70 – 11.83	11.84 – 18.24	> 18.24
Soil erosion (ton/ha/year)	8.06	6.04	4.03	≤ 55.21	195.29	605.56	> 605.56
Land preparation (lp)							
Rock outcrops (%)	7.30	5.47	3.85	0 – 4.45	4.46 – 13.09	13.10 – 31.78	> 31.78
Surface rock (%)	7.30	5.47	3.85	0 – 4.45	4.46 – 13.09	13.10 – 31.78	> 31.78

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

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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].

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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 [14]. 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 [38].

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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

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.

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

Land Quality/Land Characteristics	New Land Suitability Criterion of Hybrid Maize				Land Suitability Criterion of General Maize [68]			
	S1	S2	S3	N	S1	S2	S3	N
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	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	> 40
Surface rock (%)	0 – 4.45	4.46 – 13.09	13.10 – 31.78	> 31.78	< 5	5 – 15	15 – 40	> 40

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

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

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428 **References**

- 429 [1] K. Pawlak and M. Kołodziejczak, “The Role of Agriculture in Ensuring Food Security
430 in Developing Countries: Considerations in the Context of the Problem of Sustainable
431 Food Production,” *Sustainability*, vol. 12, no. 13, p. 5488, Jul. 2020, doi:
432 10.3390/su12135488.
- 433 [2] O. Erenstein, M. Jaleta, K. Sonder, K. Mottaleb, and B. M. Prasanna, “Global maize
434 production, consumption and trade: trends and R&D implications,” *Food Secur.* 2022,
435 pp. 1–25, May 2022, doi: 10.1007/S12571-022-01288-7.
- 436 [3] U. Grote, A. Fasse, T. T. Nguyen, and O. Erenstein, “Food Security and the Dynamics
437 of Wheat and Maize Value Chains in Africa and Asia,” *Front. Sustain. Food Syst.*, vol.
438 4, no. February, pp. 1–17, Feb. 2021, doi: 10.3389/fsufs.2020.617009.
- 439 [4] R. Wirosodarmo, A. T. Sutanhaji, and E. Kurniati, “Land Suitability Assessment Of
440 Corn (*Zea mays* L.) Using Spasial Analysis Method,” *agriTECH*, vol. 31, no. 1, pp.
441 71–78, 2012, doi: <https://doi.org/10.22146/agritech.9728>.
- 442 [5] B. Arifin, “High expectations on KSA maize production,” *Stat. Policy Br. Indones.*,
443 vol. 18, no. December, pp. 37–41, 2021, [Online]. Available:
444 <https://fmsindonesia.id/wp-content/uploads/2022/01/Buletin-17-FINAL.pdf>.
- 445 [6] Nurdin, M. L. Rayes, Soemarno, and Sudarto, “Analysis of Quality and Land
446 Characteristics That Control Local Maize Production in Gorontalo,” in *the*
447 *International Seminar on Promoting Local Resources for Sustainable Agriculture and*
448 *Development (ISPLRSAD 2020)*, 2021, vol. 13, no. Isplrsad 2020, pp. 438–446, doi:
449 10.2991/absr.k.210609.068.
- 450 [7] T. Kartika, “The Effect of Planting Distance on Growth and Production of Non Hybrid
451 Maize (*Zea Mays* L) in the Land of Integrated Technology Agro Center (ATP),”
452 *Sainmatika J. Ilm. Mat. dan Ilmu Pengetah. Alam*, vol. 15, no. 2, p. 129, Dec. 2018,
453 doi: 10.31851/sainmatika.v15i2.2378.
- 454 [8] Sutimawati, A. N. Aulia, and R. M. Muliastari, “Comparative Analysis of Hybrid Corn
455 Farming Based on Business Scale in Tempurejo Sub-District,” *J. Agribest*, vol. 3, no.
456 1, p. 61, Mar. 2019, doi: 10.32528/agribest.v3i1.1950.
- 457 [9] D. K. S. Swastika, “Corn Self-Sufficiency in Indonesia: The Past 30 years and Future
458 Prospects,” *J. Litbang Pertan.*, vol. 21, no. 3, pp. 75–83, 2002, [Online]. Available:
459 <https://agris.fao.org/agris-search/search.do?recordID=ID2005000155>.

- 460 [10] E. Kaya, A. Siregar, D. M. Y. Matulesy, and M. Hasan, "Growth and Yield of Corn
461 (Zea mays L.) due to The Granting of Sago Palm Waste Compost of Sago Palm Waste
462 Compost and Organic Liquid Fertilizer (OLF) in Ultisols," *J. Budid. Pertan.*, vol. 12,
463 no. 1, pp. 16–19, 2016, [Online]. Available:
464 <https://ojs3.unpatti.ac.id/index.php/bdp/article/view/42>.
- 465 [11] R. Yacoub, "Land Qualities as a Function to Estimate Land Productivity in the
466 Recently Reclaimed Calcareous Soils , Nubariya , Egypt .," *Egypt. J. Geosci.*, vol. 50,
467 no. 4, pp. 1–13, 2010, [Online]. Available:
468 https://www.researchgate.net/publication/327838295_Land_Qualities_as_a_Function_to_Estimate_Land_Productivity_in_the_Recently_Reclaimed_Calcareous_Soils_Nubariya_Egypt.
- 471 [12] M. Liyanda, A. Karim, and Y. Abubakar, "Analysis of Land Suitability Criteria for
472 Cocoa Production of Three Cluster Development in Pidie District," *Agrista*, vol. 16,
473 no. 2, pp. 62–79, 2012, [Online]. Available:
474 <http://jurnal.unsyiah.ac.id/agrista/article/view/289>.
- 475 [13] R. Neswati, S. Baja, and C. Lopulisa, "A modification of land suitability requirements
476 for maize in the humid tropics of South Sulawesi," *IOP Conf. Ser. Earth Environ. Sci.*,
477 vol. 921, no. 1, p. 012012, Nov. 2021, doi: 10.1088/1755-1315/921/1/012012.
- 478 [14] D. Subardja and Sudarsono, "The influence of Land Quality on Productivity of Maize
479 in Soils Derived from Volcanic and Sedimentary Rocks in the Bogor Area," *Soil Clim.*
480 *J.*, vol. 23, pp. 38–46, 2005, doi: <http://dx.doi.org/10.21082/jti.v0n23.2005.%25p>.
- 481 [15] G. O. Awe and T. P. Abegunrin, "Land Preparation Practices for Maize Production :
482 Short Term Effects on Some Hydro-Physical Properties of Analfisol and Crop
483 Performance," *Middle-East J. Sci. Res.*, vol. 25, no. 7, pp. 1420–1430, 2017, doi:
484 10.5829/idosi.mejsr.2017.1420.1430.
- 485 [16] J. Janků *et al.*, "An overview of a land evaluation in the context of ecosystem
486 services," *Soil Water Res.*, vol. 17, no. No. 1, pp. 1–14, Jan. 2022, doi:
487 10.17221/136/2021-SWR.
- 488 [17] D. Nadalia, A. Sutandi, and B. Nugroho, "Suitability criteria of land characteristics
489 related to Eucalyptus pellita production," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 694,
490 no. 1, p. 012053, Mar. 2021, doi: 10.1088/1755-1315/694/1/012053.
- 491 [18] N. Nurdin, F. Zakaria, M. A. Azis, Y. Rahim, R. Rahman, and M. Kasim,
492 "Comparison of land suitability class for endemic Coffea liberica Pinogu HP. acquired
493 using different methods and recommendations for land management in Pinogu Plateau,
494 Bone Bolango Regency, Indonesia," *SAINS TANAH - J. Soil Sci. Agroclimatol.*, vol.
495 19, no. 1, p. 42, May 2022, doi: 10.20961/stjssa.v19i1.56441.
- 496 [19] A. . Elisanti, W. Purnomo, and S. Melaniani, "Application of partial least square health
497 status of children under 5 years in indonesia," *J. Biometrika dan Kependud.*, vol. 2, no.
498 2, pp. 99–107, 2013, doi: 10.31227/osf.io/gtbq6.
- 499 [20] J.-M. Becker, C. M. Ringle, and M. Sarstedt, "Estimating Moderating Effects in PLS-
500 SEM and PLSC-SEM: Interaction Term Generation*Data Treatment," *J. Appl. Struct.*
501 *Equ. Model.*, vol. 2, no. 2, pp. 1–21, Jun. 2018, doi: 10.47263/JASEM.2(2)01.
- 502 [21] M. . Yim, "A Study on Factor Analytical Methods and Procedures for PLS-SEM
503 (Partial Least Squares Structural Equation Modeling)," *J. Ind. Distrib. Bus.*, vol. 10,
504 no. 5, pp. 7–20, 2019, doi: 10.13106/ijidb.2019.vol10.no5.7.
- 505 [22] R. Schlittgen, M. Sarstedt, and C. M. Ringle, "Data generation for composite-based

- 506 structural equation modeling methods,” *Adv. Data Anal. Classif.*, vol. 14, no. 4, pp.
507 747–757, 2020, doi: 10.1007/s11634-020-00396-6.
- 508 [23] S. Kono and M. Sato, “The potentials of partial least squares structural equation
509 modeling (PLS-SEM) in leisure research,” *J. Leis. Res.*, pp. 1–21, Jun. 2022, doi:
510 10.1080/00222216.2022.2066492.
- 511 [24] M. E. Civelek, “Comparison of Covariance-Based and Partial Least Square Structural
512 Equation Modeling Methods under Non-Normal Distribution and Small Sample Size
513 Limitations,” *Eurasian Econom. Stat. Emprical Econ. Journa*, vol. 10, no. 1, pp. 39–
514 50, 2018, doi: 10.17740/eas.stat.2018-V10-03.
- 515 [25] J. F. Hair, J. J. Risher, M. Sarstedt, and C. M. Ringle, “When to use and how to report
516 the results of PLS-SEM,” *Eur. Bus. Rev.*, vol. 31, no. 1, pp. 2–24, Jan. 2019, doi:
517 10.1108/EBR-11-2018-0203.
- 518 [26] J. F. Hair, C. M. Ringle, and M. Sarstedt, “Partial Least Squares Structural Equation
519 Modeling: Rigorous Applications, Better Results and Higher Acceptance,” *Long
520 Range Plann.*, vol. 46, no. 1–2, pp. 1–12, Feb. 2013, doi: 10.1016/j.lrp.2013.01.001.
- 521 [27] W. Reinartz, M. Haenlein, and J. Henseler, “An empirical comparison of the efficacy
522 of covariance-based and variance-based SEM,” *Int. J. Res. Mark.*, vol. 26, no. 4, pp.
523 332–344, Dec. 2009, doi: 10.1016/j.ijresmar.2009.08.001.
- 524 [28] H. Syaf, “The Relationship Evaluation Between Land Quality, Growth And Production
525 Of Advanced Age Cocoa In Kolaka East District, Southeast Sulawesi Province,”
526 *Bioedukasi*, vol. 3, no. 1, pp. 267–276, 2014, doi:
527 <http://dx.doi.org/10.33387/bioedu.v2i1.60>.
- 528 [29] Nurdin, M. L. Rayes, Soemarno, and Sudarto, “Study of Land Quality and Land
529 Characteristics that Determine the Productivity of Composite Maize Varieties in
530 Gorontalo,” *Syst. Rev. Pharm.*, vol. 11, no. 12, pp. 500–509, 2020, doi:
531 10.31838/srp.2020.12.81.
- 532 [30] R. Bhat and S. Sujatha, “stablishing leaf nutrient norms for arecanut by boundary line
533 approach,” *J. Plant Nutr.*, vol. 36, no. 6, pp. 849–862, Jan. 2013, doi:
534 10.1080/01904167.2013.770524.
- 535 [31] A. M. Ali, “Nutrient Sufficiency Ranges in Mango Using Boundary-Line Approach
536 and Compositional Nutrient Diagnosis Norms in El-Salhiya, Egypt,” *Commun. Soil
537 Sci. Plant Anal.*, vol. 49, no. 2, pp. 188–201, Jan. 2018, doi:
538 10.1080/00103624.2017.1421651.
- 539 [32] M. Ridayanti, M. L. Rayes, and C. Agustina, “Land Suitability Evaluation for Maize in
540 Dry Land Wagir District, Malang Regency,” *J. Tanah dan Sumberd. Lahan*, vol. 8, no.
541 1, pp. 149–160, Dec. 2020, doi: 10.21776/ub.jtsl.2021.008.1.18.
- 542 [33] S. Ritung, F. Lukman, and R. Purnanto, *Atlas Peta Tanah Semi Detail 1:50.000
543 Kabupaten Gorontalo Provinsi Gorontalo*, 2016th ed. Bogor: Badan Penelitian dan
544 Pengembangan Pertanian Kementerian Pertanian, 2016.
- 545 [34] Eviyati and Sulaeman, *Analysis of soil, chemical, plants, water, and fertilizer*. Bogor:
546 Indonesia Centre of Soil Research, 2009.
- 547 [35] K. K. Wong, “Partial Least Squares Structural Equation Modeling (PLS-SEM)
548 Techniques Using SmartPLS,” *Mark. Bull.*, vol. 24, no. 1, pp. 1–32, 2013, [Online].
549 Available: http://marketing-bulletin.massey.ac.nz/marketing_bulletin_articles.html#24.
- 550 [36] C. Fornell and D. F. Larcker, “Evaluating Structural Equation Models with

- 551 Unobservable Variables and Measurement Error;” *J. Mark. Res.*, vol. 18, no. 1, pp.
552 39–50, Nov. 1981, doi: 10.1177/002224378101800104.
- 553 [37] FAO, “A Framework for Innovation,” *FAO Soils Bull.*, vol. 32, no. 22, pp. 1–92, 1976,
554 doi: 10.1007/978-3-030-45139-4_4.
- 555 [38] Widiatmaka, A. Sutandi, A. Iswandi, U. Daras, M. Hikmat, and A. Krisnohadi,
556 “Establishing Land Suitability Criteria for Cashew (*Anacardium occidentale* L.) in
557 Indonesia,” *Appl. Environ. Soil Sci.*, vol. 2014, no. 743194, pp. 1–14, 2014, doi:
558 10.1155/2014/743194.
- 559 [39] R. . Darmawan, “Analysis of the Effect of Work-Family Conflict and Job Stress on the
560 Job Performance of Nurses at ‘X’ Hospital,” *Agora*, vol. 6, no. 2, pp. 1–6, 2018,
561 [Online]. Available: <https://www.neliti.com/id/publications/287084>.
- 562 [40] J. F. Hair, M. Sarstedt, C. M. Ringle, and J. A. Mena, “An assessment of the use of
563 partial least squares structural equation modeling in marketing research,” *J. Acad.*
564 *Mark. Sci.*, vol. 40, no. 3, pp. 414–433, 2012, doi: 10.1007/s11747-011-0261-6.
- 565 [41] R. P. Bagozzi and Y. Yi, “On the evaluation of structural equation models,” *J. Acad.*
566 *Mark. Sci.*, vol. 16, no. 1, pp. 74–94, Mar. 1988, doi: 10.1007/BF02723327.
- 567 [42] T. M. Basuki, D. R. Indrawati, and B. Haryadi, “The Use of Organic Matter to
568 Improve Productivity of Post Lime Mining Land,” *J. For. Nat. Conserv. Res.*, vol. 4,
569 no. 1, pp. 1–8, 2007, doi: 10.20886/jphka.2007.4.1.1-8.
- 570 [43] M. S. Alfian and H. Purnamawati, “Dose and Time of Potassium Fertilizer Application
571 on Growth and Sweet Corn Production at NATC Batangkaluku Gowa regency of
572 South Sulawesi,” *Bul. Agrohorti*, vol. 7, no. 1, pp. 8–15, 2019, doi:
573 10.29244/agrob.v7i1.24404.
- 574 [44] S. Nasreen, M. M. Haque, M. A. Hossain, and A. T. M. Farid, “Nutrient uptake and
575 yield of onion as influenced by nitrogen and sulphur fertilization,” *Bangladesh J.*
576 *Agric. Res.*, vol. 32, no. 3, pp. 413–420, Jan. 2008, doi: 10.3329/bjar.v32i3.543.
- 577 [45] Y. Abdissa, T. Tekalign, and L. M. Pant, “Growth, Bulb Yield and Quality of Onion
578 (*Allium cepa* L.) as Influenced by Nitrogen and Phosphorus Fertilization on Vertisol I.
579 Growth Attributes, Biomass Production and Bulb Yield,” *African J. Agric. Res.*, vol. 6,
580 no. 14, pp. 3252–3258, 2011, doi: 10.5897/AJAR10.1024.
- 581 [46] I. Firmansyah and N. Sumarni, “Effect of N Fertilizer Dosages and Varieties On Soil
582 pH, Soil Total-N, N Uptake, and Yield of Shallots (*Allium ascalonicum* L.) Varieties
583 On Entisols-Brebes Central Java,” *J. Hortik.*, vol. 23, no. 4, p. 358, May 2016, doi:
584 10.21082/jhort.v23n4.2013.p358-364.
- 585 [47] E. Sumiati and O. S. Gunawan, “Application of Mycorrhizal Biofertilizer to Increase
586 the Efficiency of NPK Uptake and its Effects on Yiled and Quality of Shallot Bulbs,”
587 *J. Hort*, vol. 17, no. 1, pp. 34–42, 2006, doi: 10.21082/jhort.v17n1.2007.p%p.
- 588 [48] H. R. McKenzie, “Potassium Fertilizer Application in Crop Production,” *Agri-Facts*,
589 vol. 542, no. 9, pp. 1–7, 2013, [Online]. Available:
590 <https://open.alberta.ca/publications/6060438>.
- 591 [49] M. Dianawati, “Rates and application time of K₂SO₄ on production of G₀ potato
592 seed,” *J. Kultiv.*, vol. 17, no. 1, pp. 531–536, 2018, [Online]. Available:
593 <http://jurnal.unpad.ac.id/kultivasi/article/viewFile/15499/7786>.
- 594 [50] N. Gunadi, “The Use of Potassium Sulphate as an Alternative Source of Potassium
595 Fertilizer in Potato,” *J. Hort*, vol. 17, no. 1, pp. 52–60, 2019, [Online]. Available:

- 596 <http://repository.pertanian.go.id/handle/123456789/7798>.
- 597 [51] I. S. Rahmawan, A. Z. Arifin, and Sulistyawati, “The effect of potassium (K) fertilizer
598 on growth and yield of cabbage (*Brassica oleraceae* var. *capitata*, L.),” *J.*
599 *Agroteknologi Merdeka Pasuruan*, vol. 3, no. 1, pp. 17–23, 2019.
- 600 [52] Subandi, “Role and Management of Potassium Nutrient for Food Production in
601 Indonesia,” *Agric. Innov. Dev.*, vol. 6, no. 1, pp. 1–10, 2013, [Online]. Available:
602 [https://www.neliti.com/publications/30881/role-and-management-of-potassium-](https://www.neliti.com/publications/30881/role-and-management-of-potassium-nutrient-for-food-production-in-indonesia)
603 [nutrient-for-food-production-in-indonesia](https://www.neliti.com/publications/30881/role-and-management-of-potassium-nutrient-for-food-production-in-indonesia).
- 604 [53] IIED, “Potash Case Study: Information supplied by the International Fertilizer Industry
605 Association,” *Mining, Miner. Sustain. Dev.*, vol. 65, no. February, p. 9, 2002, [Online].
606 Available: http://www.agritrade.org/documents/Biofuels_Subst_Web_Final.pdf.
- 607 [54] N. Nursjahbani, O. Rusdiana, and . D., “Suitability of *Durio zibethinus* Murr. and
608 *Nephelium lappaceum* L. on the Utilization Block at Menumbing Mountain Grand
609 Forest Park, West Bangka,” *J. Trop. Silv.*, vol. 9, no. 1, pp. 1–6, May 2018, doi:
610 10.29244/j-siltrop.9.1.1-6.
- 611 [55] I. W. Nyakudya and L. Stroosnijder, “Effect of rooting depth, plant density and
612 planting date on maize (*Zea mays* L.) yield and water use efficiency in semi-arid
613 Zimbabwe: Modelling with AquaCrop,” *Agric. Water Manag.*, vol. 146, pp. 280–296,
614 Dec. 2014, doi: 10.1016/j.agwat.2014.08.024.
- 615 [56] S. B. Wang *et al.*, “Effect of subsoiling depth on soil physical properties and summer
616 maize (*Zea mays* L.) yield,” *Plant, Soil Environ.*, vol. 65 (2019), no. No. 3, pp. 131–
617 137, Mar. 2019, doi: 10.17221/703/2018-PSE.
- 618 [57] H. Z. Khan, M. A. Malik, and M. F. Saleem, “Effect of rate and source of organic
619 material on the production potential of spring maize (*Zea mays* L.),” *Pak. J. Agri. Sci.*,
620 vol. 45, no. 1, pp. 40–43, 2008, [Online]. Available:
621 <https://pakjas.com.pk/papers/222.pdf>.
- 622 [58] A. Jalal, K. Azeem, M. C. M. T. Filho, and A. Khan, “Enhancing Soil Properties and
623 Maize Yield through Organic and Inorganic Nitrogen and Diazotrophic Bacteria,” in
624 *Sustainable Crop Production*, IntechOpen, 2020, pp. 1–14.
- 625 [59] E. E. Kandil, N. R. Abdelsalam, M. A. Mansour, H. M. Ali, and M. H. Siddiqui,
626 “Potentials of organic manure and potassium forms on maize (*Zea mays* L.) growth
627 and production,” *Sci. Rep.*, vol. 10, no. 1, p. 8752, Dec. 2020, doi: 10.1038/s41598-
628 020-65749-9.
- 629 [60] Mulyati, A. B. Baharuddin, and R. S. Tejowulan, “Improving Maize (*Zea mays* L.)
630 growth and yield by the application of inorganic and organic fertilizers plus,” *IOP*
631 *Conf. Ser. Earth Environ. Sci.*, vol. 712, no. 1, p. 012027, Mar. 2021, doi:
632 10.1088/1755-1315/712/1/012027.
- 633 [61] D. A. Kane, M. A. Bradford, E. Fuller, E. E. Oldfield, and S. A. Wood, “Soil organic
634 matter protects US maize yields and lowers crop insurance payouts under drought,”
635 *Environ. Res. Lett.*, vol. 16, no. 4, p. 044018, Apr. 2021, doi: 10.1088/1748-
636 9326/abe492.
- 637 [62] Mujiyo, W. Larasati, H. Widijanto, and A. Herawati, “The Effect of Slope Gradient of
638 land on the Soil Damage in Giritontro, Wonogiri,” *Agrotrop J. Agric. Sci.*, vol. 11,
639 no. 2, p. 115, 2021, doi: 10.24843/ajoas.2021.v11.i02.p02.
- 640 [63] D. O. Suparwata, Nurmi, and M. I. Bahua, “Using vertical mulch to upland for

- 641 reducing erosion, runoff and its responses to maize growth and yields,”
 642 *Agroteknotropika*, vol. 1, no. 3, pp. 138–145, 2012, doi: 10.31227/osf.io/5aek7.
- 643 [64] R. E. Christanto, Suryono, Mujiyo, and J. Winarno, “The Degree of Erosion Hazard
 644 Mapping in Dry Land at Jatipuro Sub District of Karanganyar with Geographic
 645 Information System (GIS,” *Sains Tanah - J. Soil Sci. Agroclimatol.*, vol. 7, no. 2, pp.
 646 114–119, 2013, doi: 10.15608/stjssa.v7i2.42.
- 647 [65] E. Elfayetti and H. Herdi, “Land Suitability Evaluation for Maize Crops in Saentis
 648 Village, Percut Sei Tuan,” *JUPIIS J. Pendidik. ILMU-ILMU Sos.*, vol. 7, no. 1, p. 33,
 649 Jul. 2015, doi: 10.24114/jupiis.v7i1.2295.
- 650 [66] Sukarman, A. Mulyani, and S. Purwanto, “The Modification of Land Evaluation
 651 Methods for Oriented Climate Change,” *J. Sumberd. Lahan*, vol. 12, no. 1, p. 1, Jun.
 652 2018, doi: 10.21082/jsdl.v12n1.2018.1-11.
- 653 [67] W. Chivasaa, O. Mutanga, and C. Biradarc, “Mapping land suitability for maize (*Zea*
 654 *mays L.*) production using GIS and AHP technique in Zimbabwe,” *South African J.*
 655 *Geomatics*, vol. 8, no. 2, pp. 265–281, Sep. 2022, doi: 10.4314/sajg.v8i2.11.
- 656 [68] Wahyunto, Hikmatullah, E. Suryani, C. Tafakresnanto, S. Ritung, A.
 657 Mulyani, Sukarman, K. Nugroho, Y. Sulaeman, Y. Apriyana, S. Suciantini, A.
 658 Pramudia, Suparto, R. E. Subandiono, T. Sutriadi, and D. Nursyamsi, *Technical*
 659 *Guidance Guidelines for Land Suitability Assessment for Strategic Agricultural*
 660 *Commodities Semi-Detailed Scale 1:50.000*. Bogor: Balai Besar Litbang Sumberdaya
 661 Lahan Pertanian, 2016.

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(24 Desember 2022)

Determination of Maize Hybrid Land Suitability Criteria Based on Optimum Yield and Selected Land Quality

UNDER REVIEW

ID 3800877

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— Response to Revision Request

Your Reply

Nurdin, Nurdin 24.12.2022

Dear Academic Editor Thank you in advance for correcting our journal articles, so that the deepening of the contents of our articles is even better. In response to the corrections that have been given, we have tried to improve as much as possible with the following description: In the introductory section, a discussion on maize development in Boalemo Regency (hybrid corn production achievement compared to local maize) has been added, the choice of research locations in this regency and the urgency of determining land suitability criteria for hybrid maize in Boalemo Regency by including some of the latest references (lines 43-63 of the revision article). In the methods section: - Lines 85-87 have been added citations/references - Soil map scale has been listed (nominal scale and bar scale). - Line 88 states that there are 35 land units, but in the legend Figure 1 there are 32 SMUs. Is there a relationship between the soil mapping carried out by Ritung et al. and the map in Figure 1? Why is the land mapping unit in Figure 1 not explained in paragraphs 83-91? It has been improved again, where the land mapping carried out by Ritung et al. (20016) as many as 35 land units became the initial reference for adding 32 new land units because the map scale changed from a scale of 1: 50,000 to a scale of 1: 40,000, so that the coverage of the land map was more detailed and the number of land units became 67 units. In addition, the land units have been described, both in terms of slope, relief, land use and soil types and their distribution in the study area. - Lines 95-110: It is better to explain each component/variable of soil characteristics at the beginning of the paragraph. In the next section, each variable is explained how to obtain the data. In this line, each component/variable of soil characteristic distance has been explained and continued with how to obtain the data. - Lines 97-99: Give reasons why it is necessary to update the available land characteristics and justification for determining the additional 32 points. Add sampling points (32 pedons) to the map. Explain how to collect climate data and place equipment/stations. In that line it has been corrected according to the correction. - Lines 112-113: these identifications must be shown on the map and indicate the points where the 2.5 x 2.5 m beams are placed. This line has been corrected and included in the map of the research location (sample points and tiled plots). - Lines 117, 119, 142, 143, etc.: each formula must be accompanied by a reference. This line has been fixed. - Lines 127-145, 175-184: please add a quote. This line has been fixed. - Lines 131: Table 1 should be completed with a column indicating secondary data sources for each land characteristic or method of obtaining data in the field (as a summary of updated lines 95-110). This line has been fixed. - Lines 397-401: It should be noted that the results of this study are of limited use for the development of hybrid corn in Boalemo, because the arrangement is only based on the characteristics of the land and optimum yields in Boalemo Regency (not representing the national scale). On the line has been fixed. Thus the improvement of the manuscript from us, hopefully we will get a good response for publication Regards Nurdin

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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
14 existing land suitability criteria. Therefore, this study aims to determine the hybrid maize land
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,
23 slopes, soil erosion, rock outcrops, and surface rocks. Furthermore, the highest optimum yield
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**

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

35 In Indonesia, the wet tropical climate with rainfall and high temperatures tends to reduce the
36 quality of land and agricultural products [4]. This country ranked 8th among the maize-
37 producing nations with a contribution of 2.19% and 2.42% of the world's total harvested area
38 [5]. However, the main problem is the relatively low level of yield in several regions because
39 the achievement of maize production has not been followed by an increase in yield per unit
40 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 In Indonesia, Gorontalo Province is one of the centers of maize production, where the hybrid
44 type is the most widely grown species [9]. The maize production in the province reached 1.8
45 million tons in 2021 [10], with several export advantages and competitiveness [11].
46 Furthermore, the planting of hybrid, composite, and local maize types has reached more than
47 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
66 maize in a region to ensure optimal production. The land suitability criteria for hybrid maize
67 are not yet available because the current criterion is the general suitability of maize plants
68 without distinguishing between hybrids and inbreds. Therefore, there is a need to make land
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

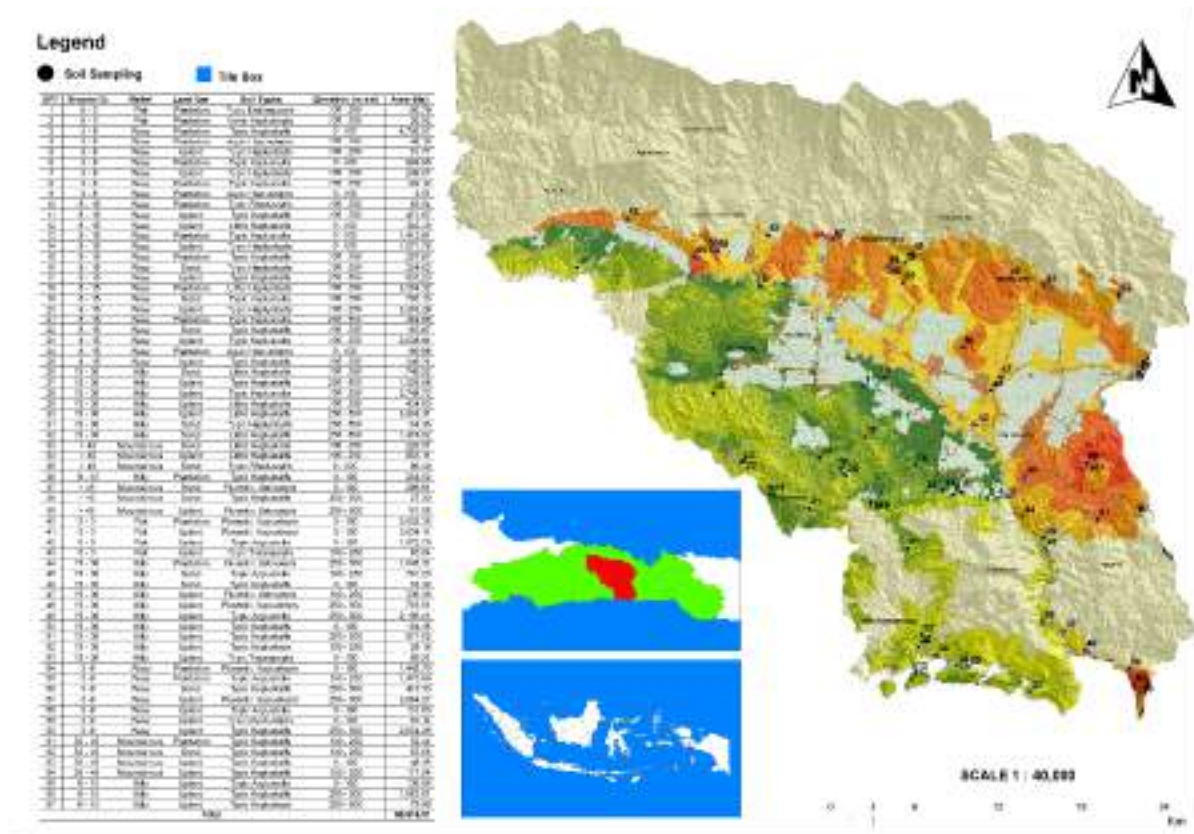
86 relatively small ranging from 30 to 100 [36]–[39]. The use of PLS-SEM to determine land
87 characteristics and qualities that control maize crop yields is still relatively rare, except for Syaf
88 [40] on older cocoa plants, maize composite [41], and on local varieties [6]. The boundary line
89 method can help determine nutrient adequacy concentrations and the optimum yield range of
90 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
97 determine land suitability criteria for hybrid maize based on the optimum yield and land
98 quality.

99 2. Materials and Methods

100 2.1 Study area

101 The study area extends from 0°28'5.6" - 0°57'30.02" N to 122°08'34.25" - 122°43'10.41"E
102 (Figure 1) on a scale of 1 : 65,000, 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 minimum was 26.79°C with an average of 28.01°C. Meanwhile, the maximum rainfall was
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
107 Ritung et al. [46] become the initial reference for determining 35 soil units, where each unit
108 has information on land characteristics, namely effective depth, drainage, texture, pH, cation
109 exchange capacity, base saturation, landform, parent material, relief, and land unit area. This
110 unit was detailed by adding 32 soil units to be surveyed and observed, making up to 67 soil
111 units in the area as shown in the legend Figure 1. The detailing was carried out because the soil
112 unit was previously presented at a scale of 1: 50,000, without including several key areas.
113 Meanwhile, the new soil unit is 1: 40,000 in scale and there has been a change in the agricultural
114 land use existing. This indicated that the slope class of 8 – 15% or hilly is more dominant in
115 the study area with a percentage of 29.77% and slopes > 40% or mountainous which is only
116 2.67%. Furthermore, the dry land is dominant with a value of 59.86% and a little shrub which
117 was only 9.21%, while the dominant Inceptisol soil type was 36.18% and very little Ultisol soil
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
 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
 128 material, and soil effective depth, nutrient retention is identified from the pH value, C-Organic,
 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
 132 slopes and soil erosion. The quality of the flood-hazard land is determined by identifying the
 133 height and the duration of the inundation, while preparation is carried out from the
 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].

136 Data on average annual air temperature and rainfall for 10 years (2010-2021) were collected
 137 from different climate stations, namely the Bandungrejo with 0°41' N - 122°38' E, the elevation
 138 40 m asl, while Harapan has 0°42' N - 122°29' E and an elevation of 37 m asl. It also includes
 139 Lakeya Rain Post with 0°42.82' N - 122°32.07' E, 32 m asl, Mohiyolo has 0°46.41' N -
 140 122°26.41' E and an elevation of 39 m asl, Saritani 0°46.45' N - 122°20.40' E, with 26 m asl,
 141 Tangkobu 0°37.25' N - 122°36.36' E, 25 m asl, Bubaa 0°31.36' N - 122°33.39' E, 16 m asl,
 142 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
144 determined wet months (> 200 mm) and dry months (<100 mm), which refers to the Oldeman
145 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].

147 Soil characteristics such as drainage, coarse material, effective soil depth, slope, inundation
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
150 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
155 using the pipette method, while soil moisture storage was evaluated using the gravimetric
156 method that can be applied in water balance analysis. The method of soil chemistry laboratory
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
161 basic cations and CEC was extracted with 1N NH₄OAc pH 7.0 (ammonium acetate) on a dry
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
164 [54] [55]. Subsequently, the data from the chemical analysis were averaged to a depth of 0-30
165 cm using the weighted averaging technique. The framework of this study is presented in Figure
166 2.

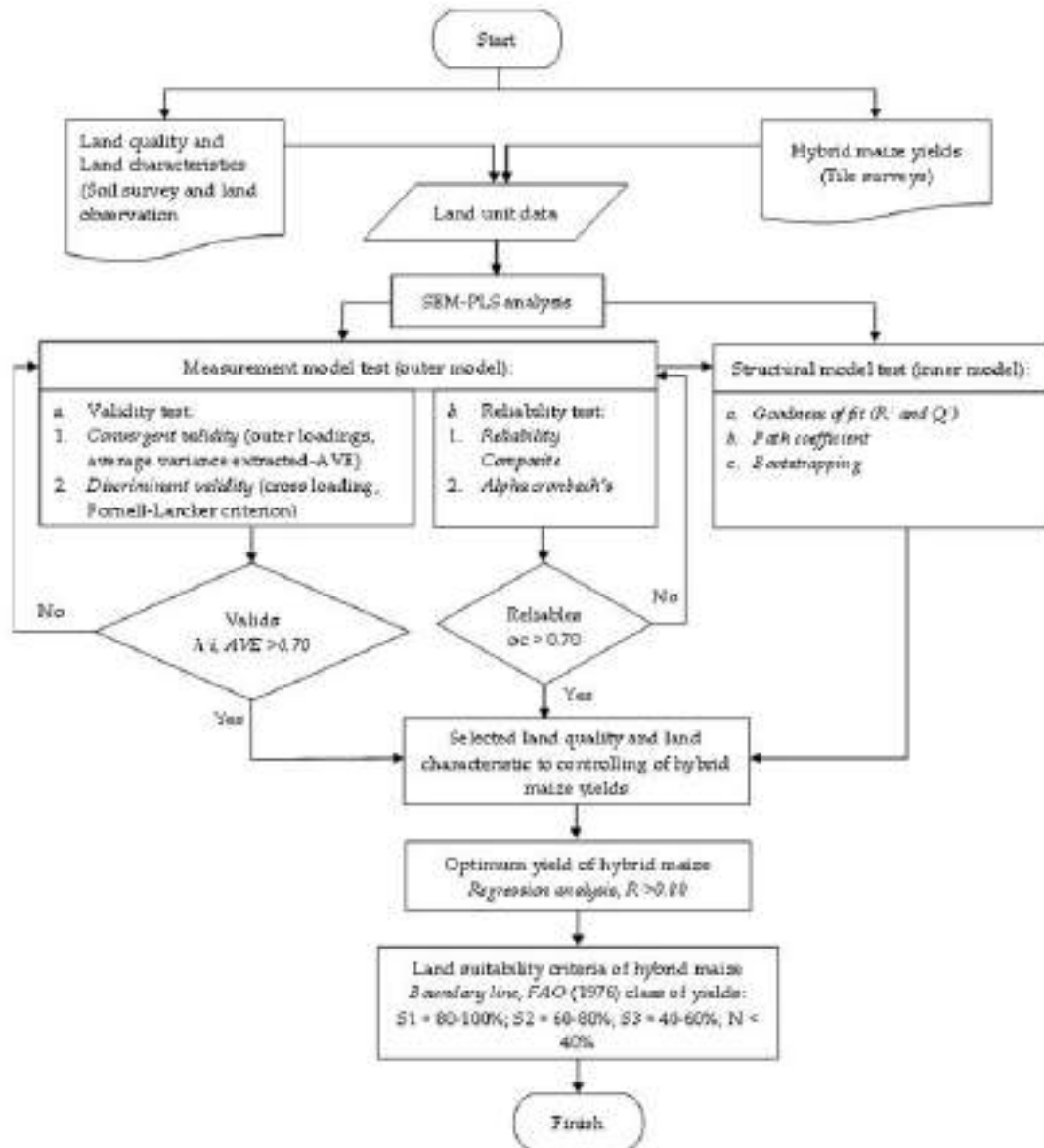


Figure 2: Research framework.

167
168169 **2.3 Dataset collection for hybrid maize yield**

170 The areas currently planted with hybrid maize were identified and blocks with a size of 2.5 m
 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
 173 carried out to obtain hybrid maize yield data from the results of tiles on each land unit.
 174 Subsequently, the results were calculated using the formula [56], as expressed below:

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

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

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

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
 184 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
 186 and characteristics were selected as the latent and manifest variables, respectively. The analysis
 187 in PLS-SEM has 2 main steps, namely (1) the measurement model (outer model) and (2) the
 188 structural model test (inner model).

189 **Table 1: Latent variables and indicators used in this study**

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

190

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.

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

$$199 \quad x_i = \lambda x_i \xi_l + \delta_i \quad (3)$$

$$200 \quad y_i = \lambda y_i \eta_l + \varepsilon_i \quad (4)$$

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

203 **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	1.06
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)								
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	

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

206 Meanwhile, the average variance extracted (AVE) value was calculated using the equation
207 [61][62][63][64][65]:

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

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

210 The loading factor of an indicator with the highest value is the strongest or most important
211 measure in reflecting the latent variable. In this study, the loading factor value is > 0.70 for
212 selecting best land characteristics, but values ranging from 0.50-0.60 can still be tolerated with
213 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]:

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

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

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

$$229 \rho_c = \frac{(\sum \lambda_i)^2}{(\sum \lambda_i)^2 + \sum i \text{ var}(\varepsilon_i)} \quad (7)$$

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]:

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

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]:

$$H_j = \gamma_j \zeta_1 + \gamma_j \zeta_2 + \dots \gamma_j \zeta_n + \zeta_j \quad (9)$$

where η_j = endogenous variable vector (dependent), $\gamma_j \zeta_1 + \gamma_j \zeta_2 + \dots \gamma_j \zeta_n$ = exogenous latent variable vector, and ζ_j = residual vector (error).

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

$$Q^2 \text{ (Predictive relevance)} = 1 - (1 - R_1^2) (1 - R_2^2) \dots (1 - R_p^2) \quad (10)$$

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, (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 data points from each class interval, (5) draw a line parallel to the X-axis according to the percentage of the result class.

268 Furthermore, with the Microsoft Excel application tools, the boundary between classes S1 to
 269 S2, S2 to S3, and S3 to N were determined by the Data menu → What-if-Analysis → Goal
 270 Seek → Set the cell at the location containing the regression equation → to value fill with the
 271 result limit values S1 to S2, S2 to S3, and S3 to N → By changing cell → the location where
 272 the value of the characteristics of the land will be sought → Ok. On location "By changing
 273 cell", the number being searched will appear, and at the location "set cell" will be equal to the
 274 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
 280 highly recommended and the indicators are considered convergently valid. In the soil texture
 281 indicator for the latent variable of root conditions as well as the cation exchange capacity (CEC)
 282 and base saturation (BS) indicators for nutrient retention, the loading factor was below the
 283 tolerance value of 0.50 at the 95% confidence level ($P < 1.960$), hence, it was not used. This
 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].

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

292 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) →	X1 (Temperature)	1.000**	11.192	Valid	1.000
X2.1 (Rainfall) →	X2 (Water availability)	0.838	0.085	Valid	0.906
X2.2 (Wet month) →		0.989	0.999	Valid	
X2.3 (Dry month) →		0.850	0.428	Valid	
X2.4 (LGP) →		0.993*	1.431	Valid	
X3.1 (Drainage) →	X3 (Oxygen availability)	1.000	0.000	Valid	1.000
X4.1 (Texture) →	X4 (Rooting condition)	0.013	0.066	Invalid	0.573
X4.2 (Coarse material) →		0.921	1.086	Valid	
X4.3 (Effective depth) →		-0.899	1.047	Valid	
X5.1 (pH H ₂ O) →	X5 (Nutrient retention)	0.647	0.857	Valid	0.360 (invalid)
X5.2 (pH KCl) →		0.570**	1.973	Valid	
X5.3 (Organic C) →		0.831**	3.135	Valid	

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

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

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

302 3.1.2 Reliability test result

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

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

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

316

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

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

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Table 5: Cross-Loading of latent variables to indicators

Indicators	Latent Variables										
	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

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

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

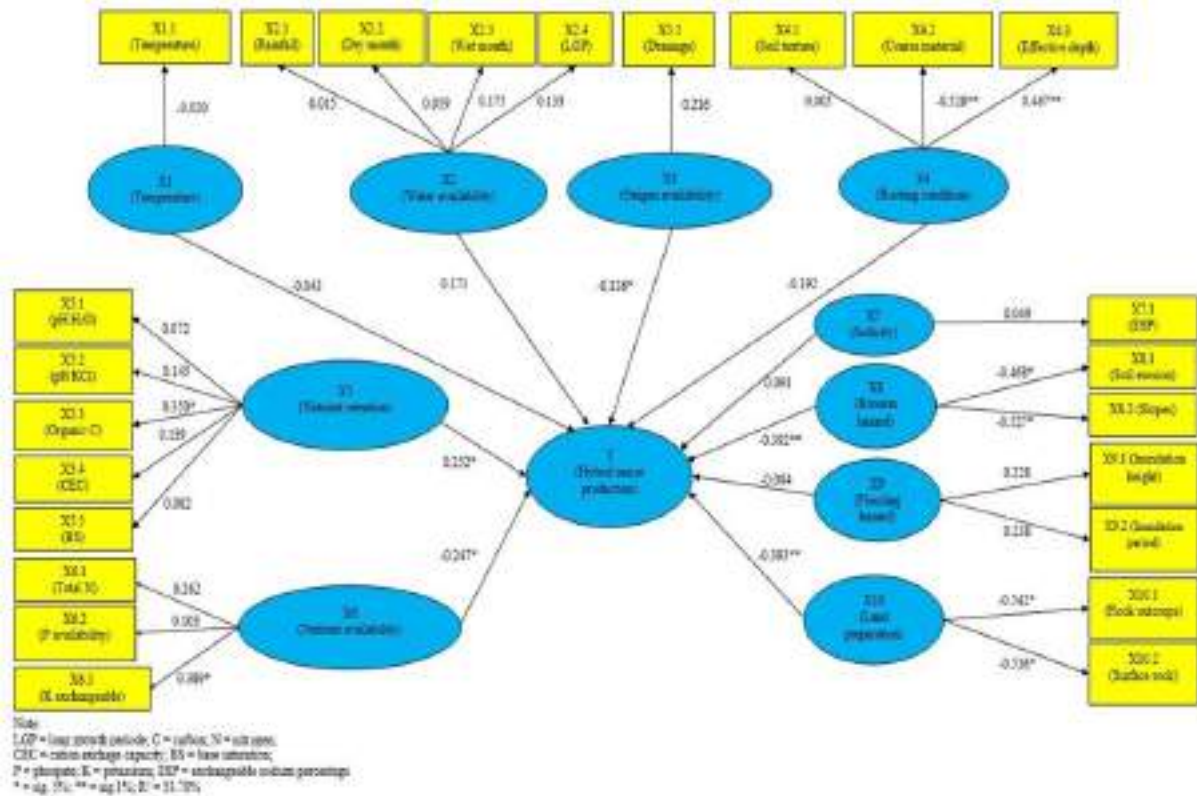
Indicators (land characteristics)	Cronbach's Alpha	Composite Reliability
X1.1 (Temperature)	1.000	1.000
X2.1 (Rainfall)		
X2.2 (Wet month)	0.975	0.965
X2.3 (Dry month)		
X2.4 (Long growth periods)		
X3.1 (Drainage)	1.000	1.000
X4.1 (Texture)		
X4.2 (Coarse material)	0.002 ^{nor}	-1.055 ^{nor}
X4.3 (Effective 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)		
X9.1 (Inundation height)	0.992	0.984
X9.2 (Inundation period)		
X10.1 (Rock outcrops)	0.998	0.995
X10.2 (Surface rock)		

334 nor = not reliable.

335 *3.1.3 Structural model test (inner models)*

336 Land characteristics that have a significant correlation with hybrid maize yields show a high
337 level of contribution to land quality in influencing hybrid maize yields as indicated in Figure
338 3. The figure shows a structural model of the relationship between indicator variables, namely
339 24 land characteristics, rectangular yellow, and latent variables, including 10 land qualities
340 maize yield, and oval blue. It also shows a model for the relationship between latent variables
341 such as land qualities and maize yield as well as loading figures. The factor for each indicator
342 and path coefficient for land qualities has a direct effect on the value of maize yields.

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



349

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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 (X10). 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
 357 well as rock outcrop and surface rock as an indicator of land preparation. It was also indicated
 358 that the drainage loading factor was unable to explain the diversity of oxygen availability.
 359 Therefore, oxygen availability cannot be used as a land quality because there are no indicators
 360 that can represent it. Only the land qualities of nutrient retention (X5), nutrient availability
 361 (x6), erosion hazard (x8), and land preparation (X10) were used next.

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

369 Indicators of rough soil characteristics, slopes, soil erosion, as well as surface and rock outcrops
 370 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
 372 outcrop is followed by an increase in hybrid maize yields by 39% to 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.

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

Land Quality/Land Characteristics	Optimum Yield (ton/ha)	Yield Equation	R ²
Rooting condition (rc)			
Coarse material	8.06	$Y = 0.0024800x^2 - 0.2457487x + 10.9082465$	0.95
Effective depth	8.35	$Y = -0.0007242x^2 + 0.1890458x - 1.2946385$	0.96
Nutrient retention (nr)			
Organic carbon	8.35	$Y = -24.3891969x^2 + 46.8464078X - 8.8894056$	0.87
Nutrient availability (na)			
Total N	8.43	$Y = -304.4463543X^2 + 144.7590906X - 2.6328530$	1.00
K Exchangeable	5.74	$Y = -10.5596308X^2 + 17.4129832X + 2.2069179$	0.94
Erosion hazard (eh)			
Slopes	8.43	$Y = 0.0172X^2 - 0.8448X + 13.907$	0.91
Soil erosion	8.06	$y = 0.0000173X^2 - 0.0187536X + 9.0426459$	0.88
Land preparation (lp)			
Rock outcrops	7.30	$Y = 0.0046385X^2 - 0.2934756X + 8.5159674$	0.91
Surface rock	7.30	$Y = 0.0046385X^2 - 0.2934756X + 8.5159674$	0.91

380

The optimum of hybrid maize yield ranged from 5.74 to 8.43 ton/ha, where the highest yield was obtained from total N and slopes of 8.43 ton/ha with an R² value of 100% and 91%. 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 [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 5.74 ton/ha with an R² value of 94%. 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

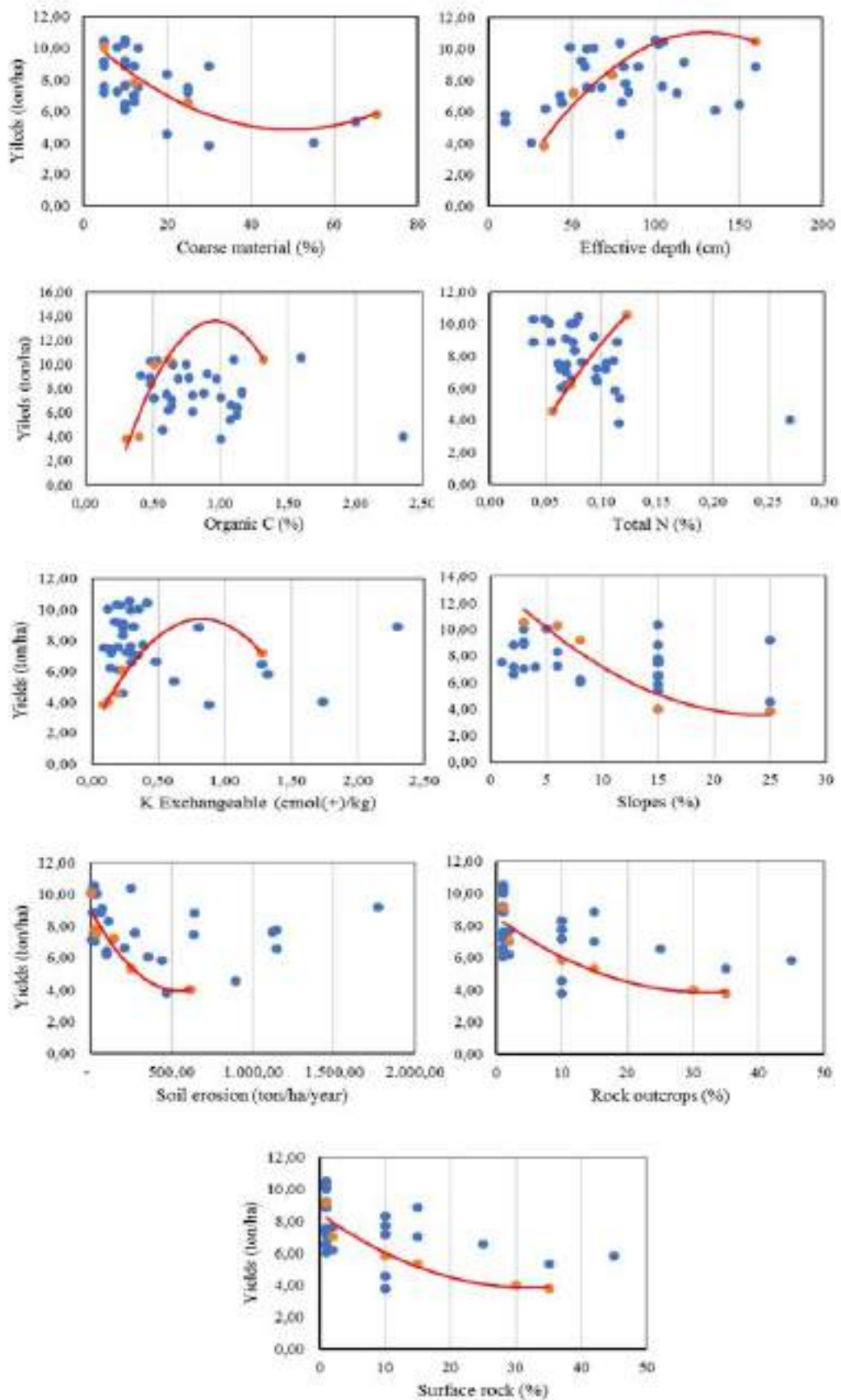
395 water use, N uptake, protein synthesis, and assimilate translocation [83]–[86]. It also plays a
396 role in improving the quality of crop yields (McKenzie, 2013, Subandi, 2013).

397 The optimum hybrid maize yield of the remaining is relatively diverse. This includes effective
398 depth and organic carbon, which were both 8.35 ton/ha with an R^2 value of 87%. Furthermore,
399 coarse material and soil erosion were 8.06 ton/ha with an R^2 value of 95% and 88%, while rock
400 outcrops and surface rock were 7.30 ton/ha with an R^2 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
404 content [95] because soil organic matter is a strong positive predictor of yield [96]. Kane et al.
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
407 degradation [97]. According to a previous study, erosion and maize yield are negatively
408 correlated, hence, increased erosion will reduce maize productivity [98]. Soil erosion on flat
409 land is slower surface runoff [99]. It was also reported that surface rocks and outcrops are the
410 limiting factors in the suitability of maize plantations [100]. Therefore, a high percentage of
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
416 indicator with a very suitable class (S1) was achieved when the value in the soil was greater
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,
421 it was obtained when the slope class ranges from 0-7.69%, while class S2 was achieved when
422 the slope class ranges from 7.70-11.83%. Furthermore, in classes S3 and N, it was obtained
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
425 indicator. In classes S1 and S2, it was achieved when the exchangeable K content in the soil
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
431 obtained as presented in Table 8.



432

433

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

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

Land Quality/Land Characteristics	Yield Limits (ton/ha)			Value of Land Suitability Criterion Obtained			
	S1 - S2 (80% x Y _{optim})	S2 - S3 (60% x Y _{optim})	S3 - N (40% x Y _{optim})	S1	S2	S3	N
Rooting condition (rc)							
Coarse material (%)	8.06	6.04	4.03	0 – 13.40	13.41 – 27.37	27.38 – 52.39	> 52.39
Effective depth (cm)	8.35	6.26	4.18	≥ 69.55	49.25 – 69.54	33.18 – 49.24	< 33.18
Nutrient retention (nr)							
Organic carbon (%)	8.35	6.26	4.18	≥ 0.50	0.41 – 0.49	0.34 – 0.40	< 0.34
Nutrient availability (na)							
Total N (%)	8.43	6.32	4.22	≥ 0.10	0.07 – 0.09	0.05 – 0.06	< 0.05
K Exchangeable (cmol(+)/kg)	5.74	4.31	2.87	≥ 0.24	0.13 – 0.23	0.04 – 0.12	< 0.04
Erosion hazard (eh)							
Slopes (%)	8.43	6.32	4.22	0 – 7.69	7.70 – 11.83	11.84 – 18.24	> 18.24
Soil erosion (ton/ha/year)	8.06	6.04	4.03	≤ 55.21	195.29	605.56	> 605.56
Land preparation (lp)							
Rock outcrops (%)	7.30	5.47	3.85	0 – 4.45	4.46 – 13.09	13.10 – 31.78	> 31.78
Surface rock (%)	7.30	5.47	3.85	0 – 4.45	4.46 – 13.09	13.10 – 31.78	> 31.78

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
 445 optimum yield. Meanwhile, the land quality and characteristics in this new criterion are less
 446 because it only consists of root conditions with characteristics of coarse material and effective
 447 depth, nutrient retention with organic C, and nutrient availability with total N and K
 448 exchangeable. It also consists of erosion hazards with characteristics of slopes and soil erosion,
 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
 451 suitability criteria. This will reduce the land characteristics and make the evaluation process
 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.

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

Land Quality/Land Characteristics	New Land Suitability Criterion of Hybrid Maize				Land Suitability Criterion of General Maize [47]			
	S1	S2	S3	N	S1	S2	S3	N
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	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	> 40
Surface rock (%)	0 – 4.45	4.46 – 13.09	13.10 – 31.78	> 31.78	< 5	5 – 15	15 – 40	> 40

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
 471 conditions, nutrient retention, available nutrients, erosion hazard, as well as land preparation,
 472 and land characteristics, including coarse material, effective depth, organic C, total N,
 473 exchangeable K, slopes, soil erosion, rock outcrops, and surface rocks. The highest optimum
 474 yield of 8.35 ton/ha was achieved by the effective depth and organic C content for a very
 475 suitable class (S1), while the lowest value of 5.47 ton/ha was attained by exchangeable K for
 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
 478 based on optimum yields and selected land quality.

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.

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492 **References**

- 493 [1] K. Pawlak and M. Kołodziejczak, “The Role of Agriculture in Ensuring Food Security
494 in Developing Countries: Considerations in the Context of the Problem of Sustainable
495 Food Production,” *Sustainability*, vol. 12, no. 13, p. 5488, Jul. 2020, doi:
496 10.3390/su12135488.
- 497 [2] O. Erenstein, M. Jaleta, K. Sonder, K. Mottaleb, and B. M. Prasanna, “Global maize
498 production, consumption and trade: trends and R&D implications,” *Food Secur.* 2022,
499 pp. 1–25, May 2022, doi: 10.1007/S12571-022-01288-7.
- 500 [3] U. Grote, A. Fasse, T. T. Nguyen, and O. Erenstein, “Food Security and the Dynamics
501 of Wheat and Maize Value Chains in Africa and Asia,” *Front. Sustain. Food Syst.*, vol.
502 4, no. February, pp. 1–17, Feb. 2021, doi: 10.3389/fsufs.2020.617009.
- 503 [4] R. Wirosoedarmo, A. T. Sutanahaji, and E. Kurniati, “Land Suitability Assessment Of
504 Corn (*Zea mays* L.) Using Spasial Analysis Method,” *agriTECH*, vol. 31, no. 1, pp.
505 71–78, 2012, doi: <https://doi.org/10.22146/agritech.9728>.
- 506 [5] B. Arifin, “High expectations on KSA maize production,” *Stat. Policy Br. Indones.*,
507 vol. 18, no. December, pp. 37–41, 2021, [Online]. Available:
508 <https://fmsindonesia.id/wp-content/uploads/2022/01/Buletin-17-FINAL.pdf>.
- 509 [6] Nurdin, M. L. Rayes, Soemarno, and Sudarto, “Analysis of Quality and Land
510 Characteristics That Control Local Maize Production in Gorontalo,” in *the*
511 *International Seminar on Promoting Local Resources for Sustainable Agriculture and*
512 *Development (ISPLRSAD 2020)*, 2021, vol. 13, no. Isplrsad 2020, pp. 438–446, doi:
513 10.2991/absr.k.210609.068.
- 514 [7] T. Kartika, “The Effect of Planting Distance on Growth and Production of Non Hybrid
515 Maize (*Zea Mays* L) in the Land of Integrated Technology Agro Center (ATP),”
516 *Sainmatika J. Ilm. Mat. dan Ilmu Pengetah. Alam*, vol. 15, no. 2, p. 129, Dec. 2018,
517 doi: 10.31851/sainmatika.v15i2.2378.
- 518 [8] Sutimawati, A. N. Aulia, and R. M. Muliasari, “Comparative Analysis of Hybrid Corn
519 Farming Based on Business Scale in Tempurejo Sub-District,” *J. Agribest*, vol. 3, no.
520 1, p. 61, Mar. 2019, doi: 10.32528/agribest.v3i1.1950.

- 521 [9] I. S. Anugrah, "Corn-Based Agribusiness for Rural Economic Development in
522 Gorontalo Province," *Anal. Kebijak. Pertan.*, vol. 8, no. 4, pp. 363–383, 2016,
523 [Online]. Available: <http://ejurnal.litbang.pertanian.go.id/index.php/akp/index>.
- 524 [10] H. Limanseto, "The Government Encourages Productivity of the Leading
525 Commodities of Gorontalo Province to Increase People's Welfare," *Coordinating
526 Ministry for Economic Affairs of the Republic of Indonesia*, vol. 1. Coordinating
527 Ministry for Economic Affairs of the Republic of Indonesia, Jakarta, pp. 1–2, 2021.
- 528 [11] N. Endey, I. K. S. Arsana, A. Y. Katili, A. Sahabi, and M. A. Talalu, "Competitiveness
529 Analysis of Gorontalo's Leading Commodities in Supporting the New Capital City of
530 the Republic of Indonesia," *Equilib. J. Pendidik.*, vol. 10, no. 3, pp. 380–396, 2022,
531 doi: 10.26618/equilibrium.v10i3.8571.
- 532 [12] K. Astuti, R. O. Prasetyo, and N. . Khasanah, *Analysis of Maize and Soybean
533 Productivity in Indonesia 2020 (the Result of Crop Cutting Survey)*, vol. 05100.2103,
534 no. 5203029. BPS RI, 2021.
- 535 [13] BPS-Statistic of Gorontalo, "Gorontalo Province In Figures 2018," *BPS-Statistic of
536 Gorontalo*, vol. 75560.1811, no. 1102001.75. pp. 1–390, 2018.
- 537 [14] W. Ardiansyah, M. A. Indrianti, M. M. Djibran, and D. R. Hippy, "The Performance
538 of Dry Land Farming for Transmigrate Farmers (Case Study in Saritani Village,
539 Wonosari Sub-District, Boalemo Regency)," *J. Agriovet*, vol. 4, no. 2, pp. 125–142,
540 Apr. 2022, doi: 10.51158/agriovet.v4i2.726.
- 541 [15] A. H. Samon, "The Analysis of Comparative and Competitive Superiority of Corn
542 Farm Enterprises in Boalemo Regency," Hasanuddin University, 2005.
- 543 [16] A. M. D. Putri and Mustofiq, *Boalemo Regency in Figures 2022*, vol. 75010.2201, no.
544 1102001.7501. BPS-Statistics of Boalemo Regency, 2022.
- 545 [17] W. Tialo, M. Arief Azis, and N. Nurdin, "Gorontalo local waxy maize growth and
546 production, agronomic, and economic effectiveness with organic fertilizer treatment in
547 Bualo, Boalemo Regency," *J. Agercolere*, vol. 4, no. 2, pp. 44–53, 2022, doi:
548 10.37195/jac.v4i2.168.
- 549 [18] K. P. W. Sukma, "Growth and Production of Local Maize, Hybrid and Composite in
550 Pamekasan, Madura," *J. Agrosains Karya Kreat. dan Inov.*, vol. 4, no. 2, p. 34, May
551 2018, doi: 10.31102/agrosains.2017.4.2.34-38.
- 552 [19] Bapelitbang Boalemo Regency, "Local Government Work Plan for 2022," *Boalemo
553 Regent Regulation Number 49 of 2020*, vol. 49. 2021.
- 554 [20] A. K. Lasiki, Nurdin, and I. Husain, "Growth and Yield of Hybrid Corn in Several
555 Classes of Slopes and Fertilization Doses in Bumela Village, District Of Gorontalo," *J.
556 Agroteknotropika*, vol. 10, no. 2, pp. 59–69, 2021, [Online]. Available:
557 <https://ejurnal.ung.ac.id/index.php/JATT/article/view/13459>.
- 558 [21] D. K. S. Swastika, "Corn Self-Sufficiency in Indonesia: The Past 30 years and Future
559 Prospects," *J. Litbang Pertan.*, vol. 21, no. 3, pp. 75–83, 2002, [Online]. Available:
560 <https://agris.fao.org/agris-search/search.do?recordID=ID2005000155>.
- 561 [22] E. Kaya, A. Siregar, D. M. Y. Matulesy, and M. Hasan, "Growth and Yield of Corn
562 (*Zea mays* L.) due to The Granting of Sago Palm Waste Compost of Sago Palm Waste
563 Compost and Organic Liquid Fertilizer (OLF) in Ultisols," *J. Budid. Pertan.*, vol. 12,
564 no. 1, pp. 16–19, 2016, [Online]. Available:
565 <https://ojs3.unpatti.ac.id/index.php/bdp/article/view/42>.

- 566 [23] R. Yacoub, “Land Qualities as a Function to Estimate Land Productivity in the
567 Recently Reclaimed Calcareous Soils , Nubariya , Egypt .,” *Egypt. J. Geosci.*, vol. 50,
568 no. 4, pp. 1–13, 2010, [Online]. Available:
569 [https://www.researchgate.net/publication/327838295_Land_Qualities_as_a_Function_](https://www.researchgate.net/publication/327838295_Land_Qualities_as_a_Function_to_Estimate_Land_Productivity_in_the_Recently_Reclaimed_Calcareous_Soils_Nubariya_Egypt)
570 [to_Estimate_Land_Productivity_in_the_Recently_Reclaimed_Calcareous_Soils_Nuba](https://www.researchgate.net/publication/327838295_Land_Qualities_as_a_Function_to_Estimate_Land_Productivity_in_the_Recently_Reclaimed_Calcareous_Soils_Nubariya_Egypt)
571 [riya_Egypt](https://www.researchgate.net/publication/327838295_Land_Qualities_as_a_Function_to_Estimate_Land_Productivity_in_the_Recently_Reclaimed_Calcareous_Soils_Nubariya_Egypt).
- 572 [24] M. Liyanda, A. Karim, and Y. Abubakar, “Analysis of Land Suitability Criteria for
573 Cocoa Production of Three Cluster Development in Pidie District,” *Agrista*, vol. 16,
574 no. 2, pp. 62–79, 2012, [Online]. Available:
575 <http://jurnal.unsyiah.ac.id/agrista/article/view/289>.
- 576 [25] R. Neswati, S. Baja, and C. Lopulisa, “A modification of land suitability requirements
577 for maize in the humid tropics of South Sulawesi,” *IOP Conf. Ser. Earth Environ. Sci.*,
578 vol. 921, no. 1, p. 012012, Nov. 2021, doi: 10.1088/1755-1315/921/1/012012.
- 579 [26] D. Subardja and Sudarsono, “The influence of Land Quality on Productivity of Maize
580 in Soils Derived from Volcanic and Sedimentary Rocks in the Bogor Area,” *Soil Clim.*
581 *J.*, vol. 23, pp. 38–46, 2005, doi: <http://dx.doi.org/10.21082/jti.v0n23.2005.%25p>.
- 582 [27] G. O. Awe and T. P. Abegunrin, “Land Preparation Practices for Maize Production :
583 Short Term Effects on Some Hydro-Physical Properties of Analfisol and Crop
584 Performance,” *Middle-East J. Sci. Res.*, vol. 25, no. 7, pp. 1420–1430, 2017, doi:
585 10.5829/idosi.mejsr.2017.1420.1430.
- 586 [28] J. Janků *et al.*, “An overview of a land evaluation in the context of ecosystem
587 services,” *Soil Water Res.*, vol. 17, no. No. 1, pp. 1–14, Jan. 2022, doi:
588 10.17221/136/2021-SWR.
- 589 [29] D. Nadalia, A. Sutandi, and B. Nugroho, “Suitability criteria of land characteristics
590 related to Eucalyptus pellita production,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 694,
591 no. 1, p. 012053, Mar. 2021, doi: 10.1088/1755-1315/694/1/012053.
- 592 [30] N. Nurdin, F. Zakaria, M. A. Azis, Y. Rahim, R. Rahman, and M. Kasim,
593 “Comparison of land suitability class for endemic Coffea liberica Pinogu HP. acquired
594 using different methods and recommendations for land management in Pinogu Plateau,
595 Bone Bolango Regency, Indonesia,” *SAINS TANAH - J. Soil Sci. Agroclimatol.*, vol.
596 19, no. 1, p. 42, May 2022, doi: 10.20961/stjssa.v19i1.56441.
- 597 [31] A. . Elisanti, W. Purnomo, and S. Melaniani, “Application of partial least square health
598 status of children under 5 years in indonesia,” *J. Biometrika dan Kependud.*, vol. 2, no.
599 2, pp. 99–107, 2013, doi: 10.31227/osf.io/gtbq6.
- 600 [32] J.-M. Becker, C. M. Ringle, and M. Sarstedt, “Estimating Moderating Effects in PLS-
601 SEM and PLSC-SEM: Interaction Term Generation*Data Treatment,” *J. Appl. Struct.*
602 *Equ. Model.*, vol. 2, no. 2, pp. 1–21, Jun. 2018, doi: 10.47263/JASEM.2(2)01.
- 603 [33] M. . Yim, “A Study on Factor Analytical Methods and Procedures for PLS-SEM
604 (Partial Least Squares Structural Equation Modeling),” *J. Ind. Distrib. Bus.*, vol. 10,
605 no. 5, pp. 7–20, 2019, doi: 10.13106/ijidb.2019.vol10.no5.7.
- 606 [34] R. Schlittgen, M. Sarstedt, and C. M. Ringle, “Data generation for composite-based
607 structural equation modeling methods,” *Adv. Data Anal. Classif.*, vol. 14, no. 4, pp.
608 747–757, 2020, doi: 10.1007/s11634-020-00396-6.
- 609 [35] S. Kono and M. Sato, “The potentials of partial least squares structural equation
610 modeling (PLS-SEM) in leisure research,” *J. Leis. Res.*, pp. 1–21, Jun. 2022, doi:
611 10.1080/00222216.2022.2066492.

- 612 [36] M. E. Civelek, “Comparison of Covariance-Based and Partial Least Square Structural
613 Equation Modeling Methods under Non-Normal Distribution and Small Sample Size
614 Limitations,” *Eurasian Econom. Stat. Emprical Econ. Journa*, vol. 10, no. 1, pp. 39–
615 50, 2018, doi: 10.17740/eas.stat.2018-V10-03.
- 616 [37] J. F. Hair, J. J. Risher, M. Sarstedt, and C. M. Ringle, “When to use and how to report
617 the results of PLS-SEM,” *Eur. Bus. Rev.*, vol. 31, no. 1, pp. 2–24, Jan. 2019, doi:
618 10.1108/EBR-11-2018-0203.
- 619 [38] J. F. Hair, C. M. Ringle, and M. Sarstedt, “Partial Least Squares Structural Equation
620 Modeling: Rigorous Applications, Better Results and Higher Acceptance,” *Long
621 Range Plann.*, vol. 46, no. 1–2, pp. 1–12, Feb. 2013, doi: 10.1016/j.lrp.2013.01.001.
- 622 [39] W. Reinartz, M. Haenlein, and J. Henseler, “An empirical comparison of the efficacy
623 of covariance-based and variance-based SEM,” *Int. J. Res. Mark.*, vol. 26, no. 4, pp.
624 332–344, Dec. 2009, doi: 10.1016/j.ijresmar.2009.08.001.
- 625 [40] H. Syaf, “The Relationship Evaluation Between Land Quality, Growth And Production
626 Of Advanced Age Cocoa In Kolaka East District, Southeast Sulawesi Province,”
627 *Bioedukasi*, vol. 3, no. 1, pp. 267–276, 2014, doi:
628 <http://dx.doi.org/10.33387/bioedu.v2i1.60>.
- 629 [41] Nurdin, M. L. Rayes, Soemarno, and Sudarto, “Study of Land Quality and Land
630 Characteristics that Determine the Productivity of Composite Maize Varieties in
631 Gorontalo,” *Syst. Rev. Pharm.*, vol. 11, no. 12, pp. 500–509, 2020, doi:
632 10.31838/srp.2020.12.81.
- 633 [42] R. Bhat and S. Sujatha, “stablishing leaf nutrient norms for arecanut by boundary line
634 approach,” *J. Plant Nutr.*, vol. 36, no. 6, pp. 849–862, Jan. 2013, doi:
635 10.1080/01904167.2013.770524.
- 636 [43] A. M. Ali, “Nutrient Sufficiency Ranges in Mango Using Boundary-Line Approach
637 and Compositional Nutrient Diagnosis Norms in El-Salhiya, Egypt,” *Commun. Soil
638 Sci. Plant Anal.*, vol. 49, no. 2, pp. 188–201, Jan. 2018, doi:
639 10.1080/00103624.2017.1421651.
- 640 [44] M. Ridayanti, M. L. Rayes, and C. Agustina, “Land Suitability Evaluation for Maize in
641 Dry Land Wagir District, Malang Regency,” *J. Tanah dan Sumberd. Lahan*, vol. 8, no.
642 1, pp. 149–160, Dec. 2020, doi: 10.21776/ub.jtsl.2021.008.1.18.
- 643 [45] BWS Sulawesi II, “Climate Data in the Paguyaman River Area for 2012-2022,” *Balai
644 Wilayah Sungai Sulawesi II Provinsi Gorontalo*, 2022.
645 <https://sda.pu.go.id/balai/bwssulawesi2/data/wilayah-sungai/ws-paguyaman/> (accessed
646 Dec. 12, 2022).
- 647 [46] S. Ritung, F. Lukman, and R. Purnanto, *Atlas of 1:50,000 scale semi-detailed soil map
648 of Boalemo District, Gorontalo Province*. Bogor: Indonesian Center for Research and
649 Development of Agricultural Land Resources, 2016.
- 650 [47] Wahyunto *et al.*, *Technical Guidance Guidelines for Land Suitability Assessment for
651 Strategic Agricultural Commodities Semi-Detailed Scale 1:50.000*. Bogor: Balai Besar
652 Litbang Sumberdaya Lahan Pertanian, 2016.
- 653 [48] L. R. Oldeman and S. Darmiyati, “An agroclimatic map of Sulawesi scale 1 -
654 2.500.000.pdf,” Bogor: *Center Research for Agriculture*, p. 1, 1977.
- 655 [49] E. Runtuwuwu, I. Las, I. Amien, and H. Syahbuddin, “Utilizing Cropping Calender in
656 Coping with Climate Change,” *J. Ecolab*, vol. 5, no. 1, pp. 1–14, Dec. 2011, doi:

- 657 10.20886/jklh.2011.5.1.1-14.
- 658 [50] M. L. Rayes, *Description of Soil Profile in the Field*. Agriculture Faculty of Brawijaya
659 University, 2006.
- 660 [51] W. H. Wischmeier and D. D. Smith, "Predicting rainfall erosion losses—a guide to
661 conservation planning," *Agric. Handb.*, vol. 537, pp. 1–60, 1978.
- 662 [52] E. Kurnia, F. Agus, A. Adimiharja, and A. Dariah, *Soil Physical Properties and
663 Analysis Methods*, vol. 1, no. 1. Bogor: Center for Research and Development of
664 Agricultural Land Resources, 2006.
- 665 [53] Eviyati and Sulaeman, *Analysis of soil, chemical, plants, water, and fertilizer*. Bogor:
666 Indonesia Centre of Soil Research, 2009.
- 667 [54] M. Seilsepour, M. Rashidi, and B. G. Khabbaz, "Prediction of Soil Exchangeable
668 Sodium Percentage Based on Soil Sodium Adsorption Ratio," *Am. J. Agric. Environ.
669 Sci.*, vol. 5, no. 1, pp. 1–4, 2009.
- 670 [55] M. Siosemarde, F. Kave, E. Pazira, H. Sedghi, and S. J. Ghaderi, "Prediction of soil
671 exchangeable sodium ratio based on soil sodium adsorption ratio," *World Acad. Sci.
672 Eng. Technol.*, vol. 46, no. 10, pp. 255–257, 2010.
- 673 [56] N. Sutrisna, Nadimin, I. Ishaq, and S. Putra, "Guide to the Jajar Legowo Rice Tiling
674 Method," *West Java Agricultural Technology Study Center*, vol. 02/Panduan. West
675 Java Agricultural Technology Study Center, Bandung, pp. 1–27, 2012.
- 676 [57] H. Wold, "Model Construction and Evaluation When Theoretical Knowledge Is
677 Scarce," in *Evaluation of Econometric Models*, J. Kmenta and B. J. Ramsey, Eds.
678 Academic Press, 1980, pp. 47–74.
- 679 [58] K. Bollen and R. Lennox, "Conventional Wisdom on Measurement: A Structural
680 Equation Perspective," *Psychol. Bull.*, vol. 110, no. 2, pp. 305–314, 1991, doi:
681 10.1037/0033-2909.110.2.305.
- 682 [59] M. Haenlein and A. M. Kaplan, "A Beginner's Guide to Partial Least Squares
683 Analysis," *Underst. Stat.*, vol. 3, no. 4, pp. 283–297, Nov. 2004, doi:
684 10.1207/s15328031us0304_4.
- 685 [60] J. F. Hair, M. Sarstedt, L. Hopkins, and V. G. Kuppelwieser, "Partial least squares
686 structural equation modeling (PLS-SEM): An emerging tool in business research,"
687 *Eur. Bus. Rev.*, vol. 26, no. 2, pp. 106–121, 2014, doi: 10.1108/EBR-10-2013-0128.
- 688 [61] C. Fornell and D. F. Larcker, "Evaluating Structural Equation Models with
689 Unobservable Variables and Measurement Error:," *J. Mark. Res.*, vol. 18, no. 1, pp.
690 39–50, Nov. 1981, doi: 10.1177/002224378101800104.
- 691 [62] W. W. Chin, "The Partial Least Squares Approach to Structural Formula Modeling,"
692 in *Modern Methods for Business Reseachr*, no. January 1998, G. A. Marcoulides, Ed.
693 Mahwah, New Jersey: Lawrence Erlbaum Associates, 1998, pp. 295–336.
- 694 [63] D. Gefen, D. Straub, and M.-C. Boudreau, "Structural Equation Modeling and
695 Regression: Guidelines for Research Practice," *Commun. Assoc. Inf. Syst.*, vol. 4, no.
696 October, pp. 1–77, 2000, doi: 10.17705/1cais.00407.
- 697 [64] J. Henseler, C. M. Ringle, and R. R. Sinkovics, "The use of partial least squares path
698 modeling in international marketing," *Adv. Int. Mark.*, vol. 20, pp. 277–319, 2009, doi:
699 10.1108/S1474-7979(2009)0000020014.
- 700 [65] M. Sarstedt, C. M. Ringle, and J. F. Hair, "Partial Least Squares Structural Equation

- 701 Modeling,” *Springer Books*, pp. 587–632, 2022, doi: 10.1007/978-3-319-57413-4_15.
- 702 [66] K. K. Wong, “Partial Least Squares Structural Equation Modeling (PLS-SEM)
703 Techniques Using SmartPLS,” *Mark. Bull.*, vol. 24, no. 1, pp. 1–32, 2013, [Online].
704 Available: http://marketing-bulletin.massey.ac.nz/marketing_bulletin_articles.html#24.
- 705 [67] J. Hulland, “Use of partial least squares (PLS) in strategic management research: a
706 review of four recent studies,” *Strateg. Manag. J.*, vol. 20, no. 2, pp. 195–204, Feb.
707 1999, doi: 10.1002/(SICI)1097-0266(199902)20:2<195::AID-SMJ13>3.0.CO;2-7.
- 708 [68] D. Barclay, R. Thompson, and C. Higgins, “The Partial Least Squares (PLS) Approach
709 to Causal Modeling: Personal Computer Adoption and Use as an Illustration,”
710 *Technol. Stud.*, vol. 2, no. 2, pp. 285–309, Nov. 1995, doi: 10.1088/1751-
711 8113/44/8/085201.
- 712 [69] J. F. Hair, G. T. M. Hult, C. . Ringle, M. Sarstedt, N. . Danks, and S. Ray, *Partial least
713 squares structural equation modeling (PLS-SEM) using R: A workbook*. 2021.
- 714 [70] V. E. Vinzi, W. W. Chin, J. Henseler, and H. Wang, *Handbook of Partial Least
715 Squares*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2010.
- 716 [71] FAO, “A Framework for Innovation,” *FAO Soils Bull.*, vol. 32, no. 22, pp. 1–92, 1976,
717 doi: 10.1007/978-3-030-45139-4_4.
- 718 [72] Widiatmaka, A. Sutandi, A. Iswandi, U. Daras, M. Hikmat, and A. Krisnohadi,
719 “Establishing Land Suitability Criteria for Cashew (*Anacardium occidentale* L.) in
720 Indonesia,” *Appl. Environ. Soil Sci.*, vol. 2014, no. 743194, pp. 1–14, 2014, doi:
721 10.1155/2014/743194.
- 722 [73] W. W. Chin, “The Partial Least Squares Approach to Structural Formula Modeling,”
723 in *Modern Methods for Business Reseach*, no. January 1998, G. A. Marcoulides, Ed.
724 Mahwah, New Jersey: Lawrence Erlbaum Associates, 1998, pp. 295–336.
- 725 [74] R. . Darmawan, “Analysis of the Effect of Work-Family Conflict and Job Stress on the
726 Job Performance of Nurses at ‘X’ Hospital,” *Agora*, vol. 6, no. 2, pp. 1–6, 2018,
727 [Online]. Available: <https://www.neliti.com/id/publications/287084>.
- 728 [75] J. F. Hair, M. Sarstedt, C. M. Ringle, and J. A. Mena, “An assessment of the use of
729 partial least squares structural equation modeling in marketing research,” *J. Acad.
730 Mark. Sci.*, vol. 40, no. 3, pp. 414–433, 2012, doi: 10.1007/s11747-011-0261-6.
- 731 [76] R. P. Bagozzi and Y. Yi, “On the evaluation of structural equation models,” *J. Acad.
732 Mark. Sci.*, vol. 16, no. 1, pp. 74–94, Mar. 1988, doi: 10.1007/BF02723327.
- 733 [77] T. M. Basuki, D. R. Indrawati, and B. Haryadi, “The Use of Organic Matter to
734 Improve Productivity of Post Lime Mining Land,” *J. For. Nat. Conserv. Res.*, vol. 4,
735 no. 1, pp. 1–8, 2007, doi: 10.20886/jphka.2007.4.1.1-8.
- 736 [78] M. S. Alfian and H. Purnamawati, “Dose and Time of Potassium Fertilizer Application
737 on Growth and Sweet Corn Production at NATC Batangkaluku Gowa regency of
738 South Sulawesi,” *Bul. Agrohorti*, vol. 7, no. 1, pp. 8–15, 2019, doi:
739 10.29244/agrob.v7i1.24404.
- 740 [79] S. Nasreen, M. M. Haque, M. A. Hossain, and A. T. M. Farid, “Nutrient uptake and
741 yield of onion as influenced by nitrogen and sulphur fertilization,” *Bangladesh J.
742 Agric. Res.*, vol. 32, no. 3, pp. 413–420, Jan. 2008, doi: 10.3329/bjar.v32i3.543.
- 743 [80] Y. Abdissa, T. Tekalign, and L. M. Pant, “Growth, Bulb Yield and Quality of Onion
744 (*Allium cepa* L.) as Influenced by Nitrogen and Phosphorus Fertilization on Vertisol I.
745 Growth Attributes, Biomass Production and Bulb Yield,” *African J. Agric. Res.*, vol. 6,

- 746 no. 14, pp. 3252–3258, 2011, doi: 10.5897/AJAR10.1024.
- 747 [81] I. Firmansyah and N. Sumarni, “Effect of N Fertilizer Dosages and Varieties On Soil
748 pH, Soil Total-N, N Uptake, and Yield of Shallots (*Allium ascalonicum* L.) Varieties
749 On Entisols-Brebes Central Java,” *J. Hortik.*, vol. 23, no. 4, p. 358, May 2016, doi:
750 10.21082/jhort.v23n4.2013.p358-364.
- 751 [82] E. Sumiati and O. S. Gunawan, “Application of Mycorrhizal Biofertilizer to Increase
752 the Efficiency of NPK Uptake and its Effects on Yiled and Quality of Shallot Bulbs,”
753 *J. Hort*, vol. 17, no. 1, pp. 34–42, 2006, doi: 10.21082/jhort.v17n1.2007.p%p.
- 754 [83] H. R. McKenzie, “Potassium Fertilizer Application in Crop Production,” *Agri-Facts*,
755 vol. 542, no. 9, pp. 1–7, 2013, [Online]. Available:
756 <https://open.alberta.ca/publications/6060438>.
- 757 [84] M. Dianawati, “Rates and application time of K₂SO₄ on production of G0 potato
758 seed,” *J. Kultiv.*, vol. 17, no. 1, pp. 531–536, 2018, [Online]. Available:
759 <http://jurnal.unpad.ac.id/kultivasi/article/viewFile/15499/7786>.
- 760 [85] N. Gunadi, “The Use of Potassium Sulphate as an Alternative Source of Potassium
761 Fertilizer in Potato,” *J. Hort*, vol. 17, no. 1, pp. 52–60, 2019, [Online]. Available:
762 <http://repository.pertanian.go.id/handle/123456789/7798>.
- 763 [86] I. S. Rahmawan, A. Z. Arifin, and Sulistyawati, “The effect of potassium (K) fertilizer
764 on growth and yield of cabbage (*Brassica oleraceae* var. *capitata*, L.),” *J.*
765 *Agroteknologi Merdeka Pasuruan*, vol. 3, no. 1, pp. 17–23, 2019.
- 766 [87] Subandi, “Role and Management of Potassium Nutrient for Food Production in
767 Indonesia,” *Agric. Innov. Dev.*, vol. 6, no. 1, pp. 1–10, 2013, [Online]. Available:
768 [https://www.neliti.com/publications/30881/role-and-management-of-potassium-](https://www.neliti.com/publications/30881/role-and-management-of-potassium-nutrient-for-food-production-in-indonesia)
769 [nutrient-for-food-production-in-indonesia](https://www.neliti.com/publications/30881/role-and-management-of-potassium-nutrient-for-food-production-in-indonesia).
- 770 [88] IIED, “Potash Case Study: Information supplied by the International Fertilizer Industry
771 Association,” *Mining, Miner. Sustain. Dev.*, vol. 65, no. February, p. 9, 2002, [Online].
772 Available: http://www.agritrade.org/documents/Biofuels_Subsub_Web_Final.pdf.
- 773 [89] N. Nursjahbani, O. Rusdiana, and . D., “Suitability of *Durio zibethinus* Murr. and
774 *Nephelium lappaceum* L. on the Utilization Block at Menumbing Mountain Grand
775 Forest Park, West Bangka,” *J. Trop. Silv.*, vol. 9, no. 1, pp. 1–6, May 2018, doi:
776 10.29244/j-siltrop.9.1.1-6.
- 777 [90] I. W. Nyakudya and L. Stroosnijder, “Effect of rooting depth, plant density and
778 planting date on maize (*Zea mays* L.) yield and water use efficiency in semi-arid
779 Zimbabwe: Modelling with AquaCrop,” *Agric. Water Manag.*, vol. 146, pp. 280–296,
780 Dec. 2014, doi: 10.1016/j.agwat.2014.08.024.
- 781 [91] S. B. Wang *et al.*, “Effect of subsoiling depth on soil physical properties and summer
782 maize (*Zea mays* L.) yield,” *Plant, Soil Environ.*, vol. 65 (2019), no. No. 3, pp. 131–
783 137, Mar. 2019, doi: 10.17221/703/2018-PSE.
- 784 [92] H. Z. Khan, M. A. Malik, and M. F. Saleem, “Effect of rate and source of organic
785 material on the production potential of spring maize (*Zea mays* L.),” *Pak. J. Agri. Sci.*,
786 vol. 45, no. 1, pp. 40–43, 2008, [Online]. Available:
787 <https://pakjas.com.pk/papers/222.pdf>.
- 788 [93] A. Jalal, K. Azeem, M. C. M. T. Filho, and A. Khan, “Enhancing Soil Properties and
789 Maize Yield through Organic and Inorganic Nitrogen and Diazotrophic Bacteria,” in
790 *Sustainable Crop Production*, IntechOpen, 2020, pp. 1–14.

- 791 [94] E. E. Kandil, N. R. Abdelsalam, M. A. Mansour, H. M. Ali, and M. H. Siddiqui,
792 “Potentials of organic manure and potassium forms on maize (*Zea mays* L.) growth
793 and production,” *Sci. Rep.*, vol. 10, no. 1, p. 8752, Dec. 2020, doi: 10.1038/s41598-
794 020-65749-9.
- 795 [95] Mulyati, A. B. Baharuddin, and R. S. Tejowulan, “Improving Maize (*Zea mays* L.)
796 growth and yield by the application of inorganic and organic fertilizers plus,” *IOP*
797 *Conf. Ser. Earth Environ. Sci.*, vol. 712, no. 1, p. 012027, Mar. 2021, doi:
798 10.1088/1755-1315/712/1/012027.
- 799 [96] D. A. Kane, M. A. Bradford, E. Fuller, E. E. Oldfield, and S. A. Wood, “Soil organic
800 matter protects US maize yields and lowers crop insurance payouts under drought,”
801 *Environ. Res. Lett.*, vol. 16, no. 4, p. 044018, Apr. 2021, doi: 10.1088/1748-
802 9326/abe492.
- 803 [97] Mujiyo, W. Larasati, H. Widijanto, and A. Herawati, “The Effect of Slope Gradient of
804 land on the Soil Damage in Giritontro, Wonogiri.,” *Agrotrop J. Agric. Sci.*, vol. 11,
805 no. 2, p. 115, 2021, doi: 10.24843/ajaoas.2021.v11.i02.p02.
- 806 [98] D. O. Suparwata, Nurmi, and M. I. Bahua, “Using vertical mulch to upland for
807 reducing erosion, runoff and its responses to maize growth and yields,”
808 *Agroteknotropika*, vol. 1, no. 3, pp. 138–145, 2012, doi: 10.31227/osf.io/5aek7.
- 809 [99] R. E. Christanto, Suryono, Mujiyo, and J. Winarno, “The Degree of Erosion Hazard
810 Mapping in Dry Land at Jatipuro Sub District of Karanganyar with Geographic
811 Information System (GIS,” *Sains Tanah - J. Soil Sci. Agroclimatol.*, vol. 7, no. 2, pp.
812 114–119, 2013, doi: 10.15608/stjssa.v7i2.42.
- 813 [100] E. Elfayetti and H. Herdi, “Land Suitability Evaluation for Maize Crops in Saentis
814 Village, Percut Sei Tuan,” *JUPIIS J. Pendidik. ILMU-ILMU Sos.*, vol. 7, no. 1, p. 33,
815 Jul. 2015, doi: 10.24114/jupiis.v7i1.2295.
- 816 [101] Sukarman, A. Mulyani, and S. Purwanto, “The Modification of Land Evaluation
817 Methods for Oriented Climate Change,” *J. Sumberd. Lahan*, vol. 12, no. 1, p. 1, Jun.
818 2018, doi: 10.21082/jsdl.v12n1.2018.1-11.
- 819 [102] W. Chivasaa, O. Mutanga, and C. Biradarc, “Mapping land suitability for maize (*Zea*
820 *mays* L.) production using GIS and AHP technique in Zimbabwe,” *South African J.*
821 *Geomatics*, vol. 8, no. 2, pp. 265–281, Sep. 2022, doi: 10.4314/sajg.v8i2.11.

822

INSTRUKSI REVISI 2

(Minor Revision

29 Desember 2022)

3800877: Revision requested

3 pesan

Maman Turjaman <support@hindawi.com>
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29 Desember 2022 pukul 14.59



Dear Dr. Nurdin,

In order for your submission "Determination of Maize Hybrid Land Suitability Criteria Based on Optimum Yield and Selected Land Quality" to Applied and Environmental Soil Science to proceed to the review process, there needs to be a revision.

Reason & Details:

“

Minor Revision

For more information about what is required, please click the link below.

MANUSCRIPT DETAILS

Kind regards,
Maman Turjaman

Applied and Environmental Soil Science

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Nurdin <nurdin@ung.ac.id>
Kepada: Karlo Lalap <karlo.lalap@hindawi.com>

30 Desember 2022 pukul 19.23

Thank you for the corrections to our manuscript improvements... We have tried to improve our journal manuscripts according to the instructions from the reviewers. Hopefully it can be accepted for the next process

Regards
Nurdin
[Kutipan teks disembunyikan]

Article Type

Research Article

Journal


Applied and Environmental Soil Science

Academic Editor Turjaman Maman

Submitted on 2022-12-12 (17 days ago)

> Abstract

> Author Declaration

 > Files 
— Editorial Comments
Recommendation

Maman Turjaman AE 29.12.2022

Minor Revision Requested

Message for Author


Minor Revision

— Response to Revision Request
Your Reply

Nurdin, Nurdin 24.12.2022

Dear Academic Editor Thank you in advance for correcting our journal articles, so that the deepening of the contents of our articles is even better. In response to the corrections that have been given, we have tried to improve as much as possible with the following description: In the introductory section, a discussion on maize development in Boalemo Regency (hybrid corn production achievement compared to local maize) has been added, the choice of research locations in this regency and the urgency of determining land suitability criteria for hybrid maize in Boalemo Regency by including some of the latest references (lines 43-63 of the revision article). In the methods section: - Lines 85-87 have been added citations/references - Soil map scale has been listed (nominal scale and bar scale). - Line 88 states that there are 35 land units, but in the legend Figure 1 there are 32 SMUs. Is there a relationship between the soil mapping carried out by Ritung et al. and the map in Figure 1? Why is the land mapping unit in Figure 1 not explained in paragraphs 83-91? It has been improved again, where the land mapping carried out by Ritung et al. (20016) as many as 35 land units became the initial reference for adding 32 new land units because the map scale changed from a scale of 1: 50,000 to a scale of 1: 40,000, so that the coverage of the land map was more detailed and the number of land units became 67 units. In addition, the land units have been described, both in terms of slope, relief, land use and soil types and their distribution in the study area. - Lines 95-110: It is better to explain each component/variable of soil characteristics at the beginning of the paragraph. In the next section, each variable is explained how to obtain the data. In this line, each component/variable of soil characteristic distance has been explained and continued with how to obtain the data. - Lines 97-99: Give reasons why it is necessary to update the available land characteristics and justification for determining the additional 32 points. Add sampling points (32 pedons) to the map. Explain how to collect climate data and place equipment/stations. In that line it has been corrected according to the correction. - Lines 112-113: these identifications must be shown on the map and indicate the points where the 2.5 x 2.5 m beams are placed. This line has been corrected and included in the map of the research location (sample points and tiled plots). - Lines 117, 119, 142, 143, etc.: each formula must be accompanied by a reference. This line has been fixed. - Lines 127-145, 175-184: please add a quote. This line has been fixed. - Lines 131: Table 1 should be completed with a column indicating secondary data sources for each land characteristic or method of obtaining data in the field (as a summary of updated lines 95-110). This line has been fixed. - Lines 397-401: It should be noted that the results of this study are of limited use for the development of hybrid corn in Boalemo, because the arrangement is only based on the characteristics of the land and optimum yields in Boalemo Regency (not representing the national scale). On the line has been fixed. Thus the improvement of the manuscript from us, hopefully we will get a good response for publication Regards Nurdin

File

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— Reviewer Reports

1 submitted

Report

Reviewer 1 28.12.2022

The authors have made improvements according to the reviewer's suggestions. A few things still need to be improved for the perfection of this manuscript:

- In this research, the land suitability criteria are only based on land characteristics and hybrid maize production in the Boalemo District, so the title of the manuscript needs to be adjusted. For example: "Determination of Land Suitability Criteria for Maize Hybrid in Boalemo District Based on Optimum Yield and Selected Land Quality." The research objective is to determine land suitability criteria for hybrid maize in Boalemo District based on the optimum yield and land quality.
- Lines 110-113: Information in these lines should be moved and combined with lines 147-151.
- Lines 117-118: The soil type classification is different from that listed in the table in Figure 1.

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
14 existing land suitability criteria. Therefore, this study aims to determine the hybrid maize land
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,
23 slopes, soil erosion, rock outcrops, and surface rocks. Furthermore, the highest optimum yield
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**

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

35 In Indonesia, the wet tropical climate with rainfall and high temperatures tends to reduce the
36 quality of land and agricultural products [4]. This country ranked 8th among the maize-
37 producing nations with a contribution of 2.19% and 2.42% of the world's total harvested area
38 [5]. However, the main problem is the relatively low level of yield in several regions because
39 the achievement of maize production has not been followed by an increase in yield per unit
40 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 In Indonesia, Gorontalo Province is one of the centers of maize production, where the hybrid
44 type is the most widely grown species [9]. The maize production in the province reached 1.8
45 million tons in 2021 [10], with several export advantages and competitiveness [11].
46 Furthermore, the planting of hybrid, composite, and local maize types has reached more than
47 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
66 maize in a region to ensure optimal production. The land suitability criteria for hybrid maize
67 are not yet available because the current criterion is the general suitability of maize plants
68 without distinguishing between hybrids and inbreds. Therefore, there is a need to make land
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

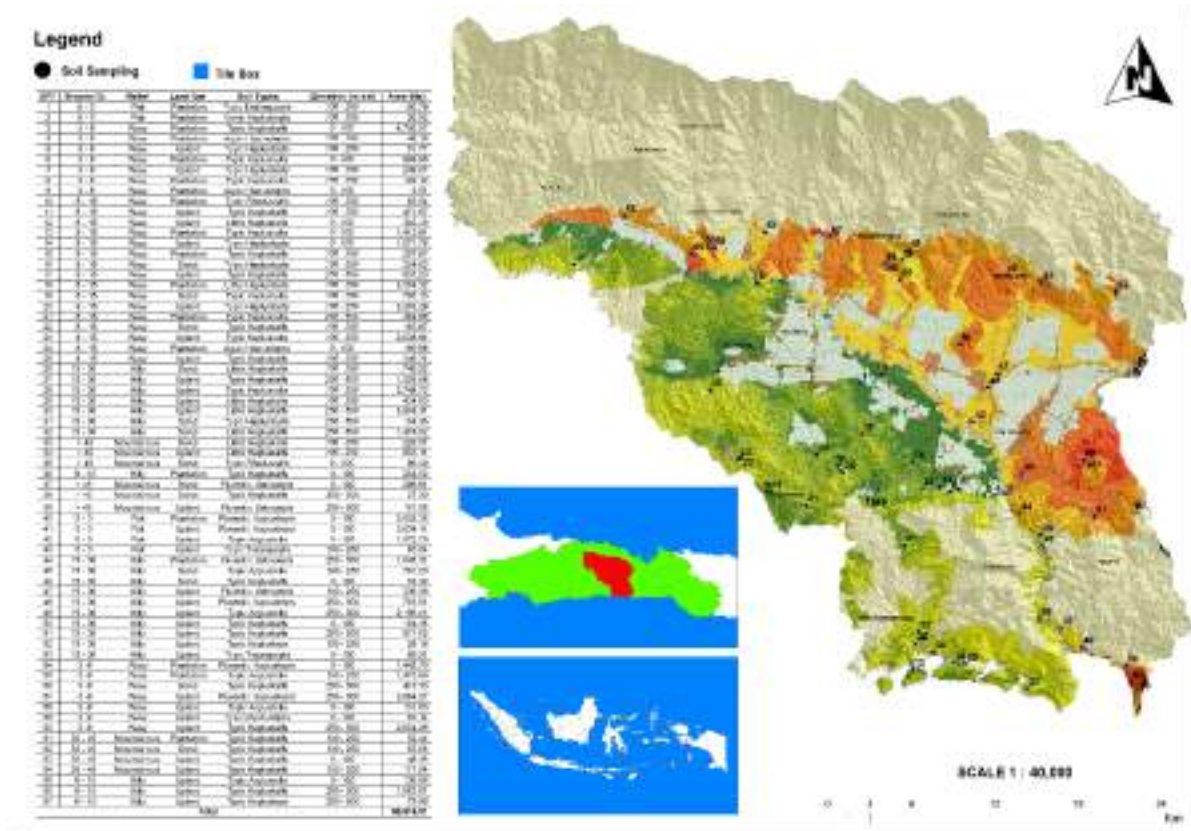
86 relatively small ranging from 30 to 100 [36]–[39]. The use of PLS-SEM to determine land
87 characteristics and qualities that control maize crop yields is still relatively rare, except for Syaf
88 [40] on older cocoa plants, maize composite [41], and on local varieties [6]. The boundary line
89 method can help determine nutrient adequacy concentrations and the optimum yield range of
90 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
97 determine land suitability criteria for hybrid maize based on the optimum yield and land
98 quality.

99 2. Materials and Methods

100 2.1 Study area

101 The study area extends from 0°28'5.6" - 0°57'30.02" N to 122°08'34.25" - 122°43'10.41"E
102 (Figure 1) on a scale of 1 : 65,000, 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 minimum was 26.79°C with an average of 28.01°C. Meanwhile, the maximum rainfall was
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
107 Ritung et al. [46] become the initial reference for determining 35 soil units, where each unit
108 has information on land characteristics, namely effective depth, drainage, texture, pH, cation
109 exchange capacity, base saturation, landform, parent material, relief, and land unit area. This
110 unit was detailed by adding 32 soil units to be surveyed and observed, making up to 67 soil
111 units in the area as shown in the legend Figure 1. The detailing was carried out because the soil
112 unit was previously presented at a scale of 1: 50,000, without including several key areas.
113 Meanwhile, the new soil unit is 1: 40,000 in scale and there has been a change in the agricultural
114 land use existing. This indicated that the slope class of 8 – 15% or hilly is more dominant in
115 the study area with a percentage of 29.77% and slopes > 40% or mountainous which is only
116 2.67%. Furthermore, the dry land is dominant with a value of 59.86% and a little shrub which
117 was only 9.21%, while the dominant Inceptisol soil type was 36.18% and very little Ultisol soil
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
 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
 128 material, and soil effective depth, nutrient retention is identified from the pH value, C-Organic,
 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
 132 slopes and soil erosion. The quality of the flood-hazard land is determined by identifying the
 133 height and the duration of the inundation, while preparation is carried out from the
 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].

136 Data on average annual air temperature and rainfall for 10 years (2010-2021) were collected
 137 from different climate stations, namely the Bandungrejo with $0^{\circ}41' N - 122^{\circ}38' E$, the elevation
 138 40 m asl, while Harapan has $0^{\circ}42' N - 122^{\circ}29' E$ and an elevation of 37 m asl. It also includes
 139 Lakeya Rain Post with $0^{\circ}42.82' N - 122^{\circ}32.07' E$, 32 m asl, Mohiyolo has $0^{\circ}46.41' N -$
 140 $122^{\circ}26.41' E$ and an elevation of 39 m asl, Saritani $0^{\circ}46.45' N - 122^{\circ}20.40' E$, with 26 m asl,
 141 Tangkobu $0^{\circ}37.25' N - 122^{\circ}36.36' E$, 25 m asl, Bubaa $0^{\circ}31.36' N - 122^{\circ}33.39' E$, 16 m asl,
 142 Wonggahu $0^{\circ}38' N - 122^{\circ}33' E$, 35 m asl, and Sambati Rain Post with $0^{\circ}31.184' N - 122^{\circ}27.074'$

143 E and an elevation of 9 m asl managed by BWS II Sulawesi. Furthermore, these data
144 determined wet months (> 200 mm) and dry months (<100 mm), which refers to the Oldeman
145 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].

147 Soil characteristics such as drainage, coarse material, effective soil depth, slope, inundation
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
150 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
155 using the pipette method, while soil moisture storage was evaluated using the gravimetric
156 method that can be applied in water balance analysis. The method of soil chemistry laboratory
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
161 basic cations and CEC was extracted with 1N NH₄OAc pH 7.0 (ammonium acetate) on a dry
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
164 [54] [55]. Subsequently, the data from the chemical analysis were averaged to a depth of 0-30
165 cm using the weighted averaging technique. The framework of this study is presented in Figure
166 2.

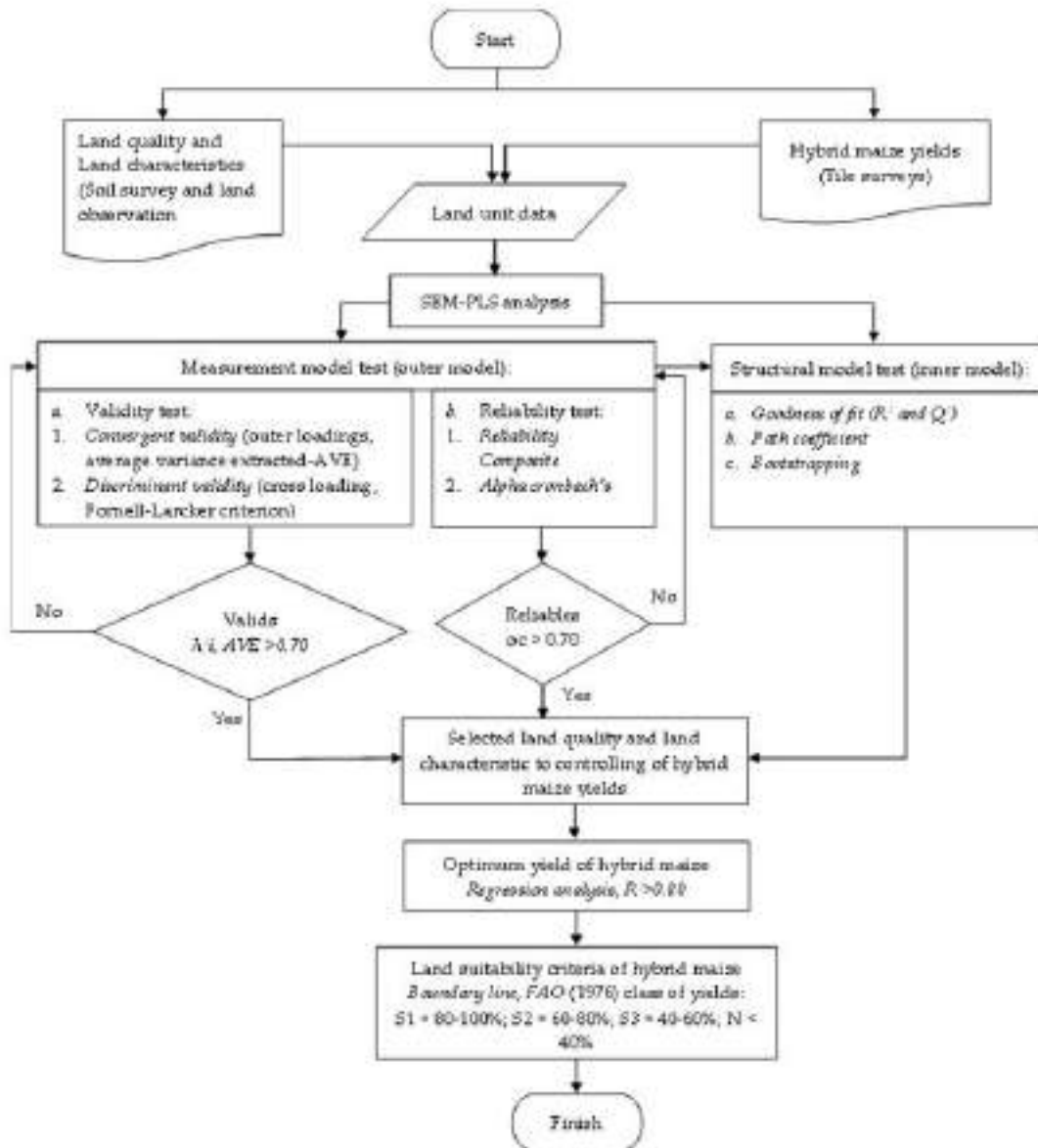


Figure 2: Research framework.

167
168

169 2.3 Dataset collection for hybrid maize yield

170 The areas currently planted with hybrid maize were identified and blocks with a size of 2.5 m
 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
 173 carried out to obtain hybrid maize yield data from the results of tiles on each land unit.
 174 Subsequently, the results were calculated using the formula [56], as expressed below:

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

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

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

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
 184 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
 186 and characteristics were selected as the latent and manifest variables, respectively. The analysis
 187 in PLS-SEM has 2 main steps, namely (1) the measurement model (outer model) and (2) the
 188 structural model test (inner model).

189 Table 1: Latent variables and indicators used in this study

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

190

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.

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

$$199 \quad x_i = \lambda x_i \xi_l + \delta_i \quad (3)$$

$$200 \quad y_i = \lambda y_i \eta_l + \varepsilon_i \quad (4)$$

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

203 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	1.06
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)							
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

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

206 Meanwhile, the average variance extracted (AVE) value was calculated using the equation
207 [61][62][63][64][65]:

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

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

210 The loading factor of an indicator with the highest value is the strongest or most important
211 measure in reflecting the latent variable. In this study, the loading factor value is > 0.70 for
212 selecting best land characteristics, but values ranging from 0.50-0.60 can still be tolerated with
213 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]:

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

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

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

$$229 \quad \rho_c = \frac{(\sum \lambda_i)^2}{(\sum \lambda_i)^2 + \sum i \text{ var}(\varepsilon_i)} \quad (7)$$

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]:

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

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

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

$$237 \quad H_j = \gamma_j \zeta_1 + \gamma_j \zeta_2 + \dots \gamma_j \zeta_n + \zeta_j \quad (9)$$

238 where η_j = endogenous variable vector (dependent), $\gamma_j \zeta_1 + \gamma_j \zeta_2 + \dots \gamma_j \zeta_n$ = exogenous latent
239 variable vector, and ζ_j = residual vector (error).

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

$$242 \quad Q^2 \text{ (Predictive relevance)} = 1 - (1 - R_1^2) (1 - R_2^2) \dots (1 - R_p^2) \quad (10)$$

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

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

251 **2.5 Class assignment**

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

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

268 Furthermore, with the Microsoft Excel application tools, the boundary between classes S1 to
 269 S2, S2 to S3, and S3 to N were determined by the Data menu → What-if-Analysis → Goal
 270 Seek → Set the cell at the location containing the regression equation → to value fill with the
 271 result limit values S1 to S2, S2 to S3, and S3 to N → By changing cell → the location where
 272 the value of the characteristics of the land will be sought → Ok. On location "By changing
 273 cell", the number being searched will appear, and at the location "set cell" will be equal to the
 274 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
 280 highly recommended and the indicators are considered convergently valid. In the soil texture
 281 indicator for the latent variable of root conditions as well as the cation exchange capacity (CEC)
 282 and base saturation (BS) indicators for nutrient retention, the loading factor was below the
 283 tolerance value of 0.50 at the 95% confidence level ($P < 1.960$), hence, it was not used. This
 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].

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

292 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) →	X1 (Temperature)	1.000**	11.192	Valid	1.000
X2.1 (Rainfall) →	X2 (Water availability)	0.838	0.085	Valid	0.906
X2.2 (Wet month) →		0.989	0.999	Valid	
X2.3 (Dry month) →		0.850	0.428	Valid	
X2.4 (LGP) →		0.993*	1.431	Valid	
X3.1 (Drainage) →	X3 (Oxygen availability)	1.000	0.000	Valid	1.000
X4.1 (Texture) →	X4 (Rooting condition)	0.013	0.066	Invalid	0.573
X4.2 (Coarse material) →		0.921	1.086	Valid	
X4.3 (Effective depth) →		-0.899	1.047	Valid	
X5.1 (pH H ₂ O) →	X5 (Nutrient retention)	0.647	0.857	Valid	0.360 (invalid)
X5.2 (pH KCl) →		0.570**	1.973	Valid	
X5.3 (Organic C) →		0.831**	3.135	Valid	

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

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

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

302 3.1.2 Reliability test result

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

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

312 The remaining variables are water availability, nutrient retention, available nutrients, erosion
 313 hazard, and land preparation variables. The coefficient of composite reliability and cronbach's
 314 alpha > 0.6, there, the variable is considered reliable. The minimum value of composite
 315 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

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

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Table 5: Cross-Loading of latent variables to indicators

Indicators	Latent Variables										
	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

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

333

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

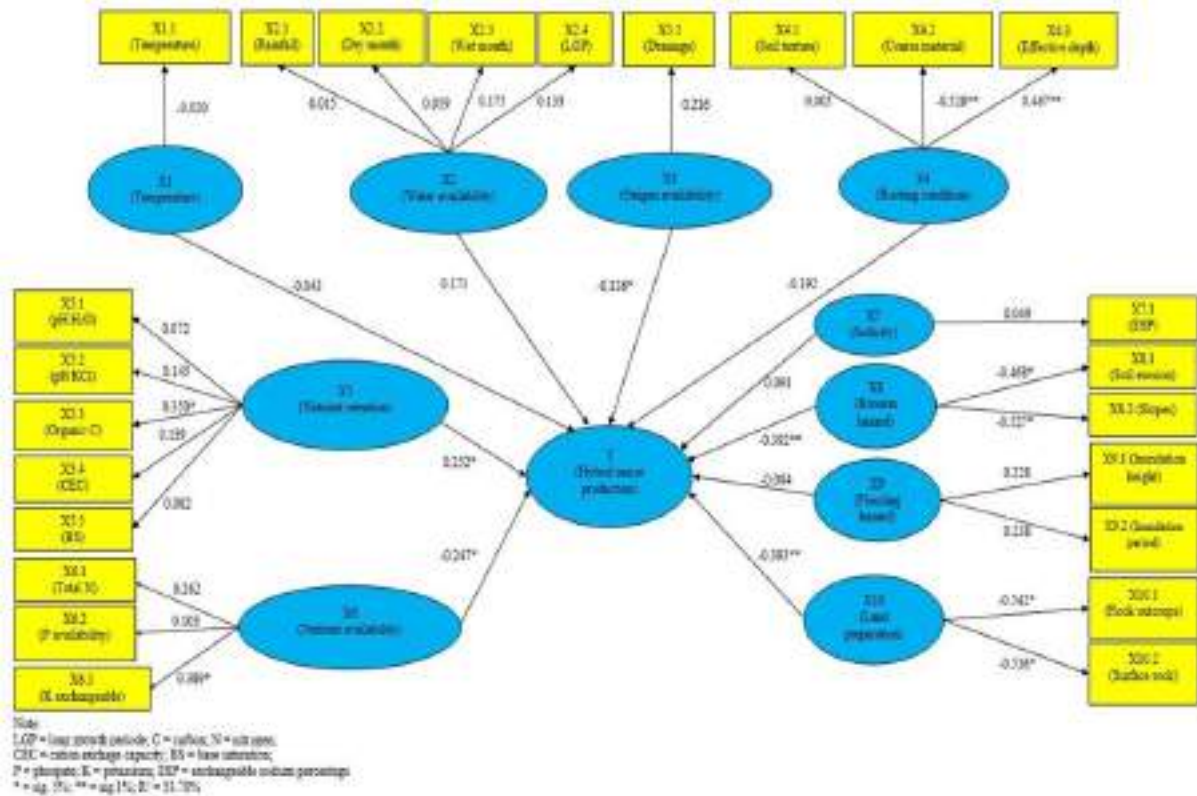
Indicators (land characteristics)	Cronbach's Alpha	Composite Reliability
X1.1 (Temperature)	1.000	1.000
X2.1 (Rainfall)		
X2.2 (Wet month)	0.975	0.965
X2.3 (Dry month)		
X2.4 (Long growth periods)		
X3.1 (Drainage)	1.000	1.000
X4.1 (Texture)		
X4.2 (Coarse material)	0.002 ^{nor}	-1.055 ^{nor}
X4.3 (Effective 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)		
X9.1 (Inundation height)	0.992	0.984
X9.2 (Inundation period)		
X10.1 (Rock outcrops)	0.998	0.995
X10.2 (Surface rock)		

334 nor = not reliable.

335 *3.1.3 Structural model test (inner models)*

336 Land characteristics that have a significant correlation with hybrid maize yields show a high
337 level of contribution to land quality in influencing hybrid maize yields as indicated in Figure
338 3. The figure shows a structural model of the relationship between indicator variables, namely
339 24 land characteristics, rectangular yellow, and latent variables, including 10 land qualities
340 maize yield, and oval blue. It also shows a model for the relationship between latent variables
341 such as land qualities and maize yield as well as loading figures. The factor for each indicator
342 and path coefficient for land qualities has a direct effect on the value of maize yields.

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



349

350

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 (X10). 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
 357 well as rock outcrop and surface rock as an indicator of land preparation. It was also indicated
 358 that the drainage loading factor was unable to explain the diversity of oxygen availability.
 359 Therefore, oxygen availability cannot be used as a land quality because there are no indicators
 360 that can represent it. Only the land qualities of nutrient retention (X5), nutrient availability
 361 (x6), erosion hazard (x8), and land preparation (X10) were used next.

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

369 Indicators of rough soil characteristics, slopes, soil erosion, as well as surface and rock outcrops
 370 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
 372 outcrop is followed by an increase in hybrid maize yields by 39% to 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.

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

Land Quality/Land Characteristics	Optimum Yield (ton/ha)	Yield Equation	R ²
Rooting condition (rc)			
Coarse material	8.06	$Y = 0.0024800x^2 - 0.2457487x + 10.9082465$	0.95
Effective depth	8.35	$Y = -0.0007242x^2 + 0.1890458x - 1.2946385$	0.96
Nutrient retention (nr)			
Organic carbon	8.35	$Y = -24.3891969x^2 + 46.8464078X - 8.8894056$	0.87
Nutrient availability (na)			
Total N	8.43	$Y = -304.4463543X^2 + 144.7590906X - 2.6328530$	1.00
K Exchangeable	5.74	$Y = -10.5596308X^2 + 17.4129832X + 2.2069179$	0.94
Erosion hazard (eh)			
Slopes	8.43	$Y = 0.0172X^2 - 0.8448X + 13.907$	0.91
Soil erosion	8.06	$y = 0.0000173X^2 - 0.0187536X + 9.0426459$	0.88
Land preparation (lp)			
Rock outcrops	7.30	$Y = 0.0046385X^2 - 0.2934756X + 8.5159674$	0.91
Surface rock	7.30	$Y = 0.0046385X^2 - 0.2934756X + 8.5159674$	0.91

380

The optimum of hybrid maize yield ranged from 5.74 to 8.43 ton/ha, where the highest yield was obtained from total N and slopes of 8.43 ton/ha with an R² value of 100% and 91%. 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 [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 5.74 ton/ha with an R² value of 94%. 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

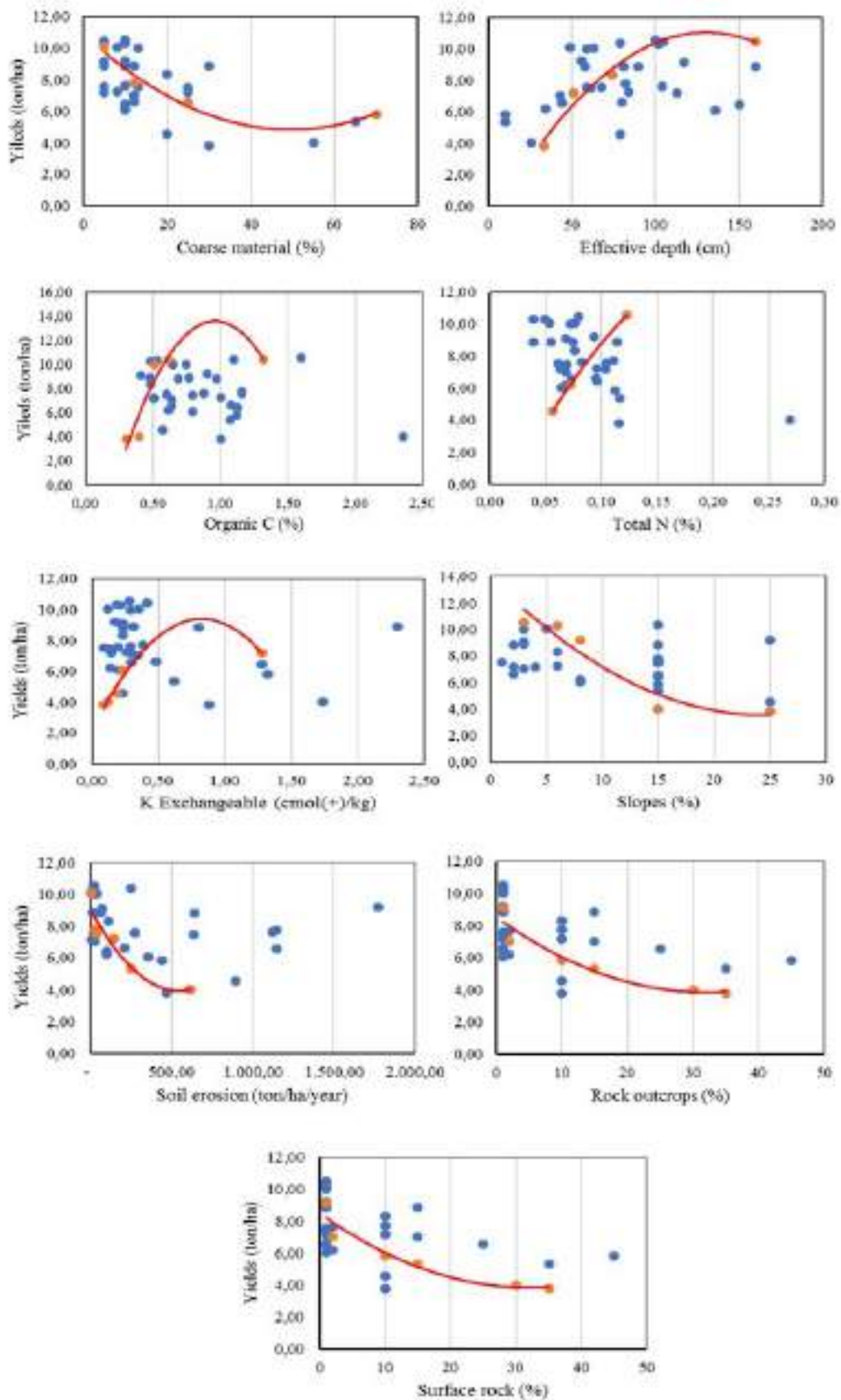
395 water use, N uptake, protein synthesis, and assimilate translocation [83]–[86]. It also plays a
396 role in improving the quality of crop yields (McKenzie, 2013, Subandi, 2013).

397 The optimum hybrid maize yield of the remaining is relatively diverse. This includes effective
398 depth and organic carbon, which were both 8.35 ton/ha with an R^2 value of 87%. Furthermore,
399 coarse material and soil erosion were 8.06 ton/ha with an R^2 value of 95% and 88%, while rock
400 outcrops and surface rock were 7.30 ton/ha with an R^2 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
404 content [95] because soil organic matter is a strong positive predictor of yield [96]. Kane et al.
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
407 degradation [97]. According to a previous study, erosion and maize yield are negatively
408 correlated, hence, increased erosion will reduce maize productivity [98]. Soil erosion on flat
409 land is slower surface runoff [99]. It was also reported that surface rocks and outcrops are the
410 limiting factors in the suitability of maize plantations [100]. Therefore, a high percentage of
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
416 indicator with a very suitable class (S1) was achieved when the value in the soil was greater
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,
421 it was obtained when the slope class ranges from 0-7.69%, while class S2 was achieved when
422 the slope class ranges from 7.70-11.83%. Furthermore, in classes S3 and N, it was obtained
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
425 indicator. In classes S1 and S2, it was achieved when the exchangeable K content in the soil
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
431 obtained as presented in Table 8.



432

433

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

434
435

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

Land Quality/Land Characteristics	Yield Limits (ton/ha)			Value of Land Suitability Criterion Obtained			
	S1 - S2 (80% x Y _{optim})	S2 - S3 (60% x Y _{optim})	S3 - N (40% x Y _{optim})	S1	S2	S3	N
Rooting condition (rc)							
Coarse material (%)	8.06	6.04	4.03	0 – 13.40	13.41 – 27.37	27.38 – 52.39	> 52.39
Effective depth (cm)	8.35	6.26	4.18	≥ 69.55	49.25 – 69.54	33.18 – 49.24	< 33.18
Nutrient retention (nr)							
Organic carbon (%)	8.35	6.26	4.18	≥ 0.50	0.41 – 0.49	0.34 – 0.40	< 0.34
Nutrient availability (na)							
Total N (%)	8.43	6.32	4.22	≥ 0.10	0.07 – 0.09	0.05 – 0.06	< 0.05
K Exchangeable (cmol(+)/kg)	5.74	4.31	2.87	≥ 0.24	0.13 – 0.23	0.04 – 0.12	< 0.04
Erosion hazard (eh)							
Slopes (%)	8.43	6.32	4.22	0 – 7.69	7.70 – 11.83	11.84 – 18.24	> 18.24
Soil erosion (ton/ha/year)	8.06	6.04	4.03	≤ 55.21	195.29	605.56	> 605.56
Land preparation (lp)							
Rock outcrops (%)	7.30	5.47	3.85	0 – 4.45	4.46 – 13.09	13.10 – 31.78	> 31.78
Surface rock (%)	7.30	5.47	3.85	0 – 4.45	4.46 – 13.09	13.10 – 31.78	> 31.78

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 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].

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 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].

456

Compared to Wahyunto et al. [47], 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

457

458

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.

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

Land Quality/Land Characteristics	New Land Suitability Criterion of Hybrid Maize				Land Suitability Criterion of General Maize [47]			
	S1	S2	S3	N	S1	S2	S3	N
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	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	> 40
Surface rock (%)	0 – 4.45	4.46 – 13.09	13.10 – 31.78	> 31.78	< 5	5 – 15	15 – 40	> 40

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
 471 conditions, nutrient retention, available nutrients, erosion hazard, as well as land preparation,
 472 and land characteristics, including coarse material, effective depth, organic C, total N,
 473 exchangeable K, slopes, soil erosion, rock outcrops, and surface rocks. The highest optimum
 474 yield of 8.35 ton/ha was achieved by the effective depth and organic C content for a very
 475 suitable class (S1), while the lowest value of 5.47 ton/ha was attained by exchangeable K for
 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
 478 based on optimum yields and selected land quality.

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.

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492 **References**

- 493 [1] K. Pawlak and M. Kołodziejczak, “The Role of Agriculture in Ensuring Food Security
494 in Developing Countries: Considerations in the Context of the Problem of Sustainable
495 Food Production,” *Sustainability*, vol. 12, no. 13, p. 5488, Jul. 2020, doi:
496 10.3390/su12135488.
- 497 [2] O. Erenstein, M. Jaleta, K. Sonder, K. Mottaleb, and B. M. Prasanna, “Global maize
498 production, consumption and trade: trends and R&D implications,” *Food Secur.* 2022,
499 pp. 1–25, May 2022, doi: 10.1007/S12571-022-01288-7.
- 500 [3] U. Grote, A. Fasse, T. T. Nguyen, and O. Erenstein, “Food Security and the Dynamics
501 of Wheat and Maize Value Chains in Africa and Asia,” *Front. Sustain. Food Syst.*, vol.
502 4, no. February, pp. 1–17, Feb. 2021, doi: 10.3389/fsufs.2020.617009.
- 503 [4] R. Wirosoedarmo, A. T. Sutanhaji, and E. Kurniati, “Land Suitability Assessment Of
504 Corn (*Zea mays* L.) Using Spasial Analysis Method,” *agriTECH*, vol. 31, no. 1, pp.
505 71–78, 2012, doi: <https://doi.org/10.22146/agritech.9728>.
- 506 [5] B. Arifin, “High expectations on KSA maize production,” *Stat. Policy Br. Indones.*,
507 vol. 18, no. December, pp. 37–41, 2021, [Online]. Available:
508 <https://fmsindonesia.id/wp-content/uploads/2022/01/Buletin-17-FINAL.pdf>.
- 509 [6] Nurdin, M. L. Rayes, Soemarno, and Sudarto, “Analysis of Quality and Land
510 Characteristics That Control Local Maize Production in Gorontalo,” in *the*
511 *International Seminar on Promoting Local Resources for Sustainable Agriculture and*
512 *Development (ISPLRSAD 2020)*, 2021, vol. 13, no. Isplrsad 2020, pp. 438–446, doi:
513 10.2991/absr.k.210609.068.
- 514 [7] T. Kartika, “The Effect of Planting Distance on Growth and Production of Non Hybrid
515 Maize (*Zea Mays* L) in the Land of Integrated Technology Agro Center (ATP),”
516 *Sainmatika J. Ilm. Mat. dan Ilmu Pengetah. Alam*, vol. 15, no. 2, p. 129, Dec. 2018,
517 doi: 10.31851/sainmatika.v15i2.2378.
- 518 [8] Sutimawati, A. N. Aulia, and R. M. Muliasari, “Comparative Analysis of Hybrid Corn
519 Farming Based on Business Scale in Tempurejo Sub-District,” *J. Agribest*, vol. 3, no.
520 1, p. 61, Mar. 2019, doi: 10.32528/agribest.v3i1.1950.

- 521 [9] I. S. Anugrah, "Corn-Based Agribusiness for Rural Economic Development in
522 Gorontalo Province," *Anal. Kebijak. Pertan.*, vol. 8, no. 4, pp. 363–383, 2016,
523 [Online]. Available: <http://ejurnal.litbang.pertanian.go.id/index.php/akp/index>.
- 524 [10] H. Limanseto, "The Government Encourages Productivity of the Leading
525 Commodities of Gorontalo Province to Increase People's Welfare," *Coordinating
526 Ministry for Economic Affairs of the Republic of Indonesia*, vol. 1. Coordinating
527 Ministry for Economic Affairs of the Republic of Indonesia, Jakarta, pp. 1–2, 2021.
- 528 [11] N. Endey, I. K. S. Arsana, A. Y. Katili, A. Sahabi, and M. A. Talalu, "Competitiveness
529 Analysis of Gorontalo's Leading Commodities in Supporting the New Capital City of
530 the Republic of Indonesia," *Equilib. J. Pendidik.*, vol. 10, no. 3, pp. 380–396, 2022,
531 doi: 10.26618/equilibrium.v10i3.8571.
- 532 [12] K. Astuti, R. O. Prasetyo, and N. . Khasanah, *Analysis of Maize and Soybean
533 Productivity in Indonesia 2020 (the Result of Crop Cutting Survey)*, vol. 05100.2103,
534 no. 5203029. BPS RI, 2021.
- 535 [13] BPS-Statistic of Gorontalo, "Gorontalo Province In Figures 2018," *BPS-Statistic of
536 Gorontalo*, vol. 75560.1811, no. 1102001.75. pp. 1–390, 2018.
- 537 [14] W. Ardiansyah, M. A. Indrianti, M. M. Djibran, and D. R. Hippy, "The Performance
538 of Dry Land Farming for Transmigrate Farmers (Case Study in Saritani Village,
539 Wonosari Sub-District, Boalemo Regency)," *J. Agriovet*, vol. 4, no. 2, pp. 125–142,
540 Apr. 2022, doi: 10.51158/agriovet.v4i2.726.
- 541 [15] A. H. Samon, "The Analysis of Comparative and Competitive Superiority of Corn
542 Farm Enterprises in Boalemo Regency," Hasanuddin University, 2005.
- 543 [16] A. M. D. Putri and Mustofiq, *Boalemo Regency in Figures 2022*, vol. 75010.2201, no.
544 1102001.7501. BPS-Statistics of Boalemo Regency, 2022.
- 545 [17] W. Tialo, M. Arief Azis, and N. Nurdin, "Gorontalo local waxy maize growth and
546 production, agronomic, and economic effectiveness with organic fertilizer treatment in
547 Bualo, Boalemo Regency," *J. Agercolere*, vol. 4, no. 2, pp. 44–53, 2022, doi:
548 10.37195/jac.v4i2.168.
- 549 [18] K. P. W. Sukma, "Growth and Production of Local Maize, Hybrid and Composite in
550 Pamekasan, Madura," *J. Agrosains Karya Kreat. dan Inov.*, vol. 4, no. 2, p. 34, May
551 2018, doi: 10.31102/agrosains.2017.4.2.34-38.
- 552 [19] Bapelitbang Boalemo Regency, "Local Government Work Plan for 2022," *Boalemo
553 Regent Regulation Number 49 of 2020*, vol. 49. 2021.
- 554 [20] A. K. Lasiki, Nurdin, and I. Husain, "Growth and Yield of Hybrid Corn in Several
555 Classes of Slopes and Fertilization Doses in Bumela Village, District Of Gorontalo," *J.
556 Agroteknotropika*, vol. 10, no. 2, pp. 59–69, 2021, [Online]. Available:
557 <https://ejurnal.ung.ac.id/index.php/JATT/article/view/13459>.
- 558 [21] D. K. S. Swastika, "Corn Self-Sufficiency in Indonesia: The Past 30 years and Future
559 Prospects," *J. Litbang Pertan.*, vol. 21, no. 3, pp. 75–83, 2002, [Online]. Available:
560 <https://agris.fao.org/agris-search/search.do?recordID=ID2005000155>.
- 561 [22] E. Kaya, A. Siregar, D. M. Y. Matulessy, and M. Hasan, "Growth and Yield of Corn
562 (*Zea mays* L.) due to The Granting of Sago Palm Waste Compost of Sago Palm Waste
563 Compost and Organic Liquid Fertilizer (OLF) in Ultisols," *J. Budid. Pertan.*, vol. 12,
564 no. 1, pp. 16–19, 2016, [Online]. Available:
565 <https://ojs3.unpatti.ac.id/index.php/bdp/article/view/42>.

- 566 [23] R. Yacoub, “Land Qualities as a Function to Estimate Land Productivity in the
567 Recently Reclaimed Calcareous Soils , Nubariya , Egypt .,” *Egypt. J. Geosci.*, vol. 50,
568 no. 4, pp. 1–13, 2010, [Online]. Available:
569 [https://www.researchgate.net/publication/327838295_Land_Qualities_as_a_Function_](https://www.researchgate.net/publication/327838295_Land_Qualities_as_a_Function_to_Estimate_Land_Productivity_in_the_Recently_Reclaimed_Calcareous_Soils_Nubariya_Egypt)
570 [to_Estimate_Land_Productivity_in_the_Recently_Reclaimed_Calcareous_Soils_Nuba](https://www.researchgate.net/publication/327838295_Land_Qualities_as_a_Function_to_Estimate_Land_Productivity_in_the_Recently_Reclaimed_Calcareous_Soils_Nubariya_Egypt)
571 [riya_Egypt](https://www.researchgate.net/publication/327838295_Land_Qualities_as_a_Function_to_Estimate_Land_Productivity_in_the_Recently_Reclaimed_Calcareous_Soils_Nubariya_Egypt).
- 572 [24] M. Liyanda, A. Karim, and Y. Abubakar, “Analysis of Land Suitability Criteria for
573 Cocoa Production of Three Cluster Development in Pidie District,” *Agrista*, vol. 16,
574 no. 2, pp. 62–79, 2012, [Online]. Available:
575 <http://jurnal.unsyiah.ac.id/agrista/article/view/289>.
- 576 [25] R. Neswati, S. Baja, and C. Lopulisa, “A modification of land suitability requirements
577 for maize in the humid tropics of South Sulawesi,” *IOP Conf. Ser. Earth Environ. Sci.*,
578 vol. 921, no. 1, p. 012012, Nov. 2021, doi: 10.1088/1755-1315/921/1/012012.
- 579 [26] D. Subardja and Sudarsono, “The influence of Land Quality on Productivity of Maize
580 in Soils Derived from Volcanic and Sedimentary Rocks in the Bogor Area,” *Soil Clim.*
581 *J.*, vol. 23, pp. 38–46, 2005, doi: <http://dx.doi.org/10.21082/jti.v0n23.2005.%25p>.
- 582 [27] G. O. Awe and T. P. Abegunrin, “Land Preparation Practices for Maize Production :
583 Short Term Effects on Some Hydro-Physical Properties of Analfisol and Crop
584 Performance,” *Middle-East J. Sci. Res.*, vol. 25, no. 7, pp. 1420–1430, 2017, doi:
585 10.5829/idosi.mejsr.2017.1420.1430.
- 586 [28] J. Janků *et al.*, “An overview of a land evaluation in the context of ecosystem
587 services,” *Soil Water Res.*, vol. 17, no. No. 1, pp. 1–14, Jan. 2022, doi:
588 10.17221/136/2021-SWR.
- 589 [29] D. Nadalia, A. Sutandi, and B. Nugroho, “Suitability criteria of land characteristics
590 related to Eucalyptus pellita production,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 694,
591 no. 1, p. 012053, Mar. 2021, doi: 10.1088/1755-1315/694/1/012053.
- 592 [30] N. Nurdin, F. Zakaria, M. A. Azis, Y. Rahim, R. Rahman, and M. Kasim,
593 “Comparison of land suitability class for endemic Coffea liberica Pinogu HP. acquired
594 using different methods and recommendations for land management in Pinogu Plateau,
595 Bone Bolango Regency, Indonesia,” *SAINS TANAH - J. Soil Sci. Agroclimatol.*, vol.
596 19, no. 1, p. 42, May 2022, doi: 10.20961/stjssa.v19i1.56441.
- 597 [31] A. . Elisanti, W. Purnomo, and S. Melaniani, “Application of partial least square health
598 status of children under 5 years in indonesia,” *J. Biometrika dan Kependud.*, vol. 2, no.
599 2, pp. 99–107, 2013, doi: 10.31227/osf.io/gtbq6.
- 600 [32] J.-M. Becker, C. M. Ringle, and M. Sarstedt, “Estimating Moderating Effects in PLS-
601 SEM and PLSC-SEM: Interaction Term Generation*Data Treatment,” *J. Appl. Struct.*
602 *Equ. Model.*, vol. 2, no. 2, pp. 1–21, Jun. 2018, doi: 10.47263/JASEM.2(2)01.
- 603 [33] M. . Yim, “A Study on Factor Analytical Methods and Procedures for PLS-SEM
604 (Partial Least Squares Structural Equation Modeling),” *J. Ind. Distrib. Bus.*, vol. 10,
605 no. 5, pp. 7–20, 2019, doi: 10.13106/ijidb.2019.vol10.no5.7.
- 606 [34] R. Schlittgen, M. Sarstedt, and C. M. Ringle, “Data generation for composite-based
607 structural equation modeling methods,” *Adv. Data Anal. Classif.*, vol. 14, no. 4, pp.
608 747–757, 2020, doi: 10.1007/s11634-020-00396-6.
- 609 [35] S. Kono and M. Sato, “The potentials of partial least squares structural equation
610 modeling (PLS-SEM) in leisure research,” *J. Leis. Res.*, pp. 1–21, Jun. 2022, doi:
611 10.1080/00222216.2022.2066492.

- 612 [36] M. E. Civelek, “Comparison of Covariance-Based and Partial Least Square Structural
613 Equation Modeling Methods under Non-Normal Distribution and Small Sample Size
614 Limitations,” *Eurasian Econom. Stat. Emprical Econ. Journa*, vol. 10, no. 1, pp. 39–
615 50, 2018, doi: 10.17740/eas.stat.2018-V10-03.
- 616 [37] J. F. Hair, J. J. Risher, M. Sarstedt, and C. M. Ringle, “When to use and how to report
617 the results of PLS-SEM,” *Eur. Bus. Rev.*, vol. 31, no. 1, pp. 2–24, Jan. 2019, doi:
618 10.1108/EBR-11-2018-0203.
- 619 [38] J. F. Hair, C. M. Ringle, and M. Sarstedt, “Partial Least Squares Structural Equation
620 Modeling: Rigorous Applications, Better Results and Higher Acceptance,” *Long
621 Range Plann.*, vol. 46, no. 1–2, pp. 1–12, Feb. 2013, doi: 10.1016/j.lrp.2013.01.001.
- 622 [39] W. Reinartz, M. Haenlein, and J. Henseler, “An empirical comparison of the efficacy
623 of covariance-based and variance-based SEM,” *Int. J. Res. Mark.*, vol. 26, no. 4, pp.
624 332–344, Dec. 2009, doi: 10.1016/j.ijresmar.2009.08.001.
- 625 [40] H. Syaf, “The Relationship Evaluation Between Land Quality, Growth And Production
626 Of Advanced Age Cocoa In Kolaka East District, Southeast Sulawesi Province,”
627 *Bioedukasi*, vol. 3, no. 1, pp. 267–276, 2014, doi:
628 <http://dx.doi.org/10.33387/bioedu.v2i1.60>.
- 629 [41] Nurdin, M. L. Rayes, Soemarno, and Sudarto, “Study of Land Quality and Land
630 Characteristics that Determine the Productivity of Composite Maize Varieties in
631 Gorontalo,” *Syst. Rev. Pharm.*, vol. 11, no. 12, pp. 500–509, 2020, doi:
632 10.31838/srp.2020.12.81.
- 633 [42] R. Bhat and S. Sujatha, “stablishing leaf nutrient norms for arecanut by boundary line
634 approach,” *J. Plant Nutr.*, vol. 36, no. 6, pp. 849–862, Jan. 2013, doi:
635 10.1080/01904167.2013.770524.
- 636 [43] A. M. Ali, “Nutrient Sufficiency Ranges in Mango Using Boundary-Line Approach
637 and Compositional Nutrient Diagnosis Norms in El-Salhiya, Egypt,” *Commun. Soil
638 Sci. Plant Anal.*, vol. 49, no. 2, pp. 188–201, Jan. 2018, doi:
639 10.1080/00103624.2017.1421651.
- 640 [44] M. Ridayanti, M. L. Rayes, and C. Agustina, “Land Suitability Evaluation for Maize in
641 Dry Land Wagir District, Malang Regency,” *J. Tanah dan Sumberd. Lahan*, vol. 8, no.
642 1, pp. 149–160, Dec. 2020, doi: 10.21776/ub.jtsl.2021.008.1.18.
- 643 [45] BWS Sulawesi II, “Climate Data in the Paguyaman River Area for 2012-2022,” *Balai
644 Wilayah Sungai Sulawesi II Provinsi Gorontalo*, 2022.
645 <https://sda.pu.go.id/balai/bwssulawesi2/data/wilayah-sungai/ws-paguyaman/> (accessed
646 Dec. 12, 2022).
- 647 [46] S. Ritung, F. Lukman, and R. Purnanto, *Atlas of 1:50,000 scale semi-detailed soil map
648 of Boalemo District, Gorontalo Province*. Bogor: Indonesian Center for Research and
649 Development of Agricultural Land Resources, 2016.
- 650 [47] Wahyunto *et al.*, *Technical Guidance Guidelines for Land Suitability Assessment for
651 Strategic Agricultural Commodities Semi-Detailed Scale 1:50.000*. Bogor: Balai Besar
652 Litbang Sumberdaya Lahan Pertanian, 2016.
- 653 [48] L. R. Oldeman and S. Darmiyati, “An agroclimatic map of Sulawesi scale 1 -
654 2.500.000.pdf,” Bogor: *Center Research for Agriculture*, p. 1, 1977.
- 655 [49] E. Runtuwuwu, I. Las, I. Amien, and H. Syahbuddin, “Utilizing Cropping Calender in
656 Coping with Climate Change,” *J. Ecolab*, vol. 5, no. 1, pp. 1–14, Dec. 2011, doi:

- 657 10.20886/jklh.2011.5.1.1-14.
- 658 [50] M. L. Rayes, *Description of Soil Profile in the Field*. Agriculture Faculty of Brawijaya
659 University, 2006.
- 660 [51] W. H. Wischmeier and D. D. Smith, "Predicting rainfall erosion losses—a guide to
661 conservation planning," *Agric. Handb.*, vol. 537, pp. 1–60, 1978.
- 662 [52] E. Kurnia, F. Agus, A. Adimiharja, and A. Dariah, *Soil Physical Properties and
663 Analysis Methods*, vol. 1, no. 1. Bogor: Center for Research and Development of
664 Agricultural Land Resources, 2006.
- 665 [53] Eviyati and Sulaeman, *Analysis of soil, chemical, plants, water, and fertilizer*. Bogor:
666 Indonesia Centre of Soil Research, 2009.
- 667 [54] M. Seilsepour, M. Rashidi, and B. G. Khabbaz, "Prediction of Soil Exchangeable
668 Sodium Percentage Based on Soil Sodium Adsorption Ratio," *Am. J. Agric. Environ.
669 Sci.*, vol. 5, no. 1, pp. 1–4, 2009.
- 670 [55] M. Siosemarde, F. Kave, E. Pazira, H. Sedghi, and S. J. Ghaderi, "Prediction of soil
671 exchangeable sodium ratio based on soil sodium adsorption ratio," *World Acad. Sci.
672 Eng. Technol.*, vol. 46, no. 10, pp. 255–257, 2010.
- 673 [56] N. Sutrisna, Nadimin, I. Ishaq, and S. Putra, "Guide to the Jajar Legowo Rice Tiling
674 Method," *West Java Agricultural Technology Study Center*, vol. 02/Panduan. West
675 Java Agricultural Technology Study Center, Bandung, pp. 1–27, 2012.
- 676 [57] H. Wold, "Model Construction and Evaluation When Theoretical Knowledge Is
677 Scarce," in *Evaluation of Econometric Models*, J. Kmenta and B. J. Ramsey, Eds.
678 Academic Press, 1980, pp. 47–74.
- 679 [58] K. Bollen and R. Lennox, "Conventional Wisdom on Measurement: A Structural
680 Equation Perspective," *Psychol. Bull.*, vol. 110, no. 2, pp. 305–314, 1991, doi:
681 10.1037/0033-2909.110.2.305.
- 682 [59] M. Haenlein and A. M. Kaplan, "A Beginner's Guide to Partial Least Squares
683 Analysis," *Underst. Stat.*, vol. 3, no. 4, pp. 283–297, Nov. 2004, doi:
684 10.1207/s15328031us0304_4.
- 685 [60] J. F. Hair, M. Sarstedt, L. Hopkins, and V. G. Kuppelwieser, "Partial least squares
686 structural equation modeling (PLS-SEM): An emerging tool in business research,"
687 *Eur. Bus. Rev.*, vol. 26, no. 2, pp. 106–121, 2014, doi: 10.1108/EBR-10-2013-0128.
- 688 [61] C. Fornell and D. F. Larcker, "Evaluating Structural Equation Models with
689 Unobservable Variables and Measurement Error:," *J. Mark. Res.*, vol. 18, no. 1, pp.
690 39–50, Nov. 1981, doi: 10.1177/002224378101800104.
- 691 [62] W. W. Chin, "The Partial Least Squares Approach to Structural Formula Modeling,"
692 in *Modern Methods for Business Reseachr*, no. January 1998, G. A. Marcoulides, Ed.
693 Mahwah, New Jersey: Lawrence Erlbaum Associates, 1998, pp. 295–336.
- 694 [63] D. Gefen, D. Straub, and M.-C. Boudreau, "Structural Equation Modeling and
695 Regression: Guidelines for Research Practice," *Commun. Assoc. Inf. Syst.*, vol. 4, no.
696 October, pp. 1–77, 2000, doi: 10.17705/1cais.00407.
- 697 [64] J. Henseler, C. M. Ringle, and R. R. Sinkovics, "The use of partial least squares path
698 modeling in international marketing," *Adv. Int. Mark.*, vol. 20, pp. 277–319, 2009, doi:
699 10.1108/S1474-7979(2009)0000020014.
- 700 [65] M. Sarstedt, C. M. Ringle, and J. F. Hair, "Partial Least Squares Structural Equation

- 701 Modeling,” *Springer Books*, pp. 587–632, 2022, doi: 10.1007/978-3-319-57413-4_15.
- 702 [66] K. K. Wong, “Partial Least Squares Structural Equation Modeling (PLS-SEM)
703 Techniques Using SmartPLS,” *Mark. Bull.*, vol. 24, no. 1, pp. 1–32, 2013, [Online].
704 Available: http://marketing-bulletin.massey.ac.nz/marketing_bulletin_articles.html#24.
- 705 [67] J. Hulland, “Use of partial least squares (PLS) in strategic management research: a
706 review of four recent studies,” *Strateg. Manag. J.*, vol. 20, no. 2, pp. 195–204, Feb.
707 1999, doi: 10.1002/(SICI)1097-0266(199902)20:2<195::AID-SMJ13>3.0.CO;2-7.
- 708 [68] D. Barclay, R. Thompson, and C. Higgins, “The Partial Least Squares (PLS) Approach
709 to Causal Modeling: Personal Computer Adoption and Use as an Illustration,”
710 *Technol. Stud.*, vol. 2, no. 2, pp. 285–309, Nov. 1995, doi: 10.1088/1751-
711 8113/44/8/085201.
- 712 [69] J. F. Hair, G. T. M. Hult, C. . Ringle, M. Sarstedt, N. . Danks, and S. Ray, *Partial least
713 squares structural equation modeling (PLS-SEM) using R: A workbook*. 2021.
- 714 [70] V. E. Vinzi, W. W. Chin, J. Henseler, and H. Wang, *Handbook of Partial Least
715 Squares*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2010.
- 716 [71] FAO, “A Framework for Innovation,” *FAO Soils Bull.*, vol. 32, no. 22, pp. 1–92, 1976,
717 doi: 10.1007/978-3-030-45139-4_4.
- 718 [72] Widiatmaka, A. Sutandi, A. Iswandi, U. Daras, M. Hikmat, and A. Krisnohadi,
719 “Establishing Land Suitability Criteria for Cashew (*Anacardium occidentale* L.) in
720 Indonesia,” *Appl. Environ. Soil Sci.*, vol. 2014, no. 743194, pp. 1–14, 2014, doi:
721 10.1155/2014/743194.
- 722 [73] W. W. Chin, “The Partial Least Squares Approach to Structural Formula Modeling,”
723 in *Modern Methods for Business Reseach*, no. January 1998, G. A. Marcoulides, Ed.
724 Mahwah, New Jersey: Lawrence Erlbaum Associates, 1998, pp. 295–336.
- 725 [74] R. . Darmawan, “Analysis of the Effect of Work-Family Conflict and Job Stress on the
726 Job Performance of Nurses at ‘X’ Hospital,” *Agora*, vol. 6, no. 2, pp. 1–6, 2018,
727 [Online]. Available: <https://www.neliti.com/id/publications/287084>.
- 728 [75] J. F. Hair, M. Sarstedt, C. M. Ringle, and J. A. Mena, “An assessment of the use of
729 partial least squares structural equation modeling in marketing research,” *J. Acad.
730 Mark. Sci.*, vol. 40, no. 3, pp. 414–433, 2012, doi: 10.1007/s11747-011-0261-6.
- 731 [76] R. P. Bagozzi and Y. Yi, “On the evaluation of structural equation models,” *J. Acad.
732 Mark. Sci.*, vol. 16, no. 1, pp. 74–94, Mar. 1988, doi: 10.1007/BF02723327.
- 733 [77] T. M. Basuki, D. R. Indrawati, and B. Haryadi, “The Use of Organic Matter to
734 Improve Productivity of Post Lime Mining Land,” *J. For. Nat. Conserv. Res.*, vol. 4,
735 no. 1, pp. 1–8, 2007, doi: 10.20886/jphka.2007.4.1.1-8.
- 736 [78] M. S. Alfian and H. Purnamawati, “Dose and Time of Potassium Fertilizer Application
737 on Growth and Sweet Corn Production at NATC Batangkaluku Gowa regency of
738 South Sulawesi,” *Bul. Agrohorti*, vol. 7, no. 1, pp. 8–15, 2019, doi:
739 10.29244/agrob.v7i1.24404.
- 740 [79] S. Nasreen, M. M. Haque, M. A. Hossain, and A. T. M. Farid, “Nutrient uptake and
741 yield of onion as influenced by nitrogen and sulphur fertilization,” *Bangladesh J.
742 Agric. Res.*, vol. 32, no. 3, pp. 413–420, Jan. 2008, doi: 10.3329/bjar.v32i3.543.
- 743 [80] Y. Abdissa, T. Tekalign, and L. M. Pant, “Growth, Bulb Yield and Quality of Onion
744 (*Allium cepa* L.) as Influenced by Nitrogen and Phosphorus Fertilization on Vertisol I.
745 Growth Attributes, Biomass Production and Bulb Yield,” *African J. Agric. Res.*, vol. 6,

- 746 no. 14, pp. 3252–3258, 2011, doi: 10.5897/AJAR10.1024.
- 747 [81] I. Firmansyah and N. Sumarni, “Effect of N Fertilizer Dosages and Varieties On Soil
748 pH, Soil Total-N, N Uptake, and Yield of Shallots (*Allium ascalonicum* L.) Varieties
749 On Entisols-Brebes Central Java,” *J. Hortik.*, vol. 23, no. 4, p. 358, May 2016, doi:
750 10.21082/jhort.v23n4.2013.p358-364.
- 751 [82] E. Sumiati and O. S. Gunawan, “Application of Mycorrhizal Biofertilizer to Increase
752 the Efficiency of NPK Uptake and its Effects on Yiled and Quality of Shallot Bulbs,”
753 *J. Hort*, vol. 17, no. 1, pp. 34–42, 2006, doi: 10.21082/jhort.v17n1.2007.p%p.
- 754 [83] H. R. McKenzie, “Potassium Fertilizer Application in Crop Production,” *Agri-Facts*,
755 vol. 542, no. 9, pp. 1–7, 2013, [Online]. Available:
756 <https://open.alberta.ca/publications/6060438>.
- 757 [84] M. Dianawati, “Rates and application time of K₂SO₄ on production of G0 potato
758 seed,” *J. Kultiv.*, vol. 17, no. 1, pp. 531–536, 2018, [Online]. Available:
759 <http://jurnal.unpad.ac.id/kultivasi/article/viewFile/15499/7786>.
- 760 [85] N. Gunadi, “The Use of Potassium Sulphate as an Alternative Source of Potassium
761 Fertilizer in Potato,” *J. Hort*, vol. 17, no. 1, pp. 52–60, 2019, [Online]. Available:
762 <http://repository.pertanian.go.id/handle/123456789/7798>.
- 763 [86] I. S. Rahmawan, A. Z. Arifin, and Sulistyawati, “The effect of potassium (K) fertilizer
764 on growth and yield of cabbage (*Brassica oleraceae* var. *capitata*, L.),” *J.*
765 *Agroteknologi Merdeka Pasuruan*, vol. 3, no. 1, pp. 17–23, 2019.
- 766 [87] Subandi, “Role and Management of Potassium Nutrient for Food Production in
767 Indonesia,” *Agric. Innov. Dev.*, vol. 6, no. 1, pp. 1–10, 2013, [Online]. Available:
768 [https://www.neliti.com/publications/30881/role-and-management-of-potassium-](https://www.neliti.com/publications/30881/role-and-management-of-potassium-nutrient-for-food-production-in-indonesia)
769 [nutrient-for-food-production-in-indonesia](https://www.neliti.com/publications/30881/role-and-management-of-potassium-nutrient-for-food-production-in-indonesia).
- 770 [88] IIED, “Potash Case Study: Information supplied by the International Fertilizer Industry
771 Association,” *Mining, Miner. Sustain. Dev.*, vol. 65, no. February, p. 9, 2002, [Online].
772 Available: http://www.agritrade.org/documents/Biofuels_Subsub_Web_Final.pdf.
- 773 [89] N. Nursjahbani, O. Rusdiana, and . D., “Suitability of *Durio zibethinus* Murr. and
774 *Nephelium lappaceum* L. on the Utilization Block at Menumbing Mountain Grand
775 Forest Park, West Bangka,” *J. Trop. Silv.*, vol. 9, no. 1, pp. 1–6, May 2018, doi:
776 10.29244/j-siltrop.9.1.1-6.
- 777 [90] I. W. Nyakudya and L. Stroosnijder, “Effect of rooting depth, plant density and
778 planting date on maize (*Zea mays* L.) yield and water use efficiency in semi-arid
779 Zimbabwe: Modelling with AquaCrop,” *Agric. Water Manag.*, vol. 146, pp. 280–296,
780 Dec. 2014, doi: 10.1016/j.agwat.2014.08.024.
- 781 [91] S. B. Wang *et al.*, “Effect of subsoiling depth on soil physical properties and summer
782 maize (*Zea mays* L.) yield,” *Plant, Soil Environ.*, vol. 65 (2019), no. No. 3, pp. 131–
783 137, Mar. 2019, doi: 10.17221/703/2018-PSE.
- 784 [92] H. Z. Khan, M. A. Malik, and M. F. Saleem, “Effect of rate and source of organic
785 material on the production potential of spring maize (*Zea mays* L.),” *Pak. J. Agri. Sci.*,
786 vol. 45, no. 1, pp. 40–43, 2008, [Online]. Available:
787 <https://pakjas.com.pk/papers/222.pdf>.
- 788 [93] A. Jalal, K. Azeem, M. C. M. T. Filho, and A. Khan, “Enhancing Soil Properties and
789 Maize Yield through Organic and Inorganic Nitrogen and Diazotrophic Bacteria,” in
790 *Sustainable Crop Production*, IntechOpen, 2020, pp. 1–14.

- 791 [94] E. E. Kandil, N. R. Abdelsalam, M. A. Mansour, H. M. Ali, and M. H. Siddiqui,
792 “Potentials of organic manure and potassium forms on maize (*Zea mays* L.) growth
793 and production,” *Sci. Rep.*, vol. 10, no. 1, p. 8752, Dec. 2020, doi: 10.1038/s41598-
794 020-65749-9.
- 795 [95] Mulyati, A. B. Baharuddin, and R. S. Tejowulan, “Improving Maize (*Zea mays* L.)
796 growth and yield by the application of inorganic and organic fertilizers plus,” *IOP*
797 *Conf. Ser. Earth Environ. Sci.*, vol. 712, no. 1, p. 012027, Mar. 2021, doi:
798 10.1088/1755-1315/712/1/012027.
- 799 [96] D. A. Kane, M. A. Bradford, E. Fuller, E. E. Oldfield, and S. A. Wood, “Soil organic
800 matter protects US maize yields and lowers crop insurance payouts under drought,”
801 *Environ. Res. Lett.*, vol. 16, no. 4, p. 044018, Apr. 2021, doi: 10.1088/1748-
802 9326/abe492.
- 803 [97] Mujiyo, W. Larasati, H. Widijanto, and A. Herawati, “The Effect of Slope Gradient of
804 land on the Soil Damage in Giritontro, Wonogiri.,” *Agrotrop J. Agric. Sci.*, vol. 11,
805 no. 2, p. 115, 2021, doi: 10.24843/ajaoas.2021.v11.i02.p02.
- 806 [98] D. O. Suparwata, Nurmi, and M. I. Bahua, “Using vertical mulch to upland for
807 reducing erosion, runoff and its responses to maize growth and yields,”
808 *Agroteknotropika*, vol. 1, no. 3, pp. 138–145, 2012, doi: 10.31227/osf.io/5aek7.
- 809 [99] R. E. Christanto, Suryono, Mujiyo, and J. Winarno, “The Degree of Erosion Hazard
810 Mapping in Dry Land at Jatipuro Sub District of Karanganyar with Geographic
811 Information System (GIS,” *Sains Tanah - J. Soil Sci. Agroclimatol.*, vol. 7, no. 2, pp.
812 114–119, 2013, doi: 10.15608/stjssa.v7i2.42.
- 813 [100] E. Elfayetti and H. Herdi, “Land Suitability Evaluation for Maize Crops in Saentis
814 Village, Percut Sei Tuan,” *JUPIIS J. Pendidik. ILMU-ILMU Sos.*, vol. 7, no. 1, p. 33,
815 Jul. 2015, doi: 10.24114/jupiis.v7i1.2295.
- 816 [101] Sukarman, A. Mulyani, and S. Purwanto, “The Modification of Land Evaluation
817 Methods for Oriented Climate Change,” *J. Sumberd. Lahan*, vol. 12, no. 1, p. 1, Jun.
818 2018, doi: 10.21082/jsdl.v12n1.2018.1-11.
- 819 [102] W. Chivasaa, O. Mutanga, and C. Biradarc, “Mapping land suitability for maize (*Zea*
820 *mays* L.) production using GIS and AHP technique in Zimbabwe,” *South African J.*
821 *Geomatics*, vol. 8, no. 2, pp. 265–281, Sep. 2022, doi: 10.4314/sajg.v8i2.11.

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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
 16 for hybrid maize in Boalemo Regency based on the optimum yield and land quality. It was
 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**

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

36 In Indonesia, the wet tropical climate with rainfall and high temperatures tends to reduce the
 37 quality of land and agricultural products [4]. This country ranked 8th among the maize-
 38 producing 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.

44 In Indonesia, Gorontalo Province is one of the centers of maize production, where the hybrid
 45 type is the most widely grown species [9]. The maize production in the province reached 1.8
 46 million tons in 2021 [10], with several export advantages and competitiveness [11].
 47 Furthermore, the planting of hybrid, composite, and local maize types has reached more than
 48 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
 51 district by 37.43% [14], therefore, the commodity has competitive and comparative advantages
 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 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
 65 affecting the optimum yield of maize needs to be determined [26] and increased by using hybrid
 66 varieties that have high yields. This makes it necessary to evaluate the suitability of the hybrid
 67 maize in a region to ensure optimal production. The land suitability criteria for hybrid maize
 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
 82 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
 84 used temporarily since structural equation model analysis with partial least squares produces

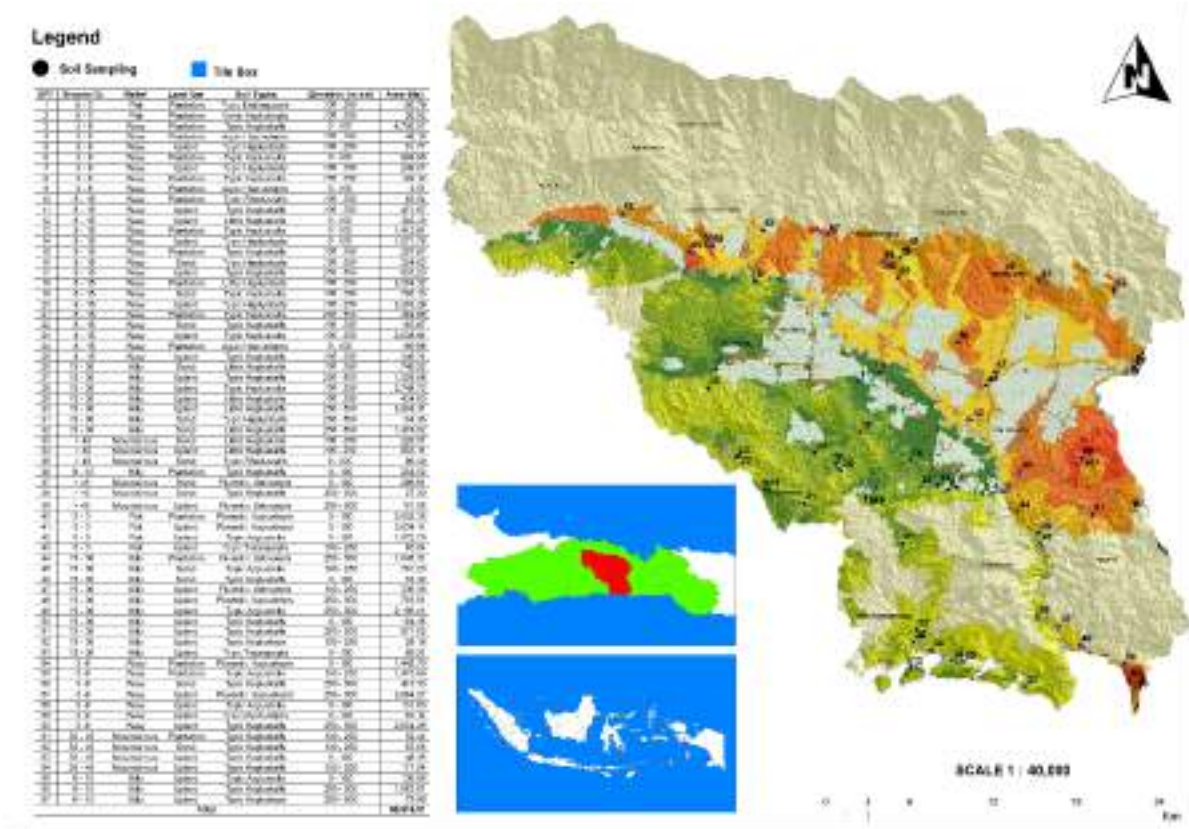
85 better indicators and models than other multivariate analyses [31]–[35]. This is because the
86 variant-based PLS-SEM has a higher level of flexibility and the size of the sample used is
87 relatively small ranging from 30 to 100 [36]–[39]. The use of PLS-SEM to determine land
88 characteristics and qualities that control maize crop yields is still relatively rare, except for Syaf
89 [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.

94 After obtaining the quality and characteristics of land affecting maize yields with PLS-SEM,
95 the boundary line method can be used to determine the optimum yield as well as land suitability
96 criteria simultaneously. This is carried out by drawing the intersection of the boundary line at
97 the yield and projecting with the land characteristics [29]. Therefore, this study aims to
98 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
103 (Figure 1) on a scale of 1 : 40,000, which is located in the agricultural land of Boalemo
104 Regency, Gorontalo Province, Indonesia. The maximum air temperature was 28.19°C and the
105 minimum was 26.79°C with an average of 28.01°C. Meanwhile, the maximum rainfall was
106 1,849 mm and the minimum was 1,246 mm with an average of 1,478 mm [45]. The wet and
107 dry seasons last for 3 months and 5 months respectively. The soil mapping carried out by
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,
110 drainage, texture, pH, cation exchange capacity, base saturation, landform, parent material,
111 relief, and land unit area. Meanwhile, the new soil unit is 1 : 40,000 in scale and there has been
112 a change in the agricultural land use existing. This indicated that the slope class of 8 – 15% or
113 hilly is more dominant in the study area with a percentage of 29.77% and slopes > 40% or
114 mountainous which is only 2.67%. Furthermore, the dry land is dominant with a value of
115 59.86% and a little shrub which was only 9.21%, while the dominant Typic Haplustalfs of soil
116 sub group classification was 22.47%, then the Fluventic Haplustepts was 21.31% and very little
117 Vertic Haplustepts of soil sub group classification was 0.04% only (Figure 1).



118

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
 124 availability is determined from the characteristics of annual rainfall, wet months, dry months,
 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
 127 material, and soil effective depth, nutrient retention is identified from the pH value, C-Organic,
 128 cation exchange capacity (CEC), and base saturation. Furthermore, the available nutrient is
 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
 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 characteristics is based on the availability of data and their impact on maize production [26].

135 Data on average annual air temperature and rainfall for 10 years (2010-2021) were collected
 136 from different climate stations, namely the Bandungrejo with 0°41' N - 122°38' E, the elevation
 137 40 m asl, while Harapan has 0°42' N - 122°29' E and an elevation of 37 m asl. It also includes
 138 Lakeya Rain Post with 0°42.82' N - 122°32.07' E, 32 m asl, Mohiyolo has 0°46.41' N -
 139 122°26.41' E and an elevation of 39 m asl, Saritani 0°46.45' N - 122°20.40' E, with 26 m asl,
 140 Tangkobu 0°37.25' N - 122°36.36' E, 25 m asl, Bubaa 0°31.36' N - 122°33.39' E, 16 m asl,
 141 Wonggahu 0°38' N - 122°33' E, 35 m asl, and Sambati Rain Post with 0°31.184' N - 122°27.074'

142 E and an elevation of 9 m asl managed by BWS II Sulawesi. Furthermore, these data
143 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 LGP methods based on the number of surplus and deficit rainy days [49].

146 Based on the previous soil unit [46], then these soil unit was detailed again by adding 32 of
147 soil units to be surveyed and observed, making up to 67 soil units in the area as shown in the
148 legend Figure 1. Soil characteristics such as drainage, coarse material, effective soil depth,
149 slope, inundation height and duration, rock outcrops and surface rocks were determined by
150 conducting soil profile descriptions and direct observation on 67 pedons referring to the
151 description guidelines in the field [50]. Meanwhile, soil erosion was determined by the USLE
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
157 using the pipette method, while soil moisture storage was evaluated using the gravimetric
158 method that can be applied in water balance analysis. The method of soil chemistry laboratory
159 analysis was carried out according to the procedures by Eviyati and Sulaeman [53]. The soil
160 pH was determined with a pH meter in a 1:2.5 soil and water solution, while the organic C
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
163 basic cations and CEC was extracted with 1N NH₄OAc pH 7.0 (ammonium acetate) on a dry
164 sample of 105°C. The base saturation was determined by calculating the percentage of basic
165 cations number with CEC, ESP was evaluated using the percentage ratio of sodium to CEC
166 [54] [55]. Subsequently, the data from the chemical analysis were averaged to a depth of 0-30
167 cm using the weighted averaging technique. The framework of this study is presented in Figure
168 2.

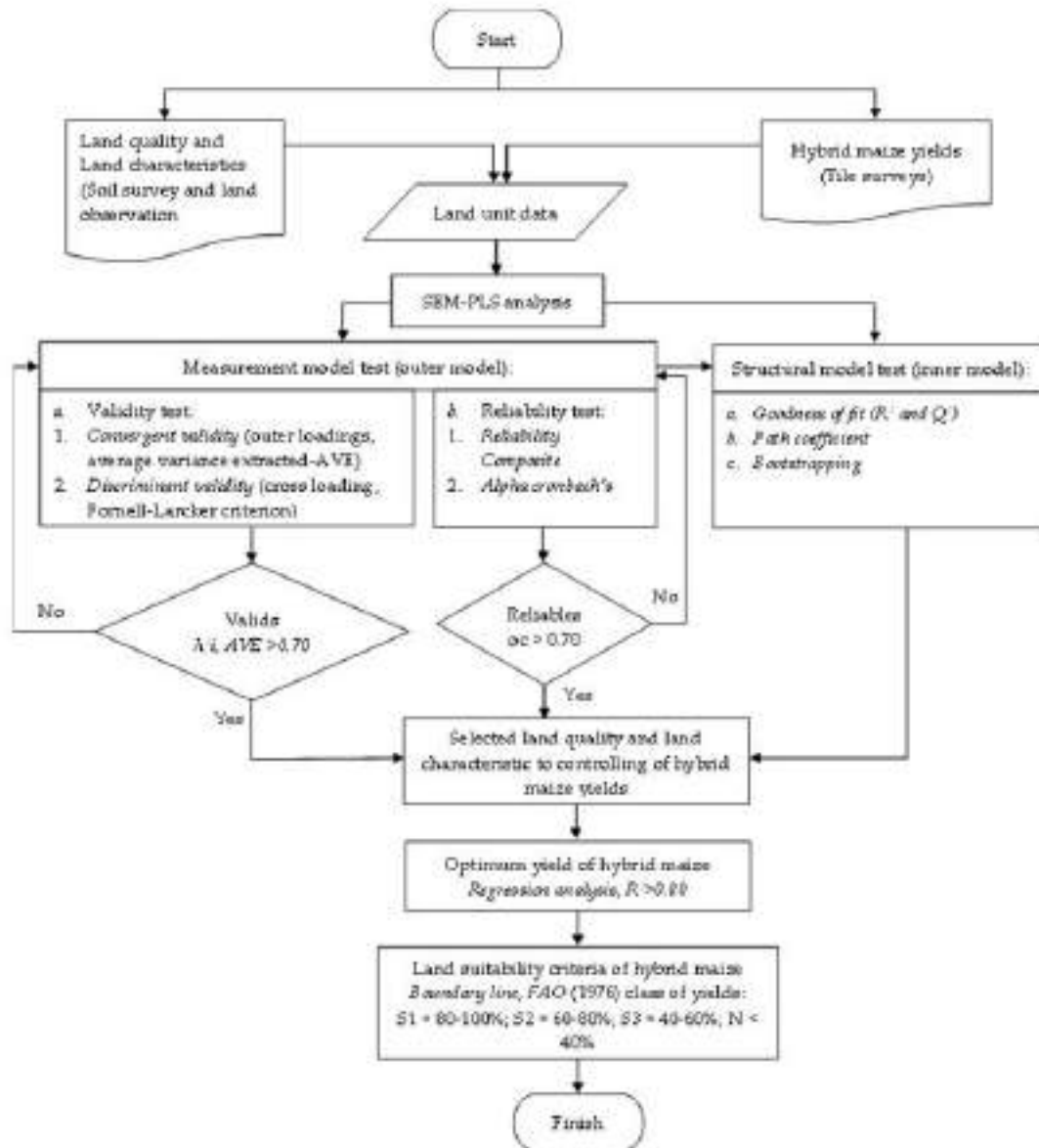


Figure 2: Research framework.

169

170

171 2.3 Dataset collection for hybrid maize yield

172 The areas currently planted with hybrid maize were identified and blocks with a size of 2.5 m
 173 x 2.5 m were made in each map unit (Figure 1). Maize plants in each block passed through
 174 standardized management according to farmers' technology. After harvesting, weighting was
 175 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:

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

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

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

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

191 Table 1: Latent variables and indicators used in this study

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

192

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

198 Convergent validity was observed from the magnitude of the outer loading and the AVE value
 199 of each indicator on the latent variable. The validity was calculated according to the equation
 200 [57][58][59][60]:

$$201 \quad x_i = \lambda x_i \xi_l + \delta_i \quad (3)$$

$$202 \quad y_i = \lambda y_i \eta_l + \varepsilon_i \quad (4)$$

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

205 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	1.06
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)							
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

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

208 Meanwhile, the average variance extracted (AVE) value was calculated using the equation
209 [61][62][63][64][65]:

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

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

212 The loading factor of an indicator with the highest value is the strongest or most important
213 measure in reflecting the latent variable. In this study, the loading factor value is > 0.70 for
214 selecting best land characteristics, but values ranging from 0.50-0.60 can still be tolerated with
215 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]:

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

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

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

$$231 \quad \rho_c = \frac{(\sum \lambda_i)^2}{(\sum \lambda_i)^2 + \sum i \text{ var}(\varepsilon_i)} \quad (7)$$

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]:

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

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

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

$$239 \quad H_j = \gamma_j \zeta_1 + \gamma_j \zeta_2 + \dots \gamma_j \zeta_n + \zeta_j \quad (9)$$

240 where η_j = endogenous variable vector (dependent), $\gamma_j \zeta_1 + \gamma_j \zeta_2 + \dots \gamma_j \zeta_n$ = exogenous latent
241 variable vector, and ζ_j = residual vector (error).

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

$$244 \quad Q^2 \text{ (Predictive relevance)} = 1 - (1 - R_1^2) (1 - R_2^2) \dots (1 - R_p^2) \quad (10)$$

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

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

253 2.5 Class assignment

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

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

270 Furthermore, with the Microsoft Excel application tools, the boundary between classes S1 to
 271 S2, S2 to S3, and S3 to N were determined by the Data menu → What-if-Analysis → Goal
 272 Seek → Set the cell at the location containing the regression equation → to value fill with the
 273 result limit values S1 to S2, S2 to S3, and S3 to N → By changing cell → the location where
 274 the value of the characteristics of the land will be sought → Ok. On location "By changing
 275 cell", the number being searched will appear, and at the location "set cell" will be equal to the
 276 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
 282 highly recommended and the indicators are considered convergently valid. In the soil texture
 283 indicator for the latent variable of root conditions as well as the cation exchange capacity (CEC)
 284 and base saturation (BS) indicators for nutrient retention, the loading factor was below the
 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].

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

294 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) →	X1 (Temperature)	1.000**	11.192	Valid	1.000
X2.1 (Rainfall) →	X2 (Water availability)	0.838	0.085	Valid	0.906
X2.2 (Wet month) →		0.989	0.999	Valid	
X2.3 (Dry month) →		0.850	0.428	Valid	
X2.4 (LGP) →		0.993*	1.431	Valid	
X3.1 (Drainage) →	X3 (Oxygen availability)	1.000	0.000	Valid	1.000
X4.1 (Texture) →	X4 (Rooting condition)	0.013	0.066	Invalid	0.573
X4.2 (Coarse material) →		0.921	1.086	Valid	
X4.3 (Effective depth) →		-0.899	1.047	Valid	
X5.1 (pH H ₂ O) →	X5 (Nutrient retention)	0.647	0.857	Valid	0.360 (invalid)
X5.2 (pH KCl) →		0.570**	1.973	Valid	
X5.3 (Organic C) →		0.831**	3.135	Valid	

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

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

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

304 3.1.2 Reliability test result

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

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

314 The remaining variables are water availability, nutrient retention, available nutrients, erosion
 315 hazard, and land preparation variables. The coefficient of composite reliability and cronbach's
 316 alpha > 0.6, there, the variable is considered reliable. The minimum value of composite
 317 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

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

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Table 5: Cross-Loading of latent variables to indicators

Indicators	Latent Variables										
	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

330 X1 = temperature, X2 = water availability, X3 = oxygen availability, X4 = rooting condition, X5 = nutrient retention, X6 = nutrient availability, X7 = sodicity, X8 = erosion
331 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 =
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, 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.

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

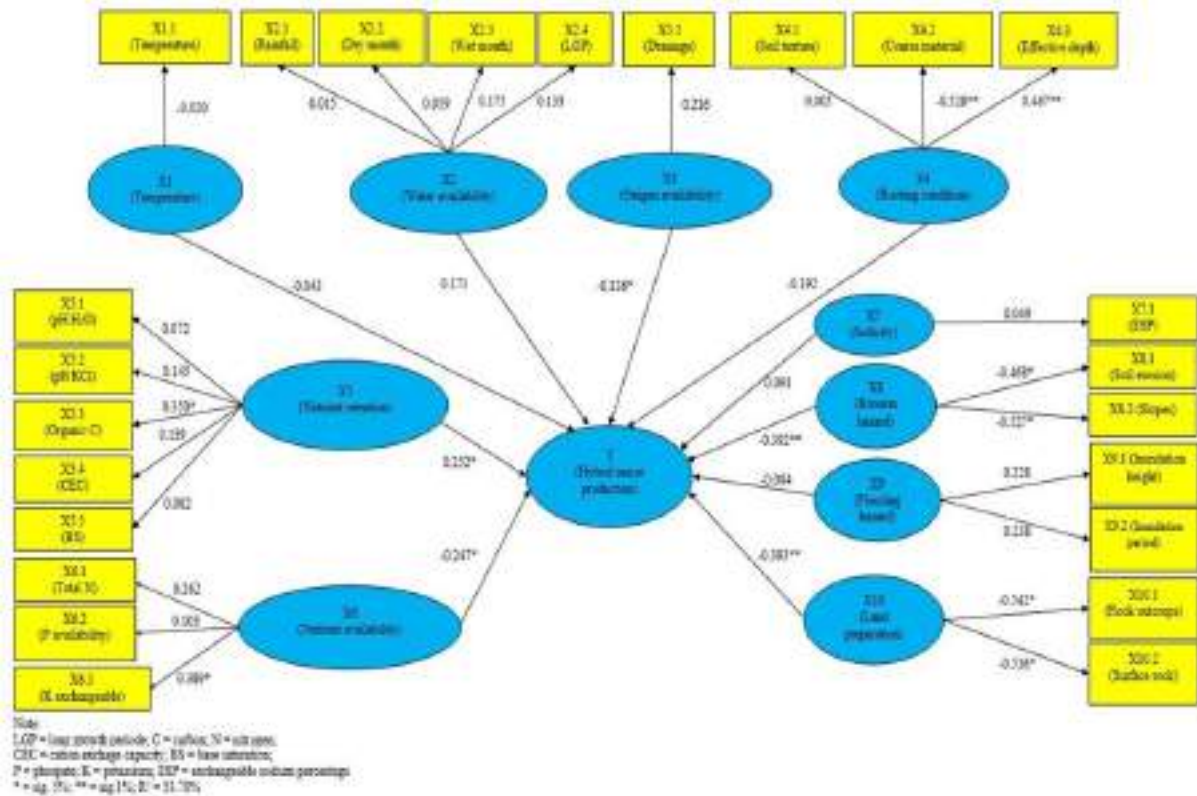
Indicators (land characteristics)	Cronbach's Alpha	Composite Reliability
X1.1 (Temperature)	1.000	1.000
X2.1 (Rainfall)		
X2.2 (Wet month)	0.975	0.965
X2.3 (Dry month)		
X2.4 (Long growth periods)		
X3.1 (Drainage)	1.000	1.000
X4.1 (Texture)		
X4.2 (Coarse material)	0.002 ^{nor}	-1.055 ^{nor}
X4.3 (Effective 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)		
X9.1 (Inundation height)	0.992	0.984
X9.2 (Inundation period)		
X10.1 (Rock outcrops)	0.998	0.995
X10.2 (Surface rock)		

336 nor = not reliable.

337 *3.1.3 Structural model test (inner models)*

338 Land characteristics that have a significant correlation with hybrid maize yields show a high
339 level of contribution to land quality in influencing hybrid maize yields as indicated in Figure
340 3. The figure shows a structural model of the relationship between indicator variables, namely
341 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.

345 For example, X8 (erosion hazard) significantly determines the hybrid maize yield with a path
346 coefficient of -0.392. The negative sign indicates that the erosion hazard is negatively related
347 to maize yield, where the higher the erosion hazard, the lower the maize yield. Furthermore,
348 nutrient retention (X5) contributes to the diversity of hybrid maize yields with a path coefficient
349 of 0.252. A positive sign indicates that nutrient retention is positively related to maize yield,
350 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.

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 (X10). 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
 357 and effective soil depth as an indicator of rooting condition, organic carbon content as nutrient
 358 retention, exchangeable K as nutrient availability, soil erosion and slope as erosion hazard, as
 359 well as rock outcrop and surface rock as an indicator of land preparation. It was also indicated
 360 that the drainage loading factor was unable to explain the diversity of oxygen availability.
 361 Therefore, oxygen availability cannot be used as a land quality because there are no indicators
 362 that can represent it. Only the land qualities of nutrient retention (X5), nutrient availability
 363 (x6), erosion hazard (x8), and land preparation (X10) were used next.

364 The indicators of land characteristics for effective depth, organic C, total N, and exchangeable
 365 K have a fairly strong positive relationship and a very significant effect on hybrid maize yields.
 366 In this relationship, an increase in these parameters by 1%, will be followed by a rise in hybrid
 367 maize yields of 39% to 57.7%. According to Wirosodarmo et al. [4], effective depth affects
 368 root growth and development, making plants grow and develop properly. Moreover, the levels
 369 of organic C, total N, and CEC are influenced by soil organic matter [77], while potassium
 370 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
 372 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
 374 outcrop is followed by an increase in hybrid maize yields by 39% to 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.

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

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	$Y = -0.0008354x^2 + 0.29100569x - 1.3957496$	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

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 R² 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 [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 R² 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

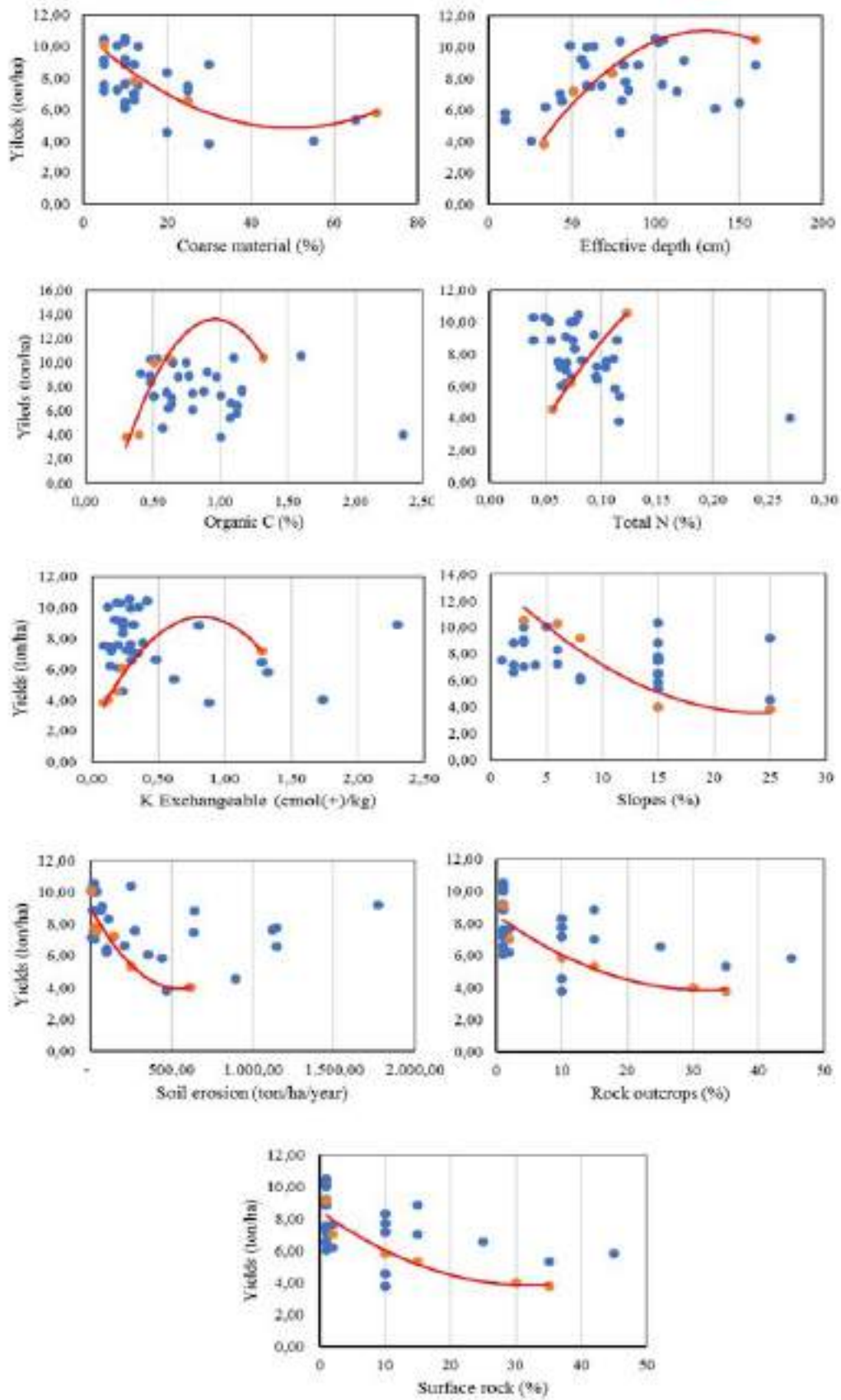
397 water use, N uptake, protein synthesis, and assimilate translocation [83]–[86]. It also plays a
398 role in improving the quality of crop yields (McKenzie, 2013, Subandi, 2013).

399 The optimum hybrid maize yield of the remaining is relatively diverse. This includes effective
400 depth and organic carbon, which were both 8.46 ton/ha with an R^2 value of 97%. Furthermore,
401 coarse material and soil erosion were 8.17 ton/ha with an R^2 value of 96% and 89%, while rock
402 outcrops and surface rock were 7.41 ton/ha with an R^2 value of 92%. The absence of coarse
403 material > 2 mm in diameter indicated that plant roots can grow freely on the surface or deeper
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
406 content [95] because soil organic matter is a strong positive predictor of yield [96]. Kane et al.
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
409 degradation [97]. According to a previous study, erosion and maize yield are negatively
410 correlated, hence, increased erosion will reduce maize productivity [98]. Soil erosion on flat
411 land is slower surface runoff [99]. It was also reported that surface rocks and outcrops are the
412 limiting factors in the suitability of maize plantations [100]. Therefore, a high percentage of
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
416 the class range for each land characteristic is derived. Based on the optimum yield of the highest
417 hybrid maize, there were 2 indicators, namely the total N content and the slope. The total N
418 indicator with a very suitable class (S1) was achieved when the value in the soil was greater
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
421 was achieved when the total N in the soil ranges from 0.06-0.07%, while the not suitable class
422 (N) was achieved when the content was less than 0.06%. On the slope indicator with class S1,
423 it was obtained when the slope class ranges from 0-7.70%, while class S2 was achieved when
424 the slope class ranges from 7.71-11.84%. Furthermore, in classes S3 and N, it was obtained
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
427 indicator. In classes S1 and S2, it was achieved when the exchangeable K content in the soil
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
433 obtained as presented in Table 8.



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

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

Land Quality/Land Characteristics	Yield Limits (ton/ha)			Value of Land Suitability Criterion Obtained			
	S1 - S2 (80% x Y _{optim})	S2 - S3 (60% x Y _{optim})	S3 - N (40% x Y _{optim})	S1	S2	S3	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

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

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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].

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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].

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Compared to Wahyunto et al. [47], 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

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

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

Land Quality/Land Characteristics	New Land Suitability Criterion of Hybrid Maize				Land Suitability Criterion of General Maize [47]			
	S1	S2	S3	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	Mo	Lo	VLo	-
K 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

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

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494 **References**

- 495 [1] K. Pawlak and M. Kołodziejczak, “The Role of Agriculture in Ensuring Food Security
496 in Developing Countries: Considerations in the Context of the Problem of Sustainable
497 Food Production,” *Sustainability*, vol. 12, no. 13, p. 5488, Jul. 2020, doi:
498 10.3390/su12135488.
- 499 [2] O. Erenstein, M. Jaleta, K. Sonder, K. Mottaleb, and B. M. Prasanna, “Global maize
500 production, consumption and trade: trends and R&D implications,” *Food Secur.* 2022,
501 pp. 1–25, May 2022, doi: 10.1007/S12571-022-01288-7.
- 502 [3] U. Grote, A. Fasse, T. T. Nguyen, and O. Erenstein, “Food Security and the Dynamics
503 of Wheat and Maize Value Chains in Africa and Asia,” *Front. Sustain. Food Syst.*, vol.
504 4, no. February, pp. 1–17, Feb. 2021, doi: 10.3389/fsufs.2020.617009.
- 505 [4] R. Wirosoedarmo, A. T. Sutanhaji, and E. Kurniati, “Land Suitability Assessment Of
506 Corn (*Zea mays* L.) Using Spasial Analysis Method,” *agriTECH*, vol. 31, no. 1, pp.
507 71–78, 2012, doi: <https://doi.org/10.22146/agritech.9728>.
- 508 [5] B. Arifin, “High expectations on KSA maize production,” *Stat. Policy Br. Indones.*,
509 vol. 18, no. December, pp. 37–41, 2021, [Online]. Available:
510 <https://fmsindonesia.id/wp-content/uploads/2022/01/Buletin-17-FINAL.pdf>.
- 511 [6] Nurdin, M. L. Rayes, Soemarno, and Sudarto, “Analysis of Quality and Land
512 Characteristics That Control Local Maize Production in Gorontalo,” in *the*
513 *International Seminar on Promoting Local Resources for Sustainable Agriculture and*
514 *Development (ISPLRSAD 2020)*, 2021, vol. 13, no. Isplrsad 2020, pp. 438–446, doi:
515 10.2991/absr.k.210609.068.
- 516 [7] T. Kartika, “The Effect of Planting Distance on Growth and Production of Non Hybrid
517 Maize (*Zea Mays* L) in the Land of Integrated Technology Agro Center (ATP),”
518 *Sainmatika J. Ilm. Mat. dan Ilmu Pengetah. Alam*, vol. 15, no. 2, p. 129, Dec. 2018,
519 doi: 10.31851/sainmatika.v15i2.2378.
- 520 [8] Sutimawati, A. N. Aulia, and R. M. Muliasari, “Comparative Analysis of Hybrid Corn
521 Farming Based on Business Scale in Tempurejo Sub-District,” *J. Agribest*, vol. 3, no.
522 1, p. 61, Mar. 2019, doi: 10.32528/agribest.v3i1.1950.

- 523 [9] I. S. Anugrah, "Corn-Based Agribusiness for Rural Economic Development in
524 Gorontalo Province," *Anal. Kebijak. Pertan.*, vol. 8, no. 4, pp. 363–383, 2016,
525 [Online]. Available: <http://ejurnal.litbang.pertanian.go.id/index.php/akp/index>.
- 526 [10] H. Limanseto, "The Government Encourages Productivity of the Leading
527 Commodities of Gorontalo Province to Increase People's Welfare," *Coordinating*
528 *Ministry for Economic Affairs of the Republic of Indonesia*, vol. 1. Coordinating
529 Ministry for Economic Affairs of the Republic of Indonesia, Jakarta, pp. 1–2, 2021.
- 530 [11] N. Endey, I. K. S. Arsana, A. Y. Katili, A. Sahabi, and M. A. Talalu, "Competitiveness
531 Analysis of Gorontalo's Leading Commodities in Supporting the New Capital City of
532 the Republic of Indonesia," *Equilib. J. Pendidik.*, vol. 10, no. 3, pp. 380–396, 2022,
533 doi: 10.26618/equilibrium.v10i3.8571.
- 534 [12] K. Astuti, R. O. Prasetyo, and N. . Khasanah, *Analysis of Maize and Soybean*
535 *Productivity in Indonesia 2020 (the Result of Crop Cutting Survey)*, vol. 05100.2103,
536 no. 5203029. BPS RI, 2021.
- 537 [13] BPS-Statistic of Gorontalo, "Gorontalo Province In Figures 2018," *BPS-Statistic of*
538 *Gorontalo*, vol. 75560.1811, no. 1102001.75. pp. 1–390, 2018.
- 539 [14] W. Ardiansyah, M. A. Indrianti, M. M. Djibran, and D. R. Hippy, "The Performance
540 of Dry Land Farming for Transmigrate Farmers (Case Study in Saritani Village,
541 Wonosari Sub-District, Boalemo Regency)," *J. Agriovet*, vol. 4, no. 2, pp. 125–142,
542 Apr. 2022, doi: 10.51158/agriovet.v4i2.726.
- 543 [15] A. H. Samon, "The Analysis of Comparative and Competitive Superiority of Corn
544 Farm Enterprises in Boalemo Regency," Hasanuddin University, 2005.
- 545 [16] A. M. D. Putri and Mustofiq, *Boalemo Regency in Figures 2022*, vol. 75010.2201, no.
546 1102001.7501. BPS-Statistics of Boalemo Regency, 2022.
- 547 [17] W. Tialo, M. Arief Azis, and N. Nurdin, "Gorontalo local waxy maize growth and
548 production, agronomic, and economic effectiveness with organic fertilizer treatment in
549 Bualo, Boalemo Regency," *J. Agercolere*, vol. 4, no. 2, pp. 44–53, 2022, doi:
550 10.37195/jac.v4i2.168.
- 551 [18] K. P. W. Sukma, "Growth and Production of Local Maize, Hybrid and Composite in
552 Pamekasan, Madura," *J. Agrosains Karya Kreat. dan Inov.*, vol. 4, no. 2, p. 34, May
553 2018, doi: 10.31102/agrosains.2017.4.2.34-38.
- 554 [19] Bapelitbang Boalemo Regency, "Local Government Work Plan for 2022," *Boalemo*
555 *Regent Regulation Number 49 of 2020*, vol. 49. 2021.
- 556 [20] A. K. Lasiki, Nurdin, and I. Husain, "Growth and Yield of Hybrid Corn in Several
557 Classes of Slopes and Fertilization Doses in Bumela Village, District Of Gorontalo," *J.*
558 *Agroteknotropika*, vol. 10, no. 2, pp. 59–69, 2021, [Online]. Available:
559 <https://ejurnal.ung.ac.id/index.php/JATT/article/view/13459>.
- 560 [21] D. K. S. Swastika, "Corn Self-Sufficiency in Indonesia: The Past 30 years and Future
561 Prospects," *J. Litbang Pertan.*, vol. 21, no. 3, pp. 75–83, 2002, [Online]. Available:
562 <https://agris.fao.org/agris-search/search.do?recordID=ID2005000155>.
- 563 [22] E. Kaya, A. Siregar, D. M. Y. Matulessy, and M. Hasan, "Growth and Yield of Corn
564 (*Zea mays* L.) due to The Granting of Sago Palm Waste Compost of Sago Palm Waste
565 Compost and Organic Liquid Fertilizer (OLF) in Ultisols," *J. Budid. Pertan.*, vol. 12,
566 no. 1, pp. 16–19, 2016, [Online]. Available:
567 <https://ojs3.unpatti.ac.id/index.php/bdp/article/view/42>.

- 568 [23] R. Yacoub, "Land Qualities as a Function to Estimate Land Productivity in the
569 Recently Reclaimed Calcareous Soils , Nubariya , Egypt .," *Egypt. J. Geosci.*, vol. 50,
570 no. 4, pp. 1–13, 2010, [Online]. Available:
571 [https://www.researchgate.net/publication/327838295_Land_Qualities_as_a_Function_](https://www.researchgate.net/publication/327838295_Land_Qualities_as_a_Function_to_Estimate_Land_Productivity_in_the_Recently_Reclaimed_Calcareous_Soils_Nubariya_Egypt)
572 [to_Estimate_Land_Productivity_in_the_Recently_Reclaimed_Calcareous_Soils_Nuba](https://www.researchgate.net/publication/327838295_Land_Qualities_as_a_Function_to_Estimate_Land_Productivity_in_the_Recently_Reclaimed_Calcareous_Soils_Nubariya_Egypt)
573 [riya_Egypt](https://www.researchgate.net/publication/327838295_Land_Qualities_as_a_Function_to_Estimate_Land_Productivity_in_the_Recently_Reclaimed_Calcareous_Soils_Nubariya_Egypt).
- 574 [24] M. Liyanda, A. Karim, and Y. Abubakar, "Analysis of Land Suitability Criteria for
575 Cocoa Production of Three Cluster Development in Pidie District," *Agrista*, vol. 16,
576 no. 2, pp. 62–79, 2012, [Online]. Available:
577 <http://jurnal.unsyiah.ac.id/agrista/article/view/289>.
- 578 [25] R. Neswati, S. Baja, and C. Lopulisa, "A modification of land suitability requirements
579 for maize in the humid tropics of South Sulawesi," *IOP Conf. Ser. Earth Environ. Sci.*,
580 vol. 921, no. 1, p. 012012, Nov. 2021, doi: 10.1088/1755-1315/921/1/012012.
- 581 [26] D. Subardja and Sudarsono, "The influence of Land Quality on Productivity of Maize
582 in Soils Derived from Volcanic and Sedimentary Rocks in the Bogor Area," *Soil Clim.*
583 *J.*, vol. 23, pp. 38–46, 2005, doi: <http://dx.doi.org/10.21082/jti.v0n23.2005.%25p>.
- 584 [27] G. O. Awe and T. P. Abegunrin, "Land Preparation Practices for Maize Production :
585 Short Term Effects on Some Hydro-Physical Properties of Analfisol and Crop
586 Performance," *Middle-East J. Sci. Res.*, vol. 25, no. 7, pp. 1420–1430, 2017, doi:
587 10.5829/idosi.mejsr.2017.1420.1430.
- 588 [28] J. Janků *et al.*, "An overview of a land evaluation in the context of ecosystem
589 services," *Soil Water Res.*, vol. 17, no. No. 1, pp. 1–14, Jan. 2022, doi:
590 10.17221/136/2021-SWR.
- 591 [29] D. Nadalia, A. Sutandi, and B. Nugroho, "Suitability criteria of land characteristics
592 related to Eucalyptus pellita production," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 694,
593 no. 1, p. 012053, Mar. 2021, doi: 10.1088/1755-1315/694/1/012053.
- 594 [30] N. Nurdin, F. Zakaria, M. A. Azis, Y. Rahim, R. Rahman, and M. Kasim,
595 "Comparison of land suitability class for endemic Coffea liberica Pinogu HP. acquired
596 using different methods and recommendations for land management in Pinogu Plateau,
597 Bone Bolango Regency, Indonesia," *SAINS TANAH - J. Soil Sci. Agroclimatol.*, vol.
598 19, no. 1, p. 42, May 2022, doi: 10.20961/stjssa.v19i1.56441.
- 599 [31] A. . Elisanti, W. Purnomo, and S. Melaniani, "Application of partial least square health
600 status of children under 5 years in indonesia," *J. Biometrika dan Kependud.*, vol. 2, no.
601 2, pp. 99–107, 2013, doi: 10.31227/osf.io/gtbq6.
- 602 [32] J.-M. Becker, C. M. Ringle, and M. Sarstedt, "Estimating Moderating Effects in PLS-
603 SEM and PLSC-SEM: Interaction Term Generation*Data Treatment," *J. Appl. Struct.*
604 *Equ. Model.*, vol. 2, no. 2, pp. 1–21, Jun. 2018, doi: 10.47263/JASEM.2(2)01.
- 605 [33] M. . Yim, "A Study on Factor Analytical Methods and Procedures for PLS-SEM
606 (Partial Least Squares Structural Equation Modeling)," *J. Ind. Distrib. Bus.*, vol. 10,
607 no. 5, pp. 7–20, 2019, doi: 10.13106/ijidb.2019.vol10.no5.7.
- 608 [34] R. Schlittgen, M. Sarstedt, and C. M. Ringle, "Data generation for composite-based
609 structural equation modeling methods," *Adv. Data Anal. Classif.*, vol. 14, no. 4, pp.
610 747–757, 2020, doi: 10.1007/s11634-020-00396-6.
- 611 [35] S. Kono and M. Sato, "The potentials of partial least squares structural equation
612 modeling (PLS-SEM) in leisure research," *J. Leis. Res.*, pp. 1–21, Jun. 2022, doi:
613 10.1080/00222216.2022.2066492.

- 614 [36] M. E. Civelek, “Comparison of Covariance-Based and Partial Least Square Structural
615 Equation Modeling Methods under Non-Normal Distribution and Small Sample Size
616 Limitations,” *Eurasian Econom. Stat. Emprical Econ. Journa*, vol. 10, no. 1, pp. 39–
617 50, 2018, doi: 10.17740/eas.stat.2018-V10-03.
- 618 [37] J. F. Hair, J. J. Risher, M. Sarstedt, and C. M. Ringle, “When to use and how to report
619 the results of PLS-SEM,” *Eur. Bus. Rev.*, vol. 31, no. 1, pp. 2–24, Jan. 2019, doi:
620 10.1108/EBR-11-2018-0203.
- 621 [38] J. F. Hair, C. M. Ringle, and M. Sarstedt, “Partial Least Squares Structural Equation
622 Modeling: Rigorous Applications, Better Results and Higher Acceptance,” *Long
623 Range Plann.*, vol. 46, no. 1–2, pp. 1–12, Feb. 2013, doi: 10.1016/j.lrp.2013.01.001.
- 624 [39] W. Reinartz, M. Haenlein, and J. Henseler, “An empirical comparison of the efficacy
625 of covariance-based and variance-based SEM,” *Int. J. Res. Mark.*, vol. 26, no. 4, pp.
626 332–344, Dec. 2009, doi: 10.1016/j.ijresmar.2009.08.001.
- 627 [40] H. Syaf, “The Relationship Evaluation Between Land Quality, Growth And Production
628 Of Advanced Age Cocoa In Kolaka East District, Southeast Sulawesi Province,”
629 *Bioedukasi*, vol. 3, no. 1, pp. 267–276, 2014, doi:
630 <http://dx.doi.org/10.33387/bioedu.v2i1.60>.
- 631 [41] Nurdin, M. L. Rayes, Soemarno, and Sudarto, “Study of Land Quality and Land
632 Characteristics that Determine the Productivity of Composite Maize Varieties in
633 Gorontalo,” *Syst. Rev. Pharm.*, vol. 11, no. 12, pp. 500–509, 2020, doi:
634 10.31838/srp.2020.12.81.
- 635 [42] R. Bhat and S. Sujatha, “stablishing leaf nutrient norms for arecanut by boundary line
636 approach,” *J. Plant Nutr.*, vol. 36, no. 6, pp. 849–862, Jan. 2013, doi:
637 10.1080/01904167.2013.770524.
- 638 [43] A. M. Ali, “Nutrient Sufficiency Ranges in Mango Using Boundary-Line Approach
639 and Compositional Nutrient Diagnosis Norms in El-Salhiya, Egypt,” *Commun. Soil
640 Sci. Plant Anal.*, vol. 49, no. 2, pp. 188–201, Jan. 2018, doi:
641 10.1080/00103624.2017.1421651.
- 642 [44] M. Ridayanti, M. L. Rayes, and C. Agustina, “Land Suitability Evaluation for Maize in
643 Dry Land Wagir District, Malang Regency,” *J. Tanah dan Sumberd. Lahan*, vol. 8, no.
644 1, pp. 149–160, Dec. 2020, doi: 10.21776/ub.jtsl.2021.008.1.18.
- 645 [45] BWS Sulawesi II, “Climate Data in the Paguyaman River Area for 2012-2022,” *Balai
646 Wilayah Sungai Sulawesi II Provinsi Gorontalo*, 2022.
647 <https://sda.pu.go.id/balai/bwssulawesi2/data/wilayah-sungai/ws-paguyaman/> (accessed
648 Dec. 12, 2022).
- 649 [46] S. Ritung, F. Lukman, and R. Purnanto, *Atlas of 1:50,000 scale semi-detailed soil map
650 of Boalemo Regency, Gorontalo Province*. Bogor: Indonesian Center for Research and
651 Development of Agricultural Land Resources, 2016.
- 652 [47] Wahyunto *et al.*, *Technical Guidance Guidelines for Land Suitability Assessment for
653 Strategic Agricultural Commodities Semi-Detailed Scale 1:50.000*. Bogor: Balai Besar
654 Litbang Sumberdaya Lahan Pertanian, 2016.
- 655 [48] L. R. Oldeman and S. Darmiyati, “An agroclimatic map of Sulawesi scale 1 -
656 2.500.000.pdf,” Bogor: *Center Research for Agriculture*, p. 1, 1977.
- 657 [49] E. Runtuwuwu, I. Las, I. Amien, and H. Syahbuddin, “Utilizing Cropping Calender in
658 Coping with Climate Change,” *J. Ecolab*, vol. 5, no. 1, pp. 1–14, Dec. 2011, doi:

- 659 10.20886/jklh.2011.5.1.1-14.
- 660 [50] M. L. Rayes, *Description of Soil Profile in the Field*. Agriculture Faculty of Brawijaya
661 University, 2006.
- 662 [51] W. H. Wischmeier and D. D. Smith, "Predicting rainfall erosion losses—a guide to
663 conservation planning," *Agric. Handb.*, vol. 537, pp. 1–60, 1978.
- 664 [52] E. Kurnia, F. Agus, A. Adimiharja, and A. Dariah, *Soil Physical Properties and
665 Analysis Methods*, vol. 1, no. 1. Bogor: Center for Research and Development of
666 Agricultural Land Resources, 2006.
- 667 [53] Eviyati and Sulaeman, *Analysis of soil, chemical, plants, water, and fertilizer*. Bogor:
668 Indonesia Centre of Soil Research, 2009.
- 669 [54] M. Seilsepour, M. Rashidi, and B. G. Khabbaz, "Prediction of Soil Exchangeable
670 Sodium Percentage Based on Soil Sodium Adsorption Ratio," *Am. J. Agric. Environ.
671 Sci.*, vol. 5, no. 1, pp. 1–4, 2009.
- 672 [55] M. Siosemarde, F. Kave, E. Pazira, H. Sedghi, and S. J. Ghaderi, "Prediction of soil
673 exchangeable sodium ratio based on soil sodium adsorption ratio," *World Acad. Sci.
674 Eng. Technol.*, vol. 46, no. 10, pp. 255–257, 2010.
- 675 [56] N. Sutrisna, Nadimin, I. Ishaq, and S. Putra, "Guide to the Jajar Legowo Rice Tiling
676 Method," *West Java Agricultural Technology Study Center*, vol. 02/Panduan. West
677 Java Agricultural Technology Study Center, Bandung, pp. 1–27, 2012.
- 678 [57] H. Wold, "Model Construction and Evaluation When Theoretical Knowledge Is
679 Scarce," in *Evaluation of Econometric Models*, J. Kmenta and B. J. Ramsey, Eds.
680 Academic Press, 1980, pp. 47–74.
- 681 [58] K. Bollen and R. Lennox, "Conventional Wisdom on Measurement: A Structural
682 Equation Perspective," *Psychol. Bull.*, vol. 110, no. 2, pp. 305–314, 1991, doi:
683 10.1037/0033-2909.110.2.305.
- 684 [59] M. Haenlein and A. M. Kaplan, "A Beginner's Guide to Partial Least Squares
685 Analysis," *Underst. Stat.*, vol. 3, no. 4, pp. 283–297, Nov. 2004, doi:
686 10.1207/s15328031us0304_4.
- 687 [60] J. F. Hair, M. Sarstedt, L. Hopkins, and V. G. Kuppelwieser, "Partial least squares
688 structural equation modeling (PLS-SEM): An emerging tool in business research,"
689 *Eur. Bus. Rev.*, vol. 26, no. 2, pp. 106–121, 2014, doi: 10.1108/EBR-10-2013-0128.
- 690 [61] C. Fornell and D. F. Larcker, "Evaluating Structural Equation Models with
691 Unobservable Variables and Measurement Error:," *J. Mark. Res.*, vol. 18, no. 1, pp.
692 39–50, Nov. 1981, doi: 10.1177/002224378101800104.
- 693 [62] W. W. Chin, "The Partial Least Squares Approach to Structural Formula Modeling,"
694 in *Modern Methods for Business Reseachr*, no. January 1998, G. A. Marcoulides, Ed.
695 Mahwah, New Jersey: Lawrence Erlbaum Associates, 1998, pp. 295–336.
- 696 [63] D. Gefen, D. Straub, and M.-C. Boudreau, "Structural Equation Modeling and
697 Regression: Guidelines for Research Practice," *Commun. Assoc. Inf. Syst.*, vol. 4, no.
698 October, pp. 1–77, 2000, doi: 10.17705/1cais.00407.
- 699 [64] J. Henseler, C. M. Ringle, and R. R. Sinkovics, "The use of partial least squares path
700 modeling in international marketing," *Adv. Int. Mark.*, vol. 20, pp. 277–319, 2009, doi:
701 10.1108/S1474-7979(2009)0000020014.
- 702 [65] M. Sarstedt, C. M. Ringle, and J. F. Hair, "Partial Least Squares Structural Equation

- 703 Modeling,” *Springer Books*, pp. 587–632, 2022, doi: 10.1007/978-3-319-57413-4_15.
- 704 [66] K. K. Wong, “Partial Least Squares Structural Equation Modeling (PLS-SEM)
705 Techniques Using SmartPLS,” *Mark. Bull.*, vol. 24, no. 1, pp. 1–32, 2013, [Online].
706 Available: http://marketing-bulletin.massey.ac.nz/marketing_bulletin_articles.html#24.
- 707 [67] J. Hulland, “Use of partial least squares (PLS) in strategic management research: a
708 review of four recent studies,” *Strateg. Manag. J.*, vol. 20, no. 2, pp. 195–204, Feb.
709 1999, doi: 10.1002/(SICI)1097-0266(199902)20:2<195::AID-SMJ13>3.0.CO;2-7.
- 710 [68] D. Barclay, R. Thompson, and C. Higgins, “The Partial Least Squares (PLS) Approach
711 to Causal Modeling: Personal Computer Adoption and Use as an Illustration,”
712 *Technol. Stud.*, vol. 2, no. 2, pp. 285–309, Nov. 1995, doi: 10.1088/1751-
713 8113/44/8/085201.
- 714 [69] J. F. Hair, G. T. M. Hult, C. . Ringle, M. Sarstedt, N. . Danks, and S. Ray, *Partial least
715 squares structural equation modeling (PLS-SEM) using R: A workbook*. 2021.
- 716 [70] V. E. Vinzi, W. W. Chin, J. Henseler, and H. Wang, *Handbook of Partial Least
717 Squares*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2010.
- 718 [71] FAO, “A Framework for Innovation,” *FAO Soils Bull.*, vol. 32, no. 22, pp. 1–92, 1976,
719 doi: 10.1007/978-3-030-45139-4_4.
- 720 [72] Widiatmaka, A. Sutandi, A. Iswandi, U. Daras, M. Hikmat, and A. Krisnohadi,
721 “Establishing Land Suitability Criteria for Cashew (*Anacardium occidentale* L.) in
722 Indonesia,” *Appl. Environ. Soil Sci.*, vol. 2014, no. 743194, pp. 1–14, 2014, doi:
723 10.1155/2014/743194.
- 724 [73] W. W. Chin, “The Partial Least Squares Approach to Structural Formula Modeling,”
725 in *Modern Methods for Business Reseach*, no. January 1998, G. A. Marcoulides, Ed.
726 Mahwah, New Jersey: Lawrence Erlbaum Associates, 1998, pp. 295–336.
- 727 [74] R. . Darmawan, “Analysis of the Effect of Work-Family Conflict and Job Stress on the
728 Job Performance of Nurses at ‘X’ Hospital,” *Agora*, vol. 6, no. 2, pp. 1–6, 2018,
729 [Online]. Available: <https://www.neliti.com/id/publications/287084>.
- 730 [75] J. F. Hair, M. Sarstedt, C. M. Ringle, and J. A. Mena, “An assessment of the use of
731 partial least squares structural equation modeling in marketing research,” *J. Acad.
732 Mark. Sci.*, vol. 40, no. 3, pp. 414–433, 2012, doi: 10.1007/s11747-011-0261-6.
- 733 [76] R. P. Bagozzi and Y. Yi, “On the evaluation of structural equation models,” *J. Acad.
734 Mark. Sci.*, vol. 16, no. 1, pp. 74–94, Mar. 1988, doi: 10.1007/BF02723327.
- 735 [77] T. M. Basuki, D. R. Indrawati, and B. Haryadi, “The Use of Organic Matter to
736 Improve Productivity of Post Lime Mining Land,” *J. For. Nat. Conserv. Res.*, vol. 4,
737 no. 1, pp. 1–8, 2007, doi: 10.20886/jphka.2007.4.1.1-8.
- 738 [78] M. S. Alfian and H. Purnamawati, “Dose and Time of Potassium Fertilizer Application
739 on Growth and Sweet Corn Production at NATC Batangkaluku Gowa regency of
740 South Sulawesi,” *Bul. Agrohorti*, vol. 7, no. 1, pp. 8–15, 2019, doi:
741 10.29244/agrob.v7i1.24404.
- 742 [79] S. Nasreen, M. M. Haque, M. A. Hossain, and A. T. M. Farid, “Nutrient uptake and
743 yield of onion as influenced by nitrogen and sulphur fertilization,” *Bangladesh J.
744 Agric. Res.*, vol. 32, no. 3, pp. 413–420, Jan. 2008, doi: 10.3329/bjar.v32i3.543.
- 745 [80] Y. Abdissa, T. Tekalign, and L. M. Pant, “Growth, Bulb Yield and Quality of Onion
746 (*Allium cepa* L.) as Influenced by Nitrogen and Phosphorus Fertilization on Vertisol I.
747 Growth Attributes, Biomass Production and Bulb Yield,” *African J. Agric. Res.*, vol. 6,

- 748 no. 14, pp. 3252–3258, 2011, doi: 10.5897/AJAR10.1024.
- 749 [81] I. Firmansyah and N. Sumarni, “Effect of N Fertilizer Dosages and Varieties On Soil
750 pH, Soil Total-N, N Uptake, and Yield of Shallots (*Allium ascalonicum* L.) Varieties
751 On Entisols-Brebes Central Java,” *J. Hortik.*, vol. 23, no. 4, p. 358, May 2016, doi:
752 10.21082/jhort.v23n4.2013.p358-364.
- 753 [82] E. Sumiati and O. S. Gunawan, “Application of Mycorrhizal Biofertilizer to Increase
754 the Efficiency of NPK Uptake and its Effects on Yiled and Quality of Shallot Bulbs,”
755 *J. Hort*, vol. 17, no. 1, pp. 34–42, 2006, doi: 10.21082/jhort.v17n1.2007.p%p.
- 756 [83] H. R. McKenzie, “Potassium Fertilizer Application in Crop Production,” *Agri-Facts*,
757 vol. 542, no. 9, pp. 1–7, 2013, [Online]. Available:
758 <https://open.alberta.ca/publications/6060438>.
- 759 [84] M. Dianawati, “Rates and application time of K₂SO₄ on production of G0 potato
760 seed,” *J. Kultiv.*, vol. 17, no. 1, pp. 531–536, 2018, [Online]. Available:
761 <http://jurnal.unpad.ac.id/kultivasi/article/viewFile/15499/7786>.
- 762 [85] N. Gunadi, “The Use of Potassium Sulphate as an Alternative Source of Potassium
763 Fertilizer in Potato,” *J. Hort*, vol. 17, no. 1, pp. 52–60, 2019, [Online]. Available:
764 <http://repository.pertanian.go.id/handle/123456789/7798>.
- 765 [86] I. S. Rahmawan, A. Z. Arifin, and Sulistyawati, “The effect of potassium (K) fertilizer
766 on growth and yield of cabbage (*Brassica oleraceae* var. *capitata*, L.),” *J.*
767 *Agroteknologi Merdeka Pasuruan*, vol. 3, no. 1, pp. 17–23, 2019.
- 768 [87] Subandi, “Role and Management of Potassium Nutrient for Food Production in
769 Indonesia,” *Agric. Innov. Dev.*, vol. 6, no. 1, pp. 1–10, 2013, [Online]. Available:
770 [https://www.neliti.com/publications/30881/role-and-management-of-potassium-](https://www.neliti.com/publications/30881/role-and-management-of-potassium-nutrient-for-food-production-in-indonesia)
771 [nutrient-for-food-production-in-indonesia](https://www.neliti.com/publications/30881/role-and-management-of-potassium-nutrient-for-food-production-in-indonesia).
- 772 [88] IIED, “Potash Case Study: Information supplied by the International Fertilizer Industry
773 Association,” *Mining, Miner. Sustain. Dev.*, vol. 65, no. February, p. 9, 2002, [Online].
774 Available: http://www.agritrade.org/documents/Biofuels_Subsub_Web_Final.pdf.
- 775 [89] N. Nursjahbani, O. Rusdiana, and . D., “Suitability of *Durio zibethinus* Murr. and
776 *Nephelium lappaceum* L. on the Utilization Block at Menumbing Mountain Grand
777 Forest Park, West Bangka,” *J. Trop. Silv.*, vol. 9, no. 1, pp. 1–6, May 2018, doi:
778 10.29244/j-siltrop.9.1.1-6.
- 779 [90] I. W. Nyakudya and L. Stroosnijder, “Effect of rooting depth, plant density and
780 planting date on maize (*Zea mays* L.) yield and water use efficiency in semi-arid
781 Zimbabwe: Modelling with AquaCrop,” *Agric. Water Manag.*, vol. 146, pp. 280–296,
782 Dec. 2014, doi: 10.1016/j.agwat.2014.08.024.
- 783 [91] S. B. Wang *et al.*, “Effect of subsoiling depth on soil physical properties and summer
784 maize (*Zea mays* L.) yield,” *Plant, Soil Environ.*, vol. 65 (2019), no. No. 3, pp. 131–
785 137, Mar. 2019, doi: 10.17221/703/2018-PSE.
- 786 [92] H. Z. Khan, M. A. Malik, and M. F. Saleem, “Effect of rate and source of organic
787 material on the production potential of spring maize (*Zea mays* L.),” *Pak. J. Agri. Sci.*,
788 vol. 45, no. 1, pp. 40–43, 2008, [Online]. Available:
789 <https://pakjas.com.pk/papers/222.pdf>.
- 790 [93] A. Jalal, K. Azeem, M. C. M. T. Filho, and A. Khan, “Enhancing Soil Properties and
791 Maize Yield through Organic and Inorganic Nitrogen and Diazotrophic Bacteria,” in
792 *Sustainable Crop Production*, IntechOpen, 2020, pp. 1–14.

- 793 [94] E. E. Kandil, N. R. Abdelsalam, M. A. Mansour, H. M. Ali, and M. H. Siddiqui,
794 “Potentials of organic manure and potassium forms on maize (*Zea mays* L.) growth
795 and production,” *Sci. Rep.*, vol. 10, no. 1, p. 8752, Dec. 2020, doi: 10.1038/s41598-
796 020-65749-9.
- 797 [95] Mulyati, A. B. Baharuddin, and R. S. Tejowulan, “Improving Maize (*Zea mays* L.)
798 growth and yield by the application of inorganic and organic fertilizers plus,” *IOP*
799 *Conf. Ser. Earth Environ. Sci.*, vol. 712, no. 1, p. 012027, Mar. 2021, doi:
800 10.1088/1755-1315/712/1/012027.
- 801 [96] D. A. Kane, M. A. Bradford, E. Fuller, E. E. Oldfield, and S. A. Wood, “Soil organic
802 matter protects US maize yields and lowers crop insurance payouts under drought,”
803 *Environ. Res. Lett.*, vol. 16, no. 4, p. 044018, Apr. 2021, doi: 10.1088/1748-
804 9326/abe492.
- 805 [97] Mujiyo, W. Larasati, H. Widijanto, and A. Herawati, “The Effect of Slope Gradient of
806 land on the Soil Damage in Giritontro, Wonogiri.,” *Agrotrop J. Agric. Sci.*, vol. 11,
807 no. 2, p. 115, 2021, doi: 10.24843/ajoas.2021.v11.i02.p02.
- 808 [98] D. O. Suparwata, Nurmi, and M. I. Bahua, “Using vertical mulch to upland for
809 reducing erosion, runoff and its responses to maize growth and yields,”
810 *Agroteknotropika*, vol. 1, no. 3, pp. 138–145, 2012, doi: 10.31227/osf.io/5aek7.
- 811 [99] R. E. Christanto, Suryono, Mujiyo, and J. Winarno, “The Degree of Erosion Hazard
812 Mapping in Dry Land at Jatipuro Sub District of Karanganyar with Geographic
813 Information System (GIS,” *Sains Tanah - J. Soil Sci. Agroclimatol.*, vol. 7, no. 2, pp.
814 114–119, 2013, doi: 10.15608/stjssa.v7i2.42.
- 815 [100] E. Elfayetti and H. Herdi, “Land Suitability Evaluation for Maize Crops in Saentis
816 Village, Percut Sei Tuan,” *JUPIIS J. Pendidik. ILMU-ILMU Sos.*, vol. 7, no. 1, p. 33,
817 Jul. 2015, doi: 10.24114/jupiis.v7i1.2295.
- 818 [101] Sukarman, A. Mulyani, and S. Purwanto, “The Modification of Land Evaluation
819 Methods for Oriented Climate Change,” *J. Sumberd. Lahan*, vol. 12, no. 1, p. 1, Jun.
820 2018, doi: 10.21082/jsdl.v12n1.2018.1-11.
- 821 [102] W. Chivasaa, O. Mutanga, and C. Biradarc, “Mapping land suitability for maize (*Zea*
822 *mays* L.) production using GIS and AHP technique in Zimbabwe,” *South African J.*
823 *Geomatics*, vol. 8, no. 2, pp. 265–281, Sep. 2022, doi: 10.4314/sajg.v8i2.11.

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

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Nurdin, Nurdin ^{SA CA} ¹, Asda Rauf¹, Yunnita Rahim¹, Echan Adam¹, Nikmah Musa¹, Fitriah Suryani Jamin¹, Rival Rahman¹, Suyono Dude¹, Hidayat Arismunandar Katili² [+ Show Affiliations](#)

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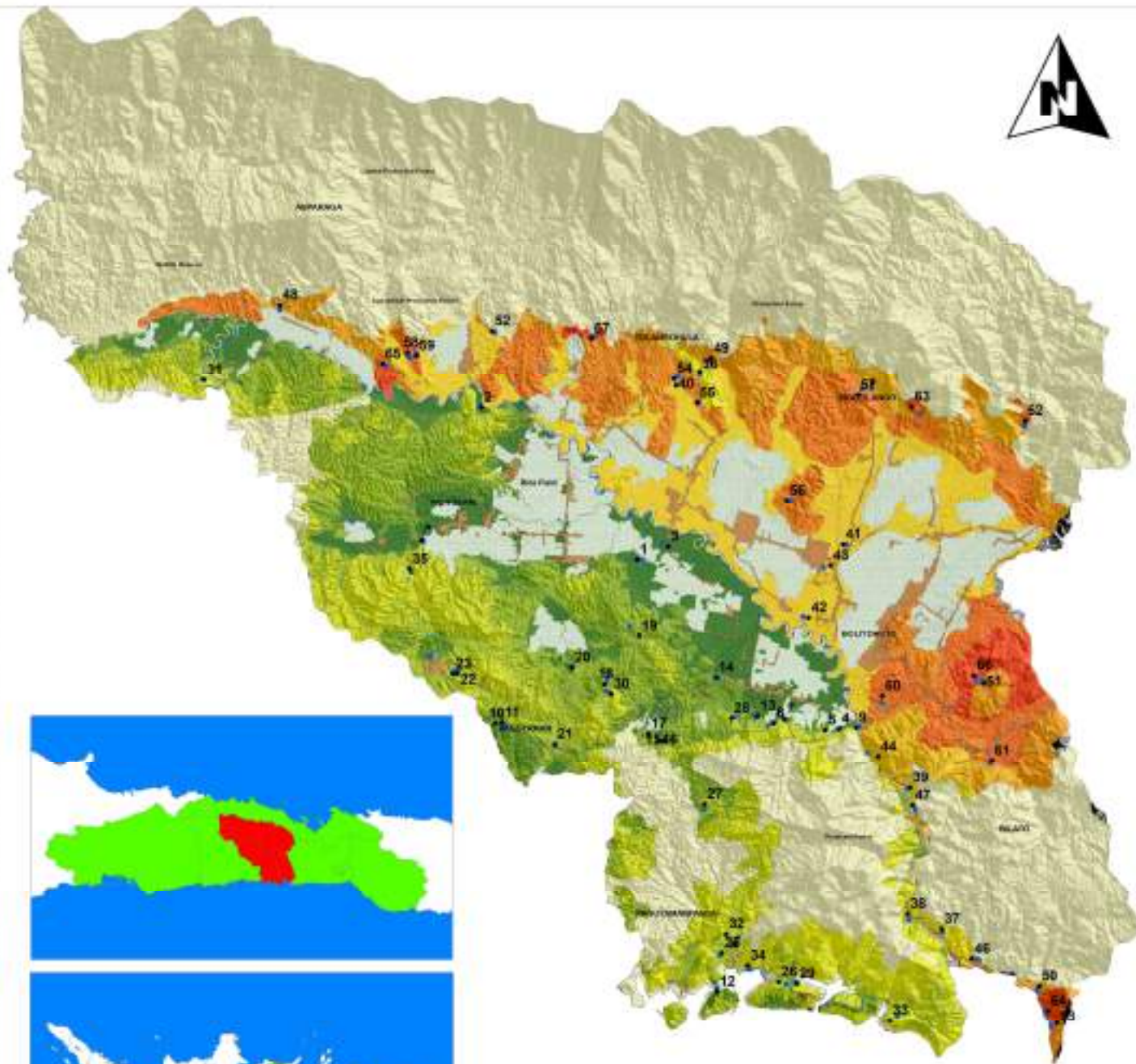
 Figures.rar **6 MB** 

Legend

● Soil Sampling

■ Tile 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	Veric Haplustepts	100 - 250	26.92
3	3 - 8	Wavy	Plantation	Typic Haplustepts	0 - 100	4,756.57
4	3 - 8	Wavy	Plantation	Aquic Haplustepts	100 - 250	48.15
5	3 - 8	Wavy	Upland	Typic Haplustepts	100 - 250	91.77
6	3 - 8	Wavy	Plantation	Typic Haplustepts	0 - 100	684.95
7	3 - 8	Wavy	Upland	Typic Haplustepts	100 - 250	249.07
8	3 - 8	Wavy	Plantation	Typic Haplustepts	100 - 250	129.12
9	3 - 8	Wavy	Plantation	Aquic Haplustepts	0 - 100	3.51
10	8 - 15	Wavy	Plantation	Typic Rhodustepts	100 - 250	65.54
11	8 - 15	Wavy	Upland	Typic Haplustepts	100 - 250	471.97
12	8 - 15	Wavy	Upland	Lithic Haplustepts	0 - 100	302.43
13	8 - 15	Wavy	Plantation	Typic Haplustepts	0 - 100	1,412.81
14	8 - 15	Wavy	Upland	Typic Haplustepts	0 - 100	1,071.76
15	8 - 15	Wavy	Plantation	Typic Haplustepts	100 - 250	297.87
16	8 - 15	Wavy	Scrub	Typic Haplustepts	100 - 250	254.62
17	8 - 15	Wavy	Upland	Typic Haplustepts	250 - 500	653.23
18	8 - 15	Wavy	Plantation	Lithic Haplustepts	100 - 250	3,304.32
19	8 - 15	Wavy	Scrub	Typic Haplustepts	100 - 250	793.13
20	8 - 15	Wavy	Upland	Typic Haplustepts	100 - 250	3,293.28
21	8 - 15	Wavy	Plantation	Typic Haplustepts	250 - 500	354.88
22	8 - 15	Wavy	Scrub	Typic Haplustepts	100 - 250	165.87
23	8 - 15	Wavy	Upland	Typic Haplustepts	100 - 250	2,038.84
24	8 - 15	Wavy	Plantation	Aquic Haplustepts	0 - 100	599.98
25	8 - 15	Wavy	Upland	Typic Haplustepts	100 - 250	349.74
26	15 - 30	Hilly	Scrub	Lithic Haplustepts	100 - 250	749.22
27	15 - 30	Hilly	Upland	Typic Haplustepts	250 - 500	1,528.98
28	15 - 30	Hilly	Upland	Typic Haplustepts	100 - 250	3,748.72
29	15 - 30	Hilly	Upland	Lithic Haplustepts	100 - 250	434.63
30	15 - 30	Hilly	Upland	Lithic Haplustepts	250 - 500	3,908.31
31	15 - 30	Hilly	Scrub	Typic Haplustepts	250 - 500	154.35
32	15 - 30	Hilly	Scrub	Lithic Haplustepts	250 - 500	1,474.02
33	> 45	Mountainous	Scrub	Lithic Haplustepts	100 - 250	229.51
34	> 45	Mountainous	Upland	Lithic Haplustepts	100 - 250	653.11
35	= 45	Mountainous	Scrub	Typic Rhodustepts	0 - 100	86.40
36	8 - 15	Hilly	Plantation	Typic Haplustepts	0 - 100	254.62
37	> 45	Mountainous	Scrub	Fluvisol Ustropepts	0 - 100	286.81
38	= 45	Mountainous	Scrub	Typic Haplustepts	250 - 500	27.33
39	> 45	Mountainous	Upland	Fluvisol Ustropepts	250 - 500	101.55
40	0 - 3	Flat	Plantation	Fluvisol Haplustepts	0 - 100	3,052.35
41	0 - 3	Flat	Upland	Fluvisol Haplustepts	0 - 100	3,834.11
42	0 - 3	Flat	Upland	Typic Argustolls	0 - 100	1,072.70
43	0 - 3	Flat	Upland	Typic Tropaquepts	100 - 250	85.04
44	15 - 30	Hilly	Plantation	Fluvisol Ustropepts	250 - 500	1,043.31
45	15 - 30	Hilly	Scrub	Typic Argustolls	100 - 250	791.23
46	15 - 30	Hilly	Scrub	Typic Haplustepts	0 - 100	53.32
47	15 - 30	Hilly	Upland	Fluvisol Ustropepts	100 - 250	336.36
48	15 - 30	Hilly	Upland	Fluvisol Haplustepts	250 - 500	705.51
49	15 - 30	Hilly	Upland	Typic Argustolls	250 - 500	2,196.41
50	15 - 30	Hilly	Upland	Typic Haplustepts	0 - 100	104.35
51	15 - 30	Hilly	Upland	Typic Haplustepts	250 - 500	871.02
52	15 - 30	Hilly	Upland	Typic Haplustepts	100 - 250	28.18
53	15 - 30	Hilly	Upland	Typic Tropaquepts	0 - 100	89.21
54	3 - 8	Wavy	Plantation	Fluvisol Haplustepts	0 - 100	1,442.70
55	3 - 8	Wavy	Plantation	Typic Argustolls	100 - 250	1,475.90
56	3 - 8	Wavy	Scrub	Typic Haplustepts	250 - 500	413.33
57	3 - 8	Wavy	Upland	Fluvisol Haplustepts	250 - 500	3,864.27
58	3 - 8	Wavy	Upland	Typic Argustolls	0 - 100	151.63
59	3 - 8	Wavy	Upland	Typic Dystrudepts	0 - 100	83.14
60	3 - 8	Wavy	Upland	Typic Haplustepts	250 - 500	2,054.29
61	30 - 45	Mountainous	Plantation	Typic Haplustepts	100 - 250	52.44
62	30 - 45	Mountainous	Scrub	Typic Haplustepts	100 - 250	63.05
63	30 - 45	Mountainous	Upland	Typic Haplustepts	0 - 100	48.35
64	30 - 45	Mountainous	Upland	Typic Haplustepts	100 - 250	171.54
65	8 - 15	Hilly	Upland	Typic Argustolls	0 - 100	136.96
66	8 - 15	Hilly	Upland	Typic Haplustepts	250 - 500	1,063.61
67	8 - 15	Hilly	Upland	Typic Haplustepts	250 - 500	73.96
Total						66,518.81



SCALE 1 : 40,000



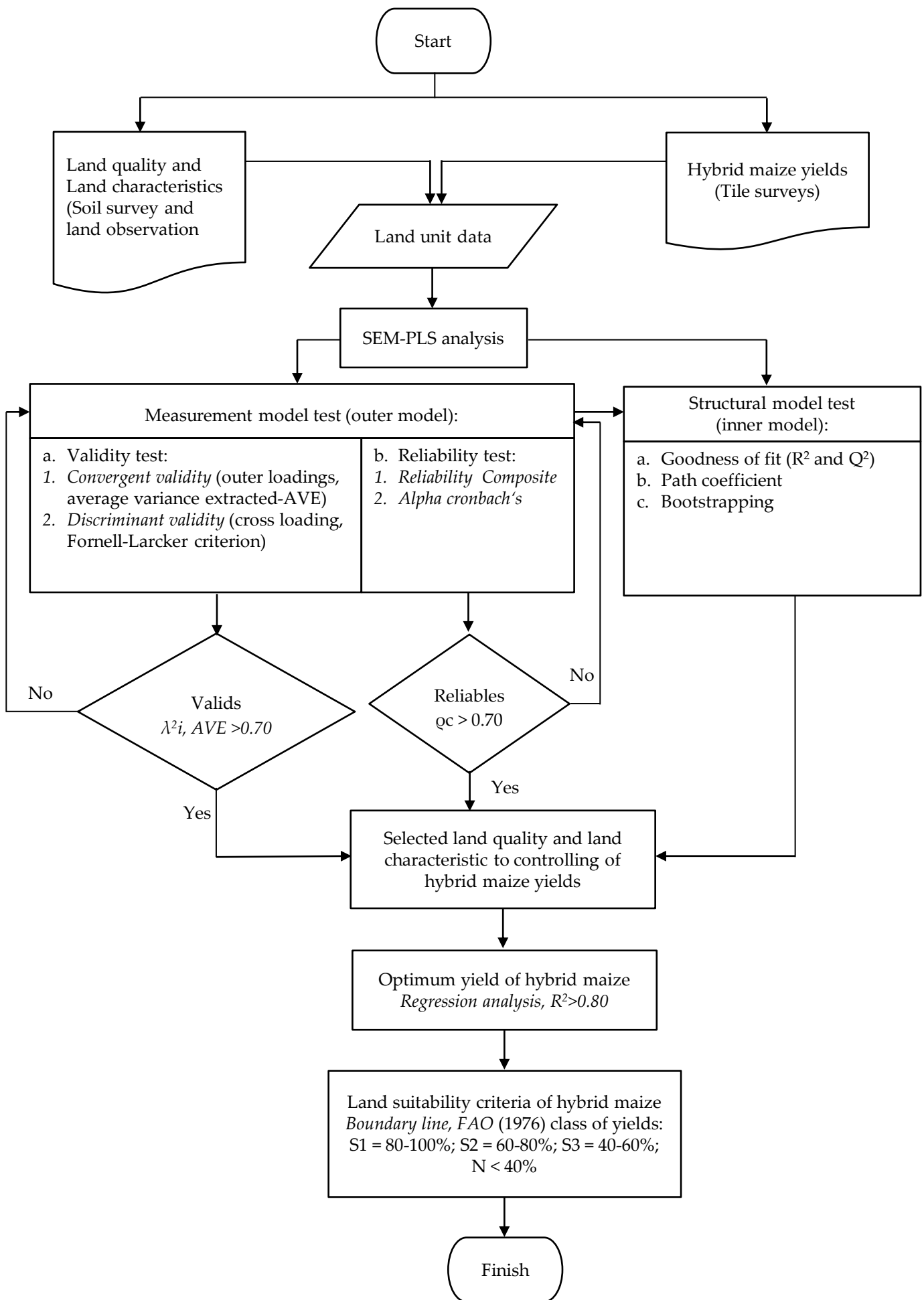
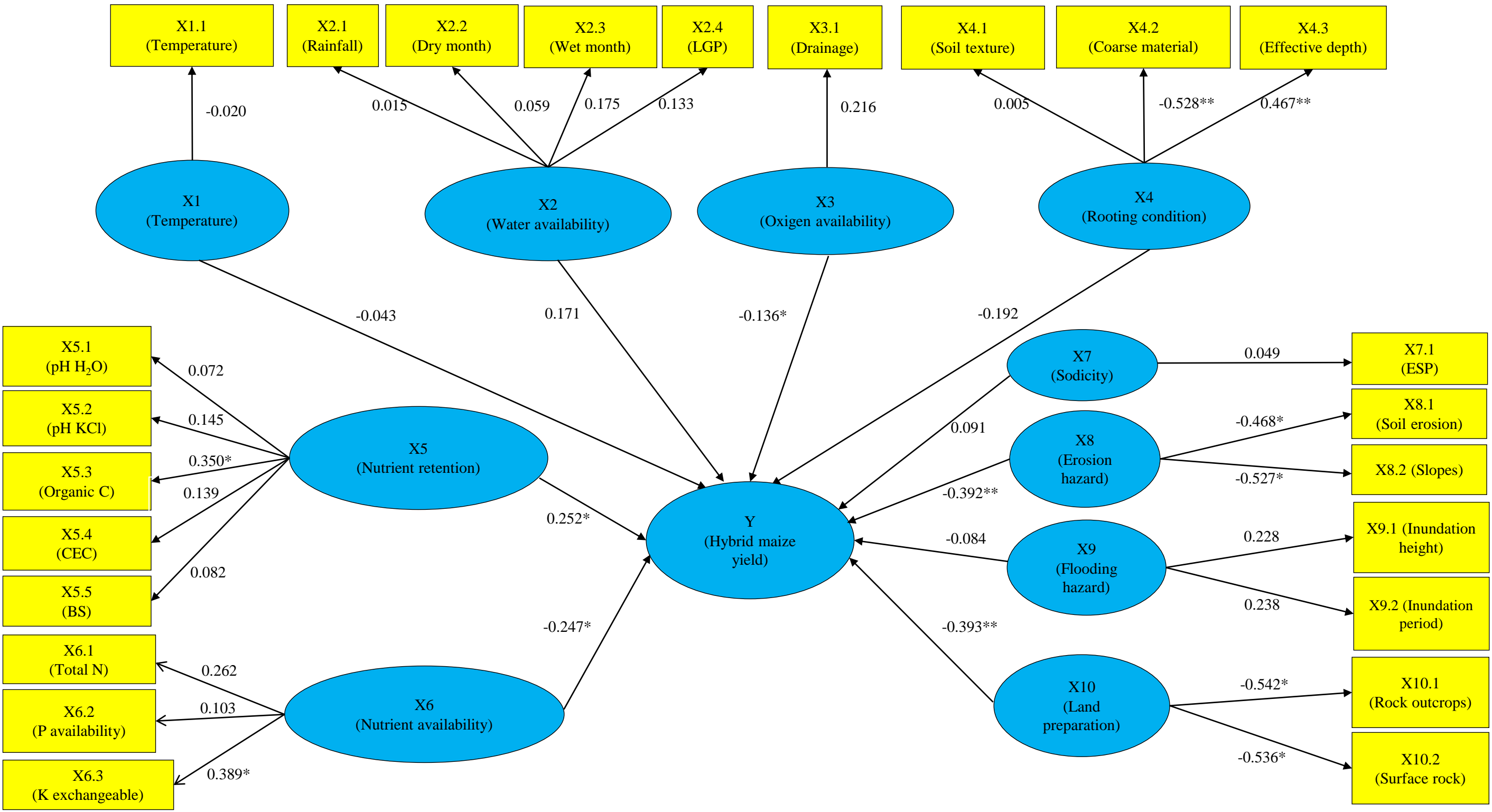


Figure 2: Research framework



Note:
 LGP = long growth periode; C = carbon; N = nitrigen;
 CEC = cation exchange capacity; BS = base saturation;
 P = phospate; K = potassium; ESP = exchangeable sodium percentage
 * = sig. 5%; ** = sig.1%; R² = 53.70%

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

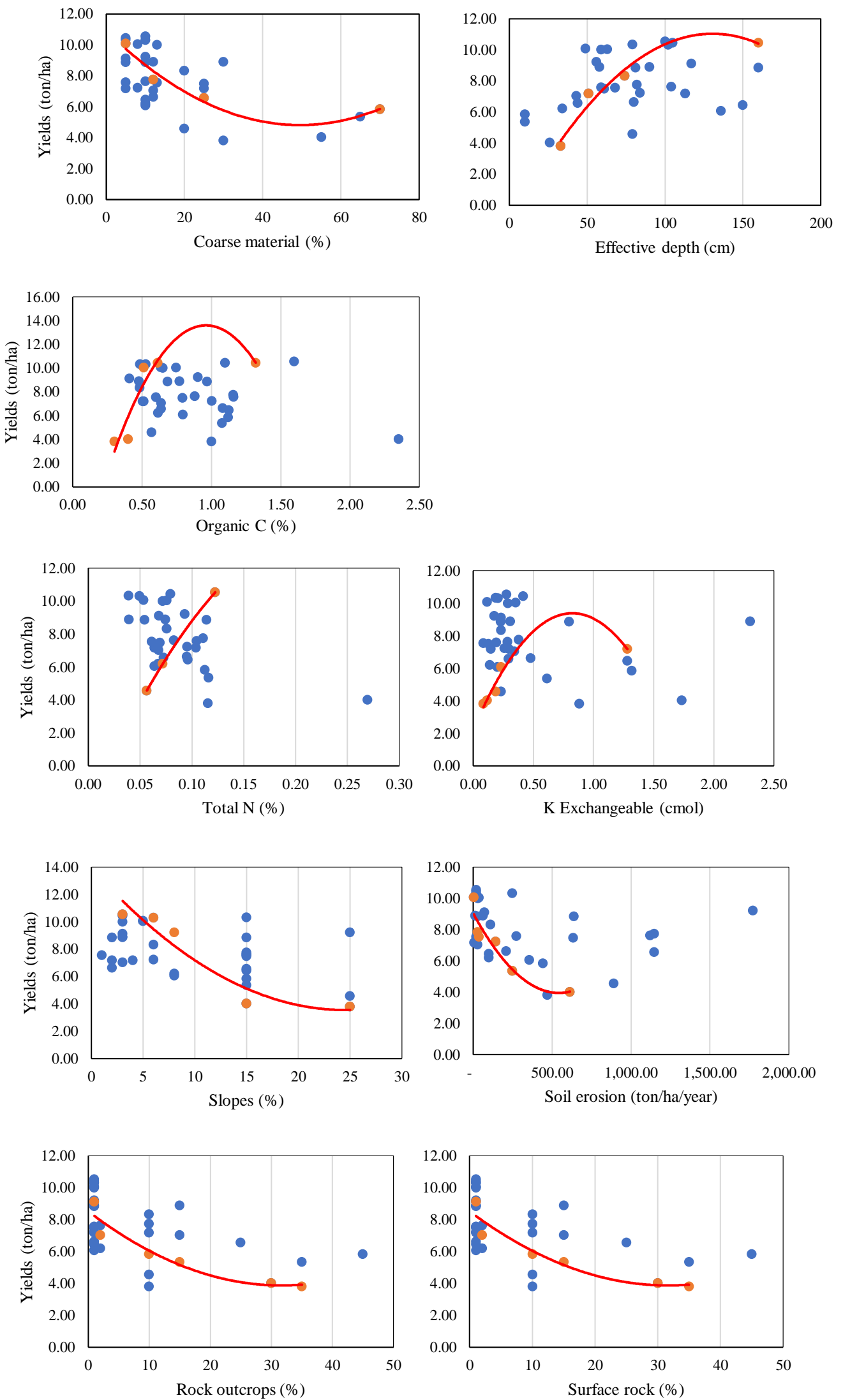


Figure 4: Scatter diagram relationship among maize yield and land characteristics

Table 1: Latent variables and indicators used in this study

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

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	1.06
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)							
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.

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)	→ X1 (Temperature)	1.000**	11.192	Valid	1.000
X2.1 (Rainfall)	→ X2 (Water availability)	0.838	0.085	Valid	0.906
X2.2 (Wet month)		0.989	0.999	Valid	
X2.3 (Dry month)		0.850	0.428	Valid	
X2.4 (LGP)		0.993*	1.431	Valid	
X3.1 (Drainage)	→ X3 (Oxygen availability)	1.000	0.000	Valid	1.000
X4.1 (Texture)	→ X4 (Rooting condition)	0.013	0.066	Invalid	0.573
X4.2 (Coarse material)		0.921	1.086	Valid	
X4.3 (Effective depth)		-0.899	1.047	Valid	
X5.1 (pH H ₂ O)		0.647	0.857	Valid	
X5.2 (pH KCl)	→ X5 (Nutrient retention)	0.570**	1.973	Valid	0.360 (invalid)
X5.3 (Organic C)		0.831**	3.135	Valid	
X5.4 (CEC)		0.436*	1.381	Invalid	
X5.5 (Base saturation)		0.365	0.845	Invalid	
X6.1 (Total N)		0.760**	3.226	Valid	
X6.2 (P availability)	→ X6 (Nutrient availability)	0.587*	1.385	Valid	0.585
X6.3 (K exchangeable)		0.897**	6.907	Valid	
X7.1 (ESP)	→ X7 (Sodicity)	1.000	0.000	Valid	1.000
X8.1 (Slopes)	→ X8 (Erosion hazard)	0.954**	21.438	Valid	0.932
X8.2 (Soil erosion)		0.941**	18.308	Valid	
X9.1 (Inundation height)	→ X9 (Flooding hazard)	0.984**	4.213	Valid	0.984
X9.2 (Inundation period)		0.985**	3.918	Valid	
X10.1 (Rock outcrops)	→ X10 (Land preparation)	0.998**	189.133	Valid	0.995
X10.2 (Surface rock)		0.998**	320.273	Valid	

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

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	Latent Variables										
	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 = 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.

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

Indicators (land characteristics)	<i>Cronbach's Alpha</i>	<i>Composite Reliability</i>
X1.1 (Temperature)	1.000	1.000
X2.1 (Rainfall)		
X2.2 (Wet month)	0.975	0.965
X2.3 (Dry month)		
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)		
X9.1 (Inundation height)	0.992	0.984
X9.2 (Inundation period)		
X10.1 (Rock outcrops)	0.998	0.995
X10.2 (Surface rock)		

nor = not reliable.

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

Land Quality/Land Characteristics	Optimum Yield (ton/ha)	Yield Equation	R²
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 8: Yield limits of hybrid maize and values obtained in each land suitability class interval by land quality and characteristics.

Land Quality/Land Characteristics	Yield Limits (ton/ha)			Value of Land Suitability Criterion Obtained			
	S1 - S2 (80% x Y _{optim})	S2 - S3 (60% x Y _{optim})	S3 - N (40% x Y _{optim})	S1	S2	S3	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

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

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

Land Quality/Land Characteristics	New Land Suitability Criterion of Hybrid Maize				Land Suitability Criterion of General Maize [47]			
	S1	S2	S3	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	Mo	Lo	VLo	-
K 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, Mo = moderate, Lo = low, VLo = very low, He = heavy, Li = light, VLi = very light, VHe = very heavy.

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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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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°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).



Figure 1: Study area.

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

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

$$Q^2 \text{ (Predictive relevance)} = 1 - (1 - R_1^2)(1 - R_2^2) \dots (1 - R_p^2), \quad (9)$$

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].

Variable	Loading Factor	Average Variance Extracted (AVE)
Soil texture	0.013	0.013
CEC	0.50	0.50
BS	0.50	0.50
Nutrient retention	0.70	0.70
Root conditions	0.70	0.70

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.

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.

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.

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References

1. K. Pawlak and M. Kołodziejczak, "The role of agriculture in ensuring food security in developing countries: considerations in the context of the problem of sustainable food production," *Sustainability*, vol. 12, no. 13, 2020.
2. O. Erenstein, M. Jaleta, K. Sonder, K. Mottaleb, and B. M. Prasanna, "Global maize production, consumption and trade: trends and R&D implications," *Food Security*, vol. 14, no. 5, pp. 1295–1319, 2022.
3. U. Grote, A. Fasse, T. T. Nguyen, and O. Erenstein, "Food security and the dynamics of wheat and maize value chains in africa and asia," *Frontiers in Sustainable Food Systems*, vol. 4, pp. 1–17, 2021.
4. R. Wirosedarmo, A. T. Sutanahaji, and E. Kurniati, "Land suitability assessment of corn (*Zea mays* L.) in Boalemo Regency, Gorontalo Province, Indonesia," *Journal of Agricultural Science*, vol. 152, pp. 1–10, 2012.

5. B. Arifin, "High expectations on KSA maize production," *Stat. Policy Br. Indones.*, vol. 18, pp. 37–41, 2021.
6. M. L. Nurdin, M. L. Rayes, and S. Sudarto, "Analysis of quality and land characteristics that control local maize production in Gorontalo," *Proceedings of the International Seminar on Promoting Local Resources for Sustainable Agriculture and Development (ISPLRSAD 2020)*, vol. 13, pp. 438–446, 2021.
7. T. Kartika, "Pengaruh jarak tanam terhadap pertumbuhan dan produksi jagung (*zea mays* L) non hibrida di Lahan balai agro teknologi terpadu (ATP)," *Sainmatika: Jurnal Ilmiah Matematika dan Ilmu Pengetahuan Alam*, vol. 15, no. 2, 2018.
8. A. N. A. Sutimawati, A. N. Aulia, and R. M. Muliarsari, "Comparative analysis of hybrid corn farming based on business scale in tempurejo sub-district," *Jurnal Agribest*, vol. 3, no. 1, 2019.
9. I. S. Anugrah, "Corn-based agribusiness for rural economic development in Gorontalo province," *Anal. Kebijakan. Pertan.*, vol. 8, no. 4, pp. 363–383, 2016.
10. H. Limanseto, "The government encourages productivity of the leading commodities of Gorontalo province to increase people's welfare," *Coordinating Ministry for Economic Affairs of the Republic of Indonesia, Jakarta*, vol. 1, pp. 1-2, 2021.
11. N. Endey, I. K. S. Arsana, A. Y. Katili, A. Sahabi, and M. A. Talalu, "Analisis daya saing komoditi unggulan Gorontalo dalam mendukung ibu kota negara baru republik Indonesia," *Equilibrium: Jurnal Pendidikan*, vol. 10, no. 3, pp. 380–396, 2022.
12. K. Astuti, R. O. Prasetyo, and N. Khasanah, *Analysis of Maize and Soybean Productivity in Indonesia 2020 (The Result of Crop Cutting Survey)*, BPS RI, Indonesia, 2021.
13. BPS-Statistic of Gorontalo, *Gorontalo Province in Figures 2018*, BPS-Statistic of Gorontalo, Indonesia, 2018.
14. W. Ardiansyah, M. A. Indrianti, M. M. Djibran, and D. R. Hippy, "KERAGAAN USAHATANI LAHAN KERING PADA PETANI TRANSMIGRAN (skkwk)," *Jurnal Agriovet*, vol. 4, no. 2, pp. 125–142, 2022.
15. A. H. Samon, *The Analysis of Comparative and Competitive Superiority of Corn Farm Enterprises in Boalemo Regency*, Hasanuddin University, Makassar, Indonesia, 2005.
16. A. M. D. Putri and Mustofiq, *Boalemo Regency in Figures 2022*, BPS-Statistics of Boalemo Regency, Indonesia, 2022.
17. W. Tialo, M. Arief Azis, and N. Nurdin, "Pertumbuhan dan produksi jagung pulut lokal Gorontalo, efektivitas agronomi, dan ekonomi dengan pemberian pupuk organik di Bualo, Kabupaten Boalemo," *Journal Agercolere*, vol. 4, no. 2, pp. 44–53, 2022.
18. K. P. Windra sukma, "Growth and production of local maize, hybrid and composite in pamekasan, madura," *Journal Agrosains: Karya Kreatif dan Inovatif*, vol. 4, no. 2, 2018.
19. Bapelitbang Boalemo Regency, "Local government work plan for 2022," *Boalemo Regent Regulation Number 49 of 2020*, vol. 49, 2021.
20. A. K. Lasiki, Nurdin, and I. Husain, "Growth and yield of hybrid corn in several classes of slopes and fertilization doses in bumela village, district of Gorontalo," *Journal of Agroteknotropika*, vol. 10, no. 2, pp. 59–69, 2021.
21. D. K. S. Swastika, "Corn self-sufficiency in Indonesia: the past 30 years and future prospects," *Journal of Litbang Pertan.*, vol. 21, no. 3, pp. 75–83, 2002.
22. E. Kaya, A. Siregar, D. M. Y. Matulesy, and M. Hasan, "Growth and yield of corn (*Zea mays* L.) due to the granting of sago palm waste compost of sago palm waste compost and organic liquid fertilizer (OLF) in ultisols," *Journal of Budid. Pertan.*, vol. 12, no. 1, pp. 16–19, 2016.
23. R. Yacoub, "Land qualities as a function to estimate land productivity in the recently reclaimed calcareous soils, nubariya, Egypt," *Egypt. Journal of Geosci.*, vol. 50, no. 4, pp. 1–13, 2010.
24. M. Liyanda, A. Karim, and Y. Abubakar, "Analysis of land suitability criteria for cocoa production of three cluster development in pidie district," *Agri*, vol. 16, no. 2, pp. 62–79, 2012.
25. R. Neswati, S. Baja, and C. Lopulisa, "A modification of land suitability requirements for maize in the humid tropics of South Sulawesi," in *Proceedings of the IOP Conference Series: Earth and Environmental Science*, vol. 921, no. 1, Indonesia, November 2021.
26. D. Subardja and Sudarsono, "The influence of land quality on productivity of maize in soils derived from volcanic and sedimentary rocks in the bogor area," *Soil Clim Journal*, vol. 23, pp. 38–46, 2005.
27. G. O. Awe and T. P. Abegunrin, "Land preparation practices for maize production: short term effects on some hydro-physical properties of analfisol and crop performance," *Middle-East Journal of Scientific Research*, vol. 25, no. 7, pp. 1420–1430, 2017.
28. J. Jankú, J. Jehlicka, K. Hermanova, D. Toth, M. Maitah, J. Kozak, J. Vopravil, R. Vacha, K. Jacko, and T. H. "A comparison of land productivity in the context of sustainable agriculture," *Soil and Water Research*, vol. 15, no. 1, pp. 1–10, 2022.

29. D. Nadalia, A. Sutandi, and B. Nugroho, "Suitability criteria of land characteristics related to Eucalyptus pellita production," in *Proceedings of the IOP Conference Series: Earth and Environmental Science*, vol. 694, no. 1, March 2021, , March 2021, <https://iopscience.iop.org/issue/1755-1315/694/1>.
30. N. Nurdin, F. Zakaria, M. A. Azis, Y. Rahim, R. Rahman, and M. Kasim, "Comparison of land suitability class for endemic Coffea liberica Pinogu HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia," *SAINS TANAH - Journal of Soil Science and Agroclimatology*, vol. 19, no. 1, p. 42, 2022.
31. A. D. Elisanti, W. Purnomo, and S. Melaniani, "Application of partial least square health status of children under 5 years in Indonesia," *Journal of Biometrika dan Kependud.*, vol. 2, no. 2, pp. 99–107, 2013.
32. J. M. Becker, C. M. Ringle, and M. Sarstedt, "Estimating moderating effects in PLS-SEM and PLSC-SEM: interaction term Generation*Data treatment," *Journal of Applied Structural Equation Modeling*, vol. 2, no. 2, pp. 1–21, 2018.
33. M. S. Yim, "A study on factor analytical methods and procedures for PLS-SEM (partial least squares structural equation modeling)," *Journal of Industrial Distribution & Business*, vol. 10, no. 5, pp. 7–20, 2019.
34. R. Schlittgen, M. Sarstedt, and C. M. Ringle, "Data generation for composite-based structural equation modeling methods," *Adv. Data Anal. Classif.*, vol. 14, no. 4, pp. 747–757, 2020.
35. S. Kono and M. Sato, "The potentials of partial least squares structural equation modeling (PLS-SEM) in leisure research," *Journal of Leisure Research*, pp. 1–21, 2022.
36. M. E. Civelek, "Comparison of covariance-based and partial least square structural equation modeling methods under non-normal distribution and small sample size limitations," *Eurasian Econom. Stat. Empirical Econ. Journa*, vol. 10, no. 1, pp. 39–50, 2018.
37. J. F. Hair, J. J. Risher, M. Sarstedt, and C. M. Ringle, "When to use and how to report the results of PLS-SEM," *European Business Review*, vol. 31, no. 1, pp. 2–24, 2019.
38. J. F. Hair, C. M. Ringle, and M. Sarstedt, "Partial least squares structural equation modeling: rigorous applications, better results and higher acceptance," *Long Range Planning*, vol. 46, pp. 1–12, 2013.
39. W. Reinartz, M. Haenlein, and J. Henseler, "An empirical comparison of the efficacy of covariance-based and variance-based SEM," *International Journal of Research in Marketing*, vol. 26, no. 4, pp. 332–344, 2009.
40. H. Syaf, "The relationship evaluation between land quality, growth and production of advanced age cocoa in kolaka east district, southeast Sulawesi province," *Bioedukasi*, vol. 3, no. 1, pp. 267–276, 2014.
41. M. L. Nurdin, S. Rayes, and Sudarto, "Study of land quality and land characteristics that determine the productivity of composite maize varieties in Gorontalo," *Systematic Reviews in Pharmacy*, vol. 11, no. 12, pp. 500–509, 2020.
42. R. Bhat and S. Sujatha, "Stablising leaf nutrient norms for arecanut by boundary line approach," *Journal of Plant Nutrition*, vol. 36, no. 6, pp. 849–862, 2013.
43. A. M. Ali, "Nutrient sufficiency ranges in mango using boundary-line approach and compositional nutrient diagnosis norms in el-salhiya, Egypt," *Communications in Soil Science and Plant Analysis*, vol. 49, no. 2, pp. 188–201, 2018.
44. M. Ridayanti, M. L. Rayes, and C. Agustina, "Evaluasi kesesuaian lahan tanaman jagung (*Zea mays* L.) pada lahan kering di kecamatan wagir kabupaten malang," *Jurnal Tanah dan Sumberdaya Lahan*, vol. 8, no. 1, pp. 149–160, 2020.
45. B. W. S. Sulawesi II, "Climate Data In The Paguyaman River Area For 2012-2022, Balai Wilayah Sungai Sulawesi Ii Provinsi Gorontalo," 2022, <https://sda.pu.go.id/balai/bwssulawesi2/data/wilayah-sungai/ws-paguyaman/>.
46. S. Ritung, F. Lukman, and R. Purnanto, *Atlas Of 1:50,000 Scale Semi-Detailed Soil Map Of Boalemo Regency*, Indonesian Center for Research and Development of Agricultural Land Resources, Gorontalo Province. Bogor, Indonesia, 2016.
47. W. Wahyunto, *Technical Guidance Guidelines for Land Suitability Assessment for Strategic Agricultural Commodities Semi-detailed Scale 1:50.000*, Balai Besar Litbang Sumberdaya Lahan Pertanian, Bogor, Indonesia, 2016.
48. L. R. Oldeman and S. Darmiyati, *An Agroclimatic Map Of Sulawesi Scale 1 - 2.500.000.Pdf*, Center Research for Agriculture, Bogor, Indonesia, 1977.
49. E. Runtuwu, I. Las, I. Amien, and H. Syahbuddin, "Utilizing cropping calendar in coping with climate change," *Journal Ecolab*, vol. 5, no. 1, pp. 1–14, 2011.
50. M. L. Rayes, *Description of Soil Profile in the Field*, Agriculture Faculty of Brawijaya University, Malang, Indonesia 2006.

52. E. Kurnia, F. Agus, A. Adimiharja, and A. Dariah, "Soil physical properties and analysis methods," *Bogor: Center for Research and Development of Agricultural Land Resources*, vol. 1, no. 1, 2006.
53. E. Eviyati and S. Sulaeman, *Analysis of Soil, Chemical, Plants, Water, and Fertilizer*, Indonesia Centre of Soil Research, Bogor, Indonesia, 2009.
54. M. Seilsepour, M. Rashidi, and B. G. Khabbaz, "Prediction of soil exchangeable sodium percentage based on soil sodium adsorption ratio," *Am. J. Agric. Environ. Sci.*, vol. 5, no. 1, pp. 1–4, 2009.
55. M. Siosemarde, F. Kave, E. Pazira, H. Sedghi, and S. J. Ghaderi, "Prediction of soil exchangeable sodium ratio based on soil sodium adsorption ratio," *World Acad. Sci. Eng. Technol.*, vol. 46, no. 10, pp. 255–257, 2010.
56. N. Sutrisna, Nadimin, I. Ishaq, and S. Putra, *Guide To The Jajar Legowo Rice Tiling Method*, Panduan. West Java Agricultural Technology Study Center, Bandung, Indonesia, 2012.
57. H. Wold, "Model construction and evaluation when theoretical knowledge is scarce," in *Evaluation of Econometric Models*, J. Kmenta and B. J. Ramsey, Eds., pp. 47–74, Academic Press, Cambridge, MA, USA, 1980.
58. K. Bollen and R. Lennox, "Conventional wisdom on measurement: a structural equation perspective," *Psychological Bulletin*, vol. 110, no. 2, pp. 305–314, 1991.
59. M. Haenlein and A. M. Kaplan, "A beginner's guide to partial least squares analysis," *Understanding Statistics*, vol. 3, no. 4, pp. 283–297, 2004.
60. J. F. Hair Jr, M. Sarstedt, L. Hopkins, and V. G. Kuppelwieser, "Partial least squares structural equation modeling (PLS-SEM): an emerging tool in business research," *European Business Review*, vol. 26, no. 2, pp. 106–121, 2014.
61. C. Fornell and D. F. Larcker, "Evaluating structural equation models with unobservable variables and measurement error," *Journal of Marketing Research*, vol. 18, no. 1, pp. 39–50, 1981.
62. W. W. Chin, "The partial least squares approach to structural formula modeling," in *Modern Methods For Business Research*, G. A. Marcoulides, Ed., pp. 295–336, Lawrence Erlbaum Associates, Mahwah, NJ, USA, 1998.
63. D. Gefen, D. Straub, and M.-C. Boudreau, "Structural equation modeling and regression: guidelines for research practice," *Communications of the Association for Information Systems*, vol. 4, pp. 1–77, 2000.
64. J. Henseler, C. M. Ringle, and R. R. Sinkovics, "The use of partial least squares path modeling in international marketing," *Advances in International Marketing*, vol. 20, pp. 277–319, 2009.
65. M. Sarstedt, C. M. Ringle, and J. F. Hair, *Partial Least Squares Structural Equation Modeling*, Springer Books, Berlin, Germany, 2022.
66. K. K. Wong, "Partial least squares structural equation modeling (PLS-SEM) techniques using SmartPLS," *Marketing Bulletin*, vol. 24, no. 1, pp. 1–32, 2013.
67. J. Hulland, "Use of partial least squares (PLS) in strategic management research: a review of four recent studies," *Strategic Management Journal*, vol. 20, no. 2, pp. 195–204, Feb. 1999.
68. D. Barclay, R. Thompson, and C. Higgins, "The partial least squares (PLS) approach to causal modeling: personal computer adoption and use as an illustration," *Technology Studies*, vol. 2, no. 2, pp. 285–309, 1995.
69. J. F. Hair, G. T. M. Hult, C. . Ringle, M. Sarstedt, N. . Danks, and S. Ray, *Partial Least Squares Structural Equation Modeling (PLS-SEM) Using R: A Workbook*, Springer, Berlin, Germany, 2021.
70. V. E. Vinzi, W. W. Chin, J. Henseler, and H. Wang, *Handbook of Partial Least Squares*, Springer, Berlin Germany, 2010.
71. FAO, "A Framework for innovation," *FAO Soils Bulletin*, vol. 32, no. 22, pp. 1–92, 1976.
72. A. Sutandi, A. Iswandi, U. Daras, M. Hikmat, and A. Krisnohadi, "Establishing land suitability criteria for cashew (*anacardium occidentale* L.) in Indonesia," *Applied and Environmental Soil Science*, vol. 2014, Article ID 743194, 14 pages, 2014.
73. R. Darmawan, "Analysis of the effect of work-family conflict and job stress on the job performance of nurses at "X" hospital," *Agora*, vol. 6, no. 2, pp. 1–6, 2018.
74. J. F. Hair, M. Sarstedt, C. M. Ringle, and J. A. Mena, "An assessment of the use of partial least squares structural equation modeling in marketing research," *Journal of the Academy of Marketing Science*, vol. 40, no. 3, pp. 414–433, 2012.
75. R. P. Bagozzi and Y. Yi, "On the evaluation of structural equation models," *Journal of the Academy of Marketing Science*, vol. 16, no. 1, pp. 74–94, Mar. 1988.
76. T. M. Basuki, D. R. Indrawati, and B. Haryadi, "The use of organic matter to improve productivity of Post lime mining land," *Jurnal Penelitian Hutan dan Konservasi Alam*, vol. 4, no. 1, pp. 1–8, 2007.

7, no. 1, pp. 8–15, 2019.

78. S. Nasreen, M. M. Haque, M. A. Hossain, and A. T. M. Farid, “Nutrient uptake and yield of onion as influenced by nitrogen and sulphur fertilization,” *Bangladesh Journal of Agricultural Research*, vol. 32, no. 3, pp. 413–420, 2008.
79. Y. Abdissa, T. Tekalign, and L. M. Pant, “Growth, bulb yield and quality of onion (*Allium cepa* L.) as influenced by nitrogen and phosphorus fertilization on vertisol I. Growth attributes, biomass production and bulb yield,” *African Journal of Agricultural Research*, vol. 6, no. 14, pp. 3252–3258, 2011.
80. I. Firmansyah and N. Sumarni, “Pengaruh dosis pupuk N dan varietas terhadap pH tanah, N-total tanah, serapan N, dan hasil umbi bawang merah (*Allium ascalonicum* L.) pada tanah entisols-brebes jawa tengah,” *Jurnal Hortikultura*, vol. 23, no. 4, 2016.
81. E. Sumiati and O. S. Gunawan, “Application of mycorrhizal biofertilizer to increase the efficiency of NPK uptake and its effects on yield and quality of shallot bulbs,” *Journal of Hort*, vol. 17, no. 1, pp. 34–42, 2006.
82. H. R. McKenzie, “Potassium fertilizer application in crop production,” *Agri-Facts*, vol. 542, no. 9, pp. 1–7, 2013.
83. M. Dianawati, “Rates and application time of K₂SO₄ on production of G0 potato seed,” *Journal of Kultiv.*, vol. 17, no. 1, pp. 531–536, 2018.
84. N. Gunadi, “The use of potassium sulphate as an alternative source of potassium fertilizer in potato,” *Journal of Hort*, vol. 17, no. 1, pp. 52–60, 2019.
85. I. S. Rahmawan, A. Z. Arifin, and Sulistyawati, “The effect of potassium (K) fertilizer on growth and yield of cabbage (*Brassica oleracea* var. capitata, L.),” *Journal of Agroteknologi Merdeka Pasuruan*, vol. 3, no. 1, pp. 17–23, 2019.
86. Subandi, “Role and management of potassium nutrient for food production in Indonesia,” *Agric. Innov. Dev*, vol. 6, no. 1, pp. 1–10, 2013.
- 10 87. IIED, “Potash case study: information supplied by the international fertilizer industry association,” *Mining, Miner. Sustain. Dev*, vol. 65, 2002.
88. N. Nursjahbani and O. Rusdiana, “Kesesuaian Durio zibethinus Murr. DAN *Nephelium lappaceum* L. Pada Lahan Blok Pemanfaatan Tahura Gunung Menumbing, Bangka Barat Suitability of Durio zibethinus Murr. and *Nephelium lappaceum* L. on the Utilization Block at Menumbing Mountain Grand Forest,” *Journal of Tropical Silviculture*, vol. 9, no. 1, pp. 1–6, 2018.
89. I. W. Nyakudya and L. Stroosnijder, “Effect of rooting depth, plant density and planting date on maize (*Zea mays* L.) yield and water use efficiency in semi-arid Zimbabwe: modelling with AquaCrop,” *Agricultural Water Management*, vol. 146, pp. 280–296, Dec. 2014.
90. S. B. Wang, L. Guo, P. Zhou, X. Wang, Y. Shen, H. Han, T. Ning, and K. Han, “Effect of subsoiling depth on soil physical properties and summer maize (*Zea mays* L.) yield,” *Plant Soil and Environment*, vol. 65, no. 3, pp. 131–137, 2019.
91. H. Z. Khan, M. A. Malik, and M. F. Saleem, “Effect of rate and source of organic material on the production potential of spring maize (*Zea mays* L.),” *Pakistan Journal of Agricultural Sciences*, vol. 45, no. 1, pp. 40–43, 2008.
92. A. Jalal, K. Azeem, M. C. M. T. Filho, and A. Khan, “Enhancing soil properties and maize yield through organic and inorganic nitrogen and diazotrophic bacteria,” in *Sustainable Crop Production*, pp. 1–14, IntechOpen, London, UK, 2020.
93. E. E. Kandil, N. R. Abdelsalam, M. A. Mansour, H. M. Ali, and M. H. Siddiqui, “Potentials of organic manure and potassium forms on maize (*Zea mays* L.) growth and production,” *Scientific Reports*, vol. 10, no. 1, 2020.
94. A. B. B. Mulyati, A. B. Baharuddin, and R. S. Tejawulan, “Improving Maize (*Zea mays* L.) growth and yield by the application of inorganic and organic fertilizers plus,” in *Proceedings of the IOP Conference Series: Earth and Environmental Science*, vol. 712, no. 1, Lombok, Indonesia, October 2021.
95. D. A. Kane, M. A. Bradford, E. Fuller, E. E. Oldfield, and S. A. Wood, “Soil organic matter protects US maize yields and lowers crop insurance payouts under drought,” *Environmental Research Letters*, vol. 16, no. 4, Article ID 044018, 2021.
96. M. Mujiyo, W. Larasati, H. Widijanto, and A. Herawati, “The Effect of Slope Gradient of land on the Soil Damage in Giritontro, Wonogiri,” *Agrotrop: Journal on Agriculture Science*, vol. 11, no. 2, 2021.
97. D. O. Suparwata, Nurmi, and M. I. Bahua, “Using vertical mulch to upland for reducing erosion, runoff and its responses to maize growth and yields,” *Agrotekno*, vol. 1, no. 3, pp. 138–145, 2012.
98. R. E. Christanto, M. Suryono, and J. Winarno, “The degree of erosion hazard mapping in dry land at jatipuro sub district of karanganyar with geographic information system (GIS),” *Sains Tanah - J. Soil Sci. Agroclimatol.*, vol. 7, no. 2, pp. 114–119, 2013.

100. S. Sukarman, A. Mulyani, and S. Purwanto, "Modifikasi meklbpi," *Jurnal Sumberdaya Lahan*, vol. 12, no. 1, 2018.
101. W. Chivasaa, O. Mutanga, and C. Biradarc, "Mapping land suitability for maize (*Zea mays* L.) production using GIS and AHP technique in Zimbabwe," *South African Journal of Geology*, vol. 8, no. 2, pp. 265–281, 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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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 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 $0^{\circ}28'5.6''-0^{\circ}57'30.02''$ 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 22.47%; then, the Fluventic Haplusteps was 21.31% and very little Vertic Haplusteps 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

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 m × 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 following formula [56]:

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

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

$$Y(\text{tha}^{-1}) = \frac{H \times 1.64 \times 56.73}{100}, \quad (2)$$

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 homogeneous, 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]:

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

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]:

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

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–Larcker 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]:

$$\text{Square root of AVE} = \sqrt{\frac{\sum \lambda_i^2}{\sum \lambda_i^2 + \sum \text{var}(\varepsilon_i)}}, \quad (5)$$

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]:

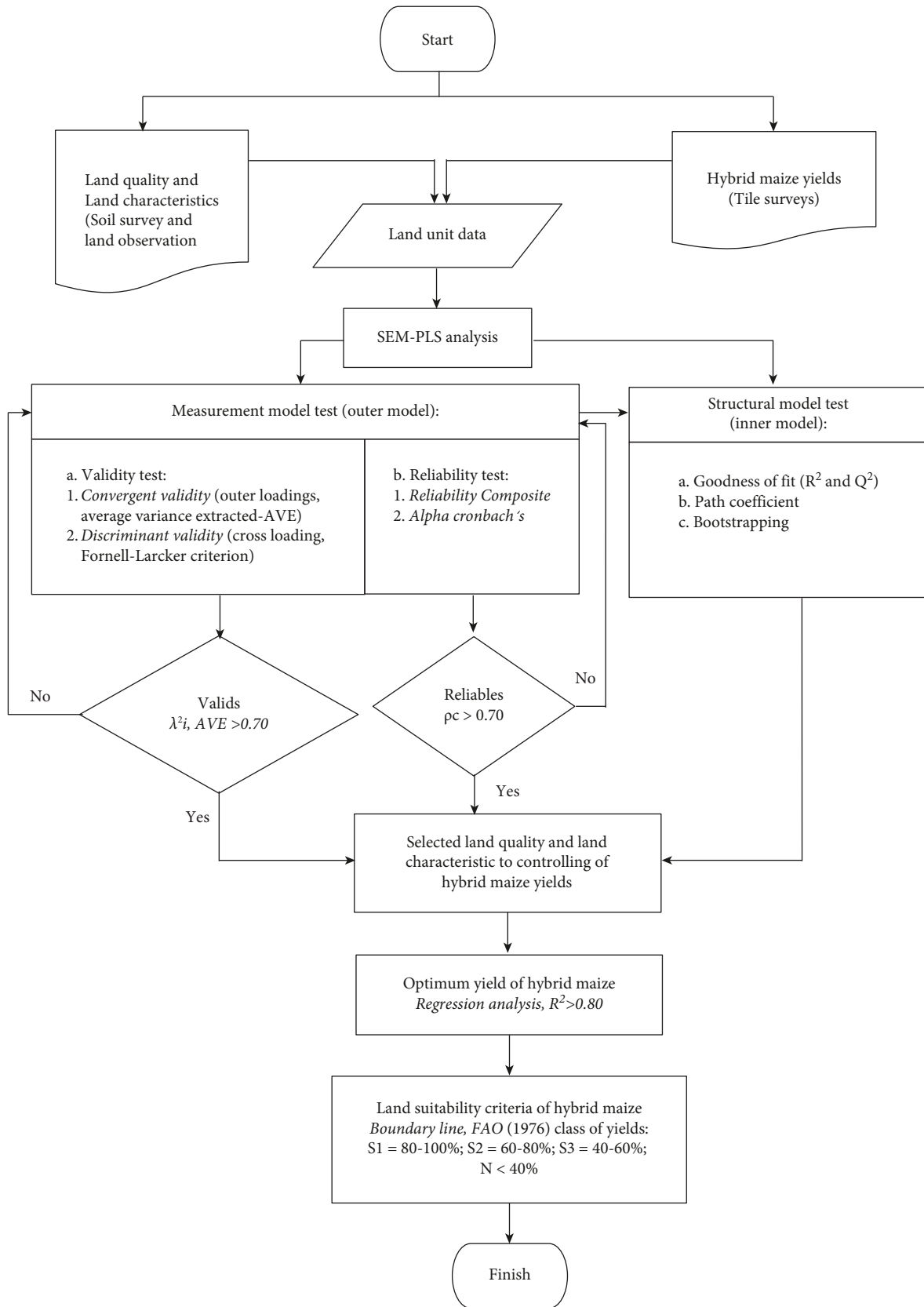


FIGURE 2: Research framework.

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

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

TABLE 2: Brief statistics of land quality and characteristics.

Latent variables/indicators	Unit	<i>n</i>	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 (<i>P</i> availability)	Mg/kg	67	0.73	8.62	3.77	58.67	12.61
X6.3 (<i>K</i> 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.

$$\rho_c = \frac{(\sum \lambda_i)^2}{(\sum \lambda_i)^2 + \sum i \text{ var}(\varepsilon_i)}, \quad (6)$$

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]:

$$\alpha = \left(\frac{\sum P \neq P \text{ } ^{i \text{ cor}}(X_{pq} \cdot X_{p'q})}{P_q + \sum P \neq P \text{ } ^{i \text{ cor}}(X_{pq} \cdot X_{p'q})} \right) \left(\frac{P_q}{P_{q-1}} \right), \quad (7)$$

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]:

$$H_j = \gamma_j \xi_1 + \gamma_j \xi_2 + \dots + \gamma_j \xi_n + \zeta_j, \quad (8)$$

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 ζ_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]:

$$Q^2 \text{ (Predictive relevance)} = 1 - (1 - R_1^2)(1 - R_2^2) \dots (1 - R_p^2), \quad (9)$$

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].

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

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

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

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

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.

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

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

Indicators	Latent Variables										
	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, 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 (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)		
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)		
X9.1 (inundation height)	0.992	0.984
X9.2 (inundation period)		
X10.1 (rock outcrops)	0.998	0.995
X10.2 (surface rock)		

nor, not reliable.

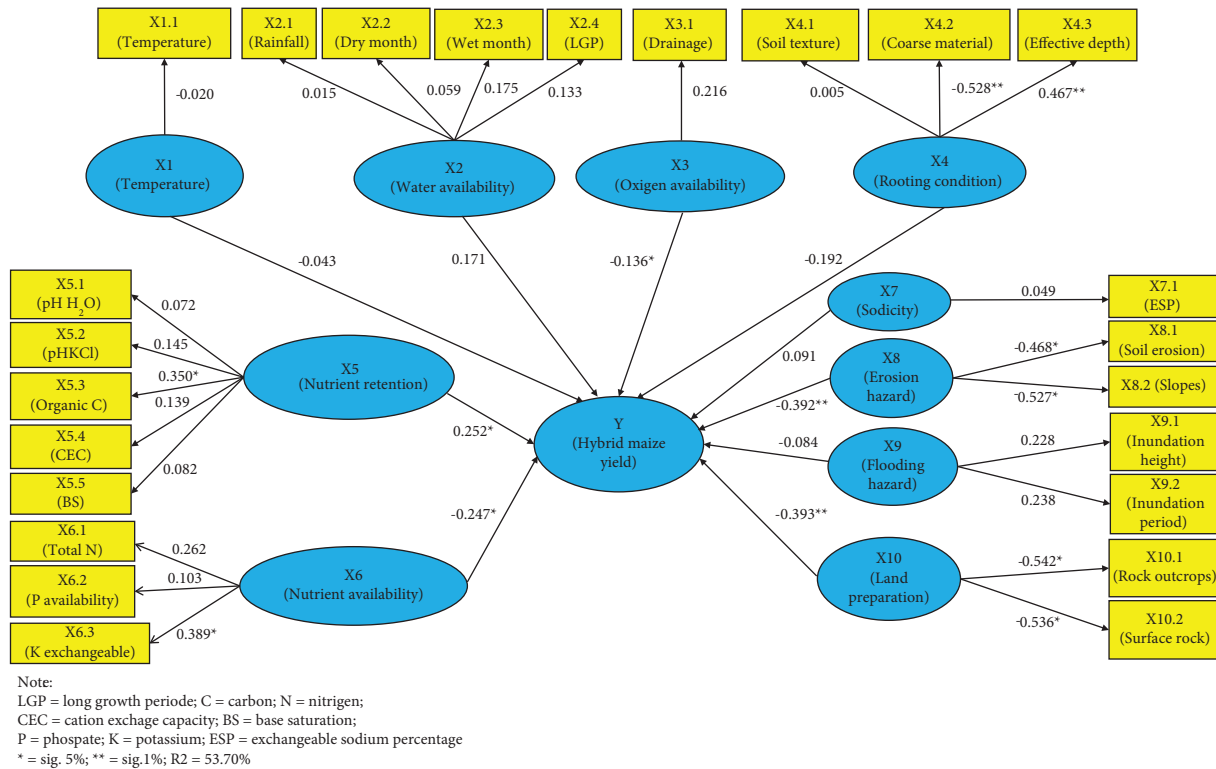


FIGURE 3: Path coefficient of land quality on hybrid maize yield.

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 Wirosedarmo 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 R² 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 R² 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 R² value of 97%. Furthermore, coarse material and soil erosion were

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

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	$Y = -0.0008354x^2 + 0.29100569x - 1.3957496$	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

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].

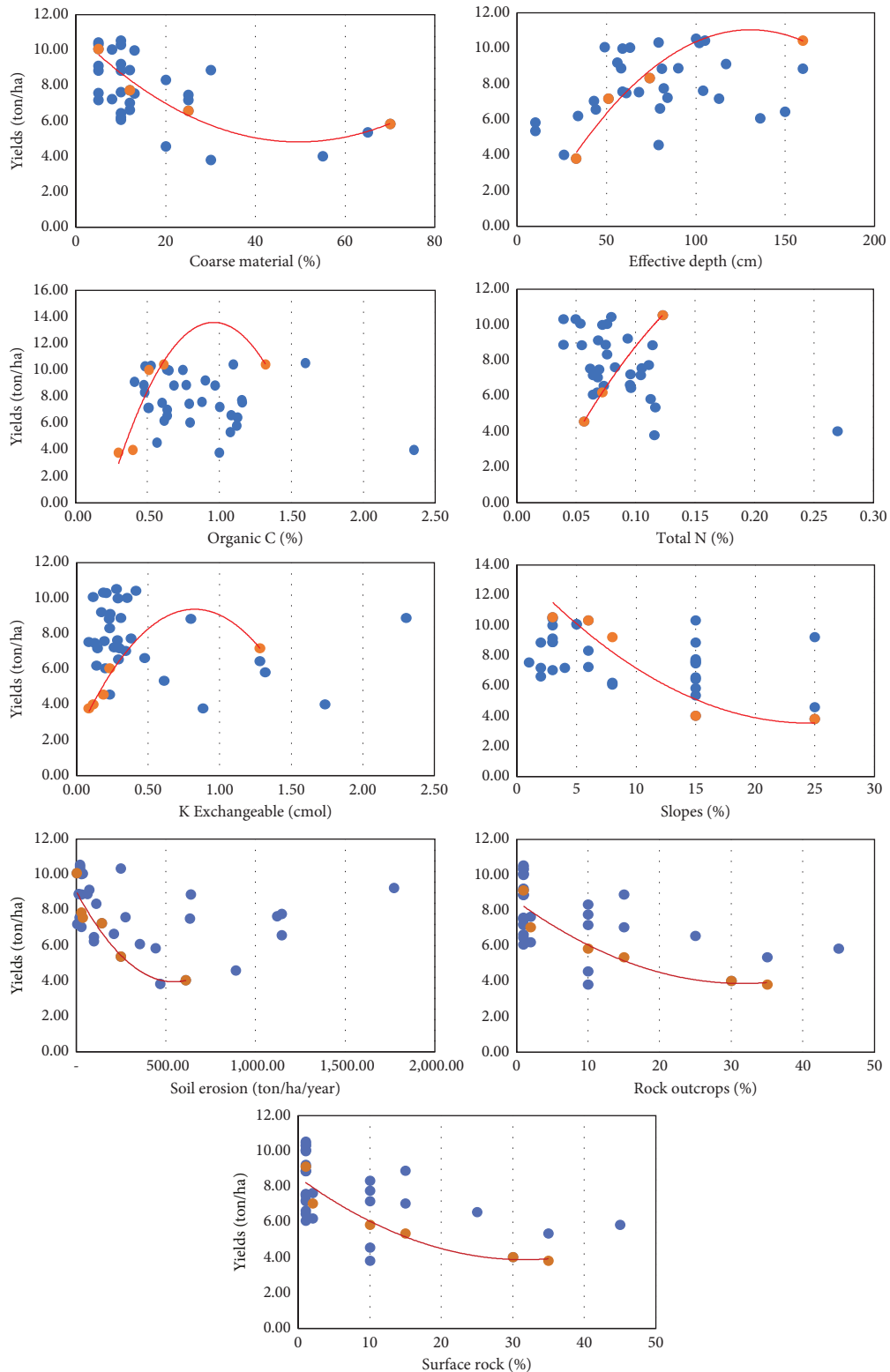


FIGURE 4: Scatter diagram relationship among maize yield and land characteristics.

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 characteristics	Yield limits (ton/ha)			Value of land suitability criterion obtained			
	S1 – S2 (80% × Y_{optim})	S2 – S3 (60% × Y_{optim})	S3 – N (40% × Y_{optim})	S1	S2	S3	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

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 quality/land characteristics	New land suitability criterion of hybrid maize				Land suitability criterion of general maize [47]			
	S1	S2	S3	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	Mo	Lo	VLo	—
K 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.

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References

- [1] K. Pawlak and M. Kołodziejczak, "The role of agriculture in ensuring food security in developing countries: considerations in the context of the problem of sustainable food production," *Sustainability*, vol. 12, no. 13, 2020.
- [2] O. Erenstein, M. Jaleta, K. Sonder, K. Mottaleb, and B. M. Prasanna, "Global maize production, consumption and trade: trends and R&D implications," *Food Security*, vol. 14, no. 5, pp. 1295–1319, 2022.
- [3] U. Grote, A. Fasse, T. T. Nguyen, and O. Erenstein, "Food security and the dynamics of wheat and maize value chains in africa and asia," *Frontiers in Sustainable Food Systems*, vol. 4, pp. 1–17, 2021.
- [4] R. Wirosoedarmo, A. T. Sutanahaji, and E. Kurniati, "Land suitability assessment of corn (*Zea mays* L.) using spasiel analysis method," *agriTECH*, vol. 31, no. 1, pp. 71–78, 2012.
- [5] B. Arifin, "High expectations on KSA maize production," *Stat. Policy Br. Indones.* vol. 18, pp. 37–41, 2021.
- [6] M. L. Nurdin, M. L. Rayes, and S. Sudarto, "Analysis of quality and land characteristics that control local maize production in Gorontalo," *Proceedings of the International Seminar on Promoting Local Resources for Sustainable Agriculture and Development (ISPLRSAD 2020)*, vol. 13, pp. 438–446, 2021.
- [7] T. Kartika, "Pengaruh jarak tanam terhadap pertumbuhan dan produksi jagung (*zea mays* L.) non hibrida di Lahan balai agro teknologi terpadu (ATP)," *Sainmatika: Jurnal Ilmiah Matematika dan Ilmu Pengetahuan Alam*, vol. 15, no. 2, 2018.
- [8] A. N. A. Sutimawati, A. N. Aulia, and R. M. Muliarsari, "Comparative analysis of hybrid corn farming based on business scale in tempurejo sub-district," *Jurnal Agribest*, vol. 3, no. 1, 2019.
- [9] I. S. Anugrah, "Corn-based agribusiness for rural economic development in Gorontalo province," *Anal. Kebijak. Pertan.* vol. 8, no. 4, pp. 363–383, 2016.
- [10] H. Limanseto, "The government encourages productivity of the leading commodities of Gorontalo province to increase people's welfare," *Coordinating Ministry for Economic Affairs of the Republic of Indonesia, Jakarta*, vol. 1, pp. 1–2, 2021.
- [11] N. Endey, I. K. S. Arsana, A. Y. Katili, A. Sahabi, and M. A. Talalu, "Analisis daya saing komoditi unggulan Gorontalo dalam mendukung ibu kota negara baru republik Indonesia," *Equilibrium: Jurnal Pendidikan*, vol. 10, no. 3, pp. 380–396, 2022.
- [12] K. Astuti, R. O. Prasetyo, and N. Khasanah, *Analysis of Maize and Soybean Productivity in Indonesia 2020 (The Result of Crop Cutting Survey)*, BPS RI, Indonesia, 2021.
- [13] BPS-Statistic of Gorontalo, *Gorontalo Province in Figures 2018*, BPS-Statistic of Gorontalo, Indonesia, 2018.
- [14] W. Ardiansyah, M. A. Indrianti, M. M. Djibran, and D. R. Hippy, "KERAGAAN USAHATANI LAHAN KER-ING PADA PETANI TRANSMIGRAN (skkwk)," *Jurnal Agriovet*, vol. 4, no. 2, pp. 125–142, 2022.
- [15] A. H. Samon, *The Analysis of Comparative and Competitive Superiority of Corn Farm Enterprises in Boalemo Regency*, Hasanuddin University, Makassar, Indonesia, 2005.
- [16] A. M. D. Putri and Mustofiq, *Boalemo Regency in Figures 2022*, BPS-Statistics of Boalemo Regency, Indonesia, 2022.
- [17] W. Tialo, M. Arief Azis, and N. Nurdin, "Pertumbuhan dan produksi jagung pulut lokal Gorontalo, efektivitas agronomi, dan ekonomi dengan pemberian pupuk organik di Bualo, Kabupaten Boalemo," *Journal Agercolere*, vol. 4, no. 2, pp. 44–53, 2022.
- [18] K. P. Windra sukma, "Growth and production of local maize, hybrid and composite in pamekasan, madura," *Journal Agrosains: Karya Kreatif dan Inovatif*, vol. 4, no. 2, 2018.
- [19] Bapelitbang Boalemo Regency, "Local government work plan for 2022," *Boalemo Regent Regulation Number 49 of 2020*, vol. 49, 2021.
- [20] A. K. Lasiki, Nurdin, and I. Husain, "Growth and yield of hybrid corn in several classes of slopes and fertilization doses in bumela village, district of Gorontalo," *Journal of Agro-teknotropika*, vol. 10, no. 2, pp. 59–69, 2021.
- [21] D. K. S. Swastika, "Corn self-sufficiency in Indonesia: the past 30 years and future prospects," *Journal of Litbang Pertan.* vol. 21, no. 3, pp. 75–83, 2002.
- [22] E. Kaya, A. Siregar, D. M. Y. Matulesy, and M. Hasan, "Growth and yield of corn (*Zea mays* L.) due to the granting of sago palm waste compost of sago palm waste compost and organic liquid fertilizer (OLF) in ultisols," *Journal of Budid. Pertan.* vol. 12, no. 1, pp. 16–19, 2016.
- [23] R. Yacoub, "Land qualities as a function to estimate land productivity in the recently reclaimed calcareous soils, nubariya, Egypt," *Egypt. Journal of Geosci.* vol. 50, no. 4, pp. 1–13, 2010.
- [24] M. Liyanda, A. Karim, and Y. Abubakar, "Analysis of land suitability criteria for cocoa production of three cluster development in pidie district," *Agri*, vol. 16, no. 2, pp. 62–79, 2012.
- [25] R. Neswati, S. Baja, and C. Lopulisa, "A modification of land suitability requirements for maize in the humid tropics of South Sulawesi," in *Proceedings of the IOP Conference Series: Earth and Environmental Science*, vol. 921, no. 1, Indonesia, November 2021.
- [26] D. Subardja and Sudarsono, "The influence of land quality on productivity of maize in soils derived from volcanic and sedimentary rocks in the bogor area," *Soil Clim Journal*, vol. 23, pp. 38–46, 2005.
- [27] G. O. Awe and T. P. Abegunrin, "Land preparation practices for maize production: short term effects on some hydro-physical properties of analfisol and crop performance," *Middle-East Journal of Scientific Research*, vol. 25, no. 7, pp. 1420–1430, 2017.
- [28] J. Janků, J. Jehlicka, K. Hermanova et al., "An overview of a land evaluation in the context of ecosystem services," *Soil and Water Research*, vol. 17, no. 1, pp. 1–14, 2022.
- [29] D. Nadalia, A. Sutandi, and B. Nugroho, "Suitability criteria of land characteristics related to Eucalyptus pellita production," in *Proceedings of the IOP Conference Series: Earth and Environmental Science*, vol. 694, no. 1, March 2021, <https://iopscience.iop.org/issue/1755-1315/694/1>.
- [30] N. Nurdin, F. Zakaria, M. A. Azis, Y. Rahim, R. Rahman, and M. Kasim, "Comparison of land suitability class for endemic

- Coffea liberica Pinogu HP. acquired using different methods and recommendations for land management in Pinogu Plateau, Bone Bolango Regency, Indonesia,” *SAINS TANAH - Journal of Soil Science and Agroclimatology*, vol. 19, no. 1, p. 42, 2022.
- [31] A. D. Elisanti, W. Purnomo, and S. Melaniani, “Application of partial least square health status of children under 5 years in Indonesia,” *Journal of Biometrika dan Kependud.*, vol. 2, no. 2, pp. 99–107, 2013.
- [32] J. M. Becker, C. M. Ringle, and M. Sarstedt, “Estimating moderating effects in PLS-SEM and PLSC-SEM: interaction term Generation*Data treatment,” *Journal of Applied Structural Equation Modeling*, vol. 2, no. 2, pp. 1–21, 2018.
- [33] M. S. Yim, “A study on factor analytical methods and procedures for PLS-SEM (partial least squares structural equation modeling),” *Journal of Industrial Distribution & Business*, vol. 10, no. 5, pp. 7–20, 2019.
- [34] R. Schlittgen, M. Sarstedt, and C. M. Ringle, “Data generation for composite-based structural equation modeling methods,” *Adv. Data Anal. Classif.*, vol. 14, no. 4, pp. 747–757, 2020.
- [35] S. Kono and M. Sato, “The potentials of partial least squares structural equation modeling (PLS-SEM) in leisure research,” *Journal of Leisure Research*, vol. 53, no. 5, pp. 1–21, 2022.
- [36] M. E. Civelek, “Comparison of covariance-based and partial least square structural equation modeling methods under non-normal distribution and small sample size limitations,” *Eurasian Econom. Stat. Emprical Econ. Journa*, vol. 10, no. 1, pp. 39–50, 2018.
- [37] J. F. Hair, J. J. Risher, M. Sarstedt, and C. M. Ringle, “When to use and how to report the results of PLS-SEM,” *European Business Review*, vol. 31, no. 1, pp. 2–24, 2019.
- [38] J. F. Hair, C. M. Ringle, and M. Sarstedt, “Partial least squares structural equation modeling: rigorous applications, better results and higher acceptance,” *Long Range Planning*, vol. 46, pp. 1–12, 2013.
- [39] W. Reinartz, M. Haenlein, and J. Henseler, “An empirical comparison of the efficacy of covariance-based and variance-based SEM,” *International Journal of Research in Marketing*, vol. 26, no. 4, pp. 332–344, 2009.
- [40] H. Syaf, “The relationship evaluation between land quality, growth and production of advanced age cocoa in kolaka east district, southeast Sulawesi province,” *Bioedukasi*, vol. 3, no. 1, pp. 267–276, 2014.
- [41] M. L. Nurdin, S. Rayes, and Sudarto, “Study of land quality and land characteristics that determine the productivity of composite maize varieties in Gorontalo,” *Systematic Reviews in Pharmacy*, vol. 11, no. 12, pp. 500–509, 2020.
- [42] R. Bhat and S. Sujatha, “Stablising leaf nutrient norms for arecanut by boundary line approach,” *Journal of Plant Nutrition*, vol. 36, no. 6, pp. 849–862, 2013.
- [43] A. M. Ali, “Nutrient sufficiency ranges in mango using boundary-line approach and compositional nutrient diagnosis norms in el-salhiya, Egypt,” *Communications in Soil Science and Plant Analysis*, vol. 49, no. 2, pp. 188–201, 2018.
- [44] M. Ridayanti, M. L. Rayes, and C. Agustina, “Evaluasi kesesuaian lahan tanaman jagung (*Zea mays* L.) pada lahan kering di kecamatan wagir kabupaten malang,” *Jurnal Tanah dan Sumberdaya Lahan*, vol. 8, no. 1, pp. 149–160, 2020.
- [45] B. W. S. Sulawesi II, “Climate Data In The Paguyaman River Area For 2012-2022, Balai Wilayah Sungai Sulawesi Ii Provinsi Gorontalo,” 2022, <https://sda.pu.go.id/balai/bwssulawesi2/data/wilayah-sungai/ws-paguyaman/>.
- [46] S. Ritung, F. Lukman, and R. Purnanto, *Atlas Of 1:50,000 Scale Semi-Detailed Soil Map Of Boalemo Regency*, Indonesian Center for Research and Development of Agricultural Land Resources, Gorontalo Province. Bogor, Indonesia, 2016.
- [47] W. Wahyunto, *Technical Guidance Guidelines for Land Suitability Assessment for Strategic Agricultural Commodities Semi-detailed Scale 1:50.000*, Balai Besar Litbang Sumberdaya Lahan Pertanian, Bogor, Indonesia, 2016.
- [48] L. R. Oldeman and S. Darmiyati, *An Agroclimatic Map Of Sulawesi Scale 1 - 2.500.000.Pdf*, Center Research for Agriculture, Bogor, Indonesia, 1977.
- [49] E. Runtunuwu, I. Las, I. Amien, and H. Syahbuddin, “Utilizing cropping calendar in coping with climate change,” *Journal Ecolab*, vol. 5, no. 1, pp. 1–14, 2011.
- [50] M. L. Rayes, *Description of Soil Profile in the Field*, Agriculture Faculty of Brawijaya University, Malang, Indonesia, 2006.
- [51] W. H. Wischmeier and D. D. Smith, “Predicting rainfall erosion losses—a guide to conservation planning,” *Agric. Handb.*, vol. 537, pp. 1–60, 1978.
- [52] E. Kurnia, F. Agus, A. Adimiharja, and A. Dariah, “Soil physical properties and analysis methods,” *Bogor: Center for Research and Development of Agricultural Land Resources*, vol. 1, no. 1, 2006.
- [53] E. Eviyati and S. Sulaeman, *Analysis of Soil, Chemical, Plants, Water, and Fertilizer*, Indonesia Centre of Soil Research, Bogor, Indonesia, 2009.
- [54] M. Seilsepour, M. Rashidi, and B. G. Khabbaz, “Prediction of soil exchangeable sodium percentage based on soil sodium adsorption ratio,” *Am. J. Agric. Environ. Sci.*, vol. 5, no. 1, pp. 1–4, 2009.
- [55] M. Siosemarde, F. Kave, E. Pazira, H. Sedghi, and S. J. Ghaderi, “Prediction of soil exchangeable sodium ratio based on soil sodium adsorption ratio,” *World Acad. Sci. Eng. Technol.*, vol. 46, no. 10, pp. 255–257, 2010.
- [56] N. Sutrisna, Nadimin, I. Ishaq, and S. Putra, *Guide To The Jajar Legowo Rice Tiling Method*, pp. 1–27, Panduan. West Java Agricultural Technology Study Center, Bandung, Indonesia, 2012.
- [57] H. Wold, “Model construction and evaluation when theoretical knowledge is scarce,” in *Evaluation of Econometric Models*, J. Kmenta and B. J. Ramsey, Eds., pp. 47–74, Academic Press, Cambridge, MA, USA, 1980.
- [58] K. Bollen and R. Lennox, “Conventional wisdom on measurement: a structural equation perspective,” *Psychological Bulletin*, vol. 110, no. 2, pp. 305–314, 1991.
- [59] M. Haenlein and A. M. Kaplan, “A beginner’s guide to partial least squares analysis,” *Understanding Statistics*, vol. 3, no. 4, pp. 283–297, 2004.
- [60] J. F. Hair Jr, M. Sarstedt, L. Hopkins, and V. G. Kuppelwieser, “Partial least squares structural equation modeling (PLS-SEM): an emerging tool in business research,” *European Business Review*, vol. 26, no. 2, pp. 106–121, 2014.
- [61] C. Fornell and D. F. Larcker, “Evaluating structural equation models with unobservable variables and measurement error,” *Journal of Marketing Research*, vol. 18, no. 1, pp. 39–50, 1981.
- [62] W. W. Chin, “The partial least squares approach to structural formula modeling,” in *Modern Methods For Business Research*, G. A. Marcoulides, Ed., pp. 295–336, Lawrence Erlbaum Associates, Mahwah, NJ, USA, 1998.
- [63] D. Gefen, D. Straub, and M.-C. Boudreau, “Structural equation modeling and regression: guidelines for research

- practice," *Communications of the Association for Information Systems*, vol. 4, pp. 1-77, 2000.
- [64] J. Henseler, C. M. Ringle, and R. R. Sinkovics, "The use of partial least squares path modeling in international marketing," *Advances in International Marketing*, vol. 20, pp. 277-319, 2009.
- [65] M. Sarstedt, C. M. Ringle, and J. F. Hair, *Partial Least Squares Structural Equation Modeling*, Springer Books, Berlin, Germany, pp. 587-632, 2022.
- [66] K. K. Wong, "Partial least squares structural equation modeling (PLS-SEM) techniques using SmartPLS," *Marketing Bulletin*, vol. 24, no. 1, pp. 1-32, 2013.
- [67] J. Hulland, "Use of partial least squares (PLS) in strategic management research: a review of four recent studies," *Strategic Management Journal*, vol. 20, no. 2, pp. 195-204, Feb. 1999.
- [68] D. Barclay, R. Thompson, and C. Higgins, "The partial least squares (PLS) approach to causal modeling: personal computer adoption and use as an illustration," *Technology Studies*, vol. 2, no. 2, pp. 285-309, 1995.
- [69] J. F. Hair, G. T. M. Hult, C. . Ringle, M. Sarstedt, N. . Danks, and S. Ray, *Partial Least Squares Structural Equation Modeling (PLS-SEM) Using R: A Workbook*, Springer, Berlin, Germany, 2021.
- [70] V. E. Vinzi, W. W. Chin, J. Henseler, and H. Wang, *Handbook of Partial Least Squares*, Springer, Berlin Germany, 2010.
- [71] FAO, "A Framework for innovation," *FAO Soils Bulletin*, vol. 32, no. 22, pp. 1-92, 1976.
- [72] A. Sutandi, A. Iswandi, U. Daras, M. Hikmat, and A. Krisnohadi, "Establishing land suitability criteria for cashew (*anacardium occidentale* L.) in Indonesia," *Applied and Environmental Soil Science*, vol. 2014, Article ID 743194, 14 pages, 2014.
- [73] R. Darmawan, "Analysis of the effect of work-family conflict and job stress on the job performance of nurses at "X" hospital," *Agora*, vol. 6, no. 2, pp. 1-6, 2018.
- [74] J. F. Hair, M. Sarstedt, C. M. Ringle, and J. A. Mena, "An assessment of the use of partial least squares structural equation modeling in marketing research," *Journal of the Academy of Marketing Science*, vol. 40, no. 3, pp. 414-433, 2012.
- [75] R. P. Bagozzi and Y. Yi, "On the evaluation of structural equation models," *Journal of the Academy of Marketing Science*, vol. 16, no. 1, pp. 74-94, Mar. 1988.
- [76] T. M. Basuki, D. R. Indrawati, and B. Haryadi, "The use of organic matter to improve productivity of Post lime mining land," *Jurnal Penelitian Hutan dan Konservasi Alam*, vol. 4, no. 1, pp. 1-8, 2007.
- [77] M. S. Alfian and H. Purnamawati, "Dosis dan Waktu Aplikasi Pupuk Kalium pada Pertumbuhan dan Produksi Jagung Manis di BBPP Batangkaluku Kabupaten Gowa Sulawesi Selatan," *Buletin Agrohorti*, vol. 7, no. 1, pp. 8-15, 2019.
- [78] Sutardjo, Sulastrri, and W. Nawfetrias, "Optimization of production of four hybrid maize varieties in kertoso, nganjuk regency," *Journal of Sains dan Teknol. Indonesia*, vol. 14, no. 1, pp. 76-80, 2012.
- [79] S. Nasreen, M. M. Haque, M. A. Hossain, and A. T. M. Farid, "Nutrient uptake and yield of onion as influenced by nitrogen and sulphur fertilization," *Bangladesh Journal of Agricultural Research*, vol. 32, no. 3, pp. 413-420, 2008.
- [80] Y. Abdissa, T. Tekalign, and L. M. Pant, "Growth, bulb yield and quality of onion (*Allium cepa* L.) as influenced by nitrogen and phosphorus fertilization on vertisol I. Growth attributes, biomass production and bulb yield," *African Journal of Agricultural Research*, vol. 6, no. 14, pp. 3252-3258, 2011.
- [81] I. Firmansyah and N. Sumarni, "Pengaruh dosis pupuk N dan varietas terhadap pH tanah, N-total tanah, serapan N, dan hasil umbi bawang merah (*Allium ascalonicum* L.) pada tanah entisols-brebes jawa tengah," *Jurnal Hortikultura*, vol. 23, no. 4, 2016.
- [82] E. Sumiati and O. S. Gunawan, "Application of mycorrhizal biofertilizer to increase the efficiency of NPK uptake and its effects on yield and quality of shallot bulbs," *Journal of Hort*, vol. 17, no. 1, pp. 34-42, 2006.
- [83] H. R. McKenzie, "Potassium fertilizer application in crop production," *Agri-Facts*, vol. 542, no. 9, pp. 1-7, 2013.
- [84] M. Dianawati, "Rates and application time of K₂SO₄ on production of G0 potato seed," *Journal of Kultiv.*, vol. 17, no. 1, pp. 531-536, 2018.
- [85] N. Gunadi, "The use of potassium sulphate as an alternative source of potassium fertilizer in potato," *Journal of Hort*, vol. 17, no. 1, pp. 52-60, 2019.
- [86] I. S. Rahmawan, A. Z. Arifin, and Sulistyawati, "The effect of potassium (K) fertilizer on growth and yield of cabbage (*Brassica oleraceae* var. *capitata*, L.)," *Journal of Agroteknologi Merdeka Pasuruan*, vol. 3, no. 1, pp. 17-23, 2019.
- [87] IIED, "Potash case study: information supplied by the international fertilizer industry association," *Mining, Miner. Sustain. Dev.*, vol. 65, 2002.
- [88] Subandi, "Role and management of potassium nutrient for food production in Indonesia," *Agric. Innov. Dev.*, vol. 6, no. 1, pp. 1-10, 2013.
- [89] N. Nursjahbani and O. Rusdiana, "Kesesuaian Durio zibethinus Murr. DAN Nephelium lappaceum l. Pada Lahan Blok Pemanfaatan Tahura Gunung Menumbing, Bangka Barat Suitability of Durio zibethinus Murr. and Nephelium lappaceum L. on the Utilization Block at Menumbing Mountain Grand Forest," *Journal of Tropical Silviculture*, vol. 9, no. 1, pp. 1-6, 2018.
- [90] I. W. Nyakudya and L. Stroosnijder, "Effect of rooting depth, plant density and planting date on maize (*Zea mays* L.) yield and water use efficiency in semi-arid Zimbabwe: modelling with AquaCrop," *Agricultural Water Management*, vol. 146, pp. 280-296, Dec. 2014.
- [91] S. B. Wang, L. Guo, P. Zhou et al., "Effect of subsoiling depth on soil physical properties and summer maize (*Zea mays* L.) yield," *Plant Soil and Environment*, vol. 65, no. 3, pp. 131-137, 2019.
- [92] H. Z. Khan, M. A. Malik, and M. F. Saleem, "Effect of rate and source of organic material on the production potential of spring maize (*Zea mays* L.)," *Pakistan Journal of Agricultural Sciences*, vol. 45, no. 1, pp. 40-43, 2008.
- [93] A. Jalal, K. Azeem, M. C. M. T. Filho, and A. Khan, "Enhancing soil properties and maize yield through organic and inorganic nitrogen and diazotrophic bacteria," in *Sustainable Crop Production*, pp. 1-14, IntechOpen, London, UK, 2020.
- [94] E. E. Kandil, N. R. Abdelsalam, M. A. Mansour, H. M. Ali, and M. H. Siddiqui, "Potentials of organic manure and potassium forms on maize (*Zea mays* L.) growth and production," *Scientific Reports*, vol. 10, no. 1, 2020.
- [95] A. B. B. Mulyati, A. B. Baharuddin, and R. S. Tejawulan, "Improving Maize (*Zea mays* L.) growth and yield by the application of inorganic and organic fertilizers plus," in *Proceedings of the IOP Conference Series: Earth and*

- Environmental Science*, vol. 712, no. 1, Lombok, Indonesia, October 2021.
- [96] D. A. Kane, M. A. Bradford, E. Fuller, E. E. Oldfield, and S. A. Wood, "Soil organic matter protects US maize yields and lowers crop insurance payouts under drought," *Environmental Research Letters*, vol. 16, no. 4, Article ID 044018, 2021.
- [97] M. Mujiyo, W. Larasati, H. Widiyanto, and A. Herawati, "The Effect of Slope Gradient of land on the Soil Damage in Giritontro, Wonogiri," *Agrotrop: Journal on Agriculture Science*, vol. 11, no. 2, 2021.
- [98] D. O. Suparwata, Nurmi, and M. I. Bahua, "Using vertical mulch to upland for reducing erosion, runoff and its responses to maize growth and yields," *Agrotekno*, vol. 1, no. 3, pp. 138–145, 2012.
- [99] R. E. Christanto, M. Suryono, and J. Winarno, "The degree of erosion hazard mapping in dry land at jatipuro sub district of karanganyar with geographic information system (GIS)," *Sains Tanah - J. Soil Sci. Agroclimatol*, vol. 7, no. 2, pp. 114–119, 2013.
- [100] E. Elfayetti and H. Herdi, "Evaluasi kesesuaian lahan untuk tanaman jagung di Desa saentis, percut sei tuan," *JUPIIS J. Pendidik. ILMU-ILMU Sos*, vol. 7, no. 1, 2015.
- [101] S. Sukarman, A. Mulyani, and S. Purwanto, "Modifikasi meklbpi," *Jurnal Sumberdaya Lahan*, vol. 12, no. 1, 2018.
- [102] W. Chivasaa, O. Mutanga, and C. Biradarc, "Mapping land suitability for maize (*Zea mays* L.) production using GIS and AHP technique in Zimbabwe," *South African Journal of Geology*, vol. 8, no. 2, pp. 265–281, 2022.