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Research Article

Establishing Land Suitability Criteria for Cashew (*Anacardium occidentale* L.) in Indonesia

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Commodity development requires site selection which should be established prior to large scale development. The land suitability criteria for cashew are not presently available. The relationship between the biophysical aspects, especially land and soil with commodity productivity, is also not known in depth. The objective of this study is to establish the criteria of land suitability for cashew in Indonesia, based on its production and land characteristics. Cashew plantations in 5 provinces were sampled. The data of production per tree per year were obtained from farmers, while the soil was sampled and analyzed in the laboratory. Age-adjusted cashew production was used as the yield response and plotted against land characteristics. Boundary lines resulting from the scatter of points were described; these lines produced the limits of land suitability criteria. The criteria were established using a projection of the intersection between the boundary line and yield interval. The criteria were also built in accordance with the productivity index of FAO for the internal boundary inside the S (suitable) class and by calculating the break-event point production for the boundary between S (suitable) and N (nonsuitable) order. The main result of this research is land suitability criteria for cashew.

1. Introduction

The cashew (*Anacardium occidentale* L.) is a prospective commodity in Indonesia, and its cultivation issues are relevant to the country's development both as an export commodity and in regard to environmental conservation. At the beginning of Indonesia's agricultural development, planting of the cashew was implemented for greening programs and reforestation. With the increase of prices, issues of cashew development began to shift from land conservation to more economic considerations. Today, Indonesia is the fifth largest cashew producer in the world after Nigeria, India, Cote d'Ivoire, and Vietnam. Indonesia's total cashew production in 2011 was 114,789 tons, originating from 575,841 Ha of plantations area [1].

One of the problems encountered in the development of cashew in Indonesia is the low productivity. Average Indonesian cashew productivity in 2011 was 367 kg·Ha^{-1} [1, 2]. In comparison, the production in Keralla, India, reached 1,180 kg·Ha^{-1} [3], while Vietnam produced 672 kg·Ha^{-1} [4], and Nigeria produced 1,970 kg·Ha^{-1} [5]. Compared to the long-term target production of this commodity in Indonesia of >1,000 kg nuts·Ha^{-1}·year^{-1} [6], actual average production is very low. One of the efforts to increase productivity is planting the commodity only on suitable land.

Land suitability analysis is a method generally used in site selection. The proper site selection should be established before any large scale development. Several methods have been developed in land suitability analysis, either qualitative or quantitative [7, 8]. Among the various systems used in qualitative land evaluation, the maximum limitation system is the most common one used in Indonesia. In this system, the degree of land use limitations is imposed by land characteristics on the basis of permanent properties. This method expresses the land suitability class qualitatively for any given area. A simple table of criteria is used, by matching land requirements with land characteristics [7]. In other words, it is necessary to have criteria to assess the suitability of land utilization. As of yet, quantitative criteria for cashew site selection are not available. In many land evaluation references used in Indonesia [9–12], the criteria for this commodity have not been included. Development of accurate criteria is thus necessary.

Appropriate criteria should reflect the production, as the use of inappropriate criteria may cause errors in the diagnosis of land being evaluated. The use of inappropriate criteria under certain circumstances assessment often does not reflect the factual growth in the field as well as the production. In some cases, assessment of suitability results in an N (not suitable) class, although the commodity growth in the field was good. In some other cases, the assessment of suitability that produces an S1 (highly suitable) class or an S2 (suitable) class was confronted by the fact that the plants do not grow as well as their suitability classes indicate. This has been frequently reported in much research [13]. Hence, criteria outlining plant growth should be developed on the basis of crop production.

In the maximum limitation method, the evaluations assess land qualities and land characteristics as compared to land use requirements, regardless of whether there is an interaction between two or more land qualities or characteristics. If the correlation between land quality and land characteristic is built empirically, it will be costly and time-consuming to an excessive degree. Therefore, it is necessary to look for quicker, cheaper, and more precise ways to develop criteria.

The objective of this study is to delineate the relationship between cashew production and land characteristics to establish land suitability criteria for cashew plantation. The criteria developed should be reflective of plant productivity.

2. Materials and Methods

2.1. Logical Framework. Many studies have been conducted to reveal the relationship between plant growth and production with land factors [14, 15]. If a specific relationship between growth factors and plant response exists, then maximum growth and production can be obtained by optimizing such growth factors. The relationship is often tentatively established with the goal of defining diagnostic models [16]. Unfortunately, the relationship is often established under controlled conditions, in which only one variable is varied, while all other factors remain stable. As a consequence, the relationship is valid only for specific conditions under which the particular experiment was conducted. In fact, the influence of growth factors changes when environment and conditions are changed due to other factors. Thus, resulted models cannot be generalized.

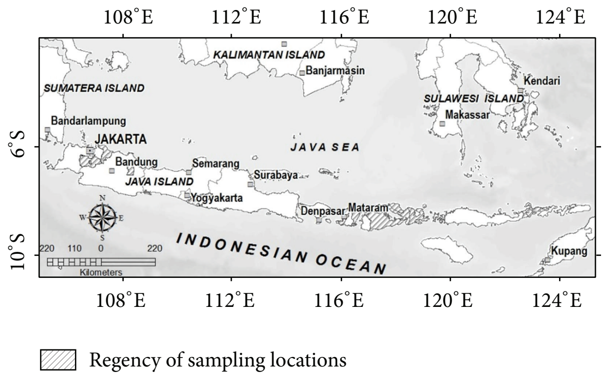

Figure 1: Sampling locations.

Alternatives can be posited using empirical models, in which data are collected from locations with a wide range of environmental characteristics, including soil and climate properties. This type of approach has already been done in several studies [17, 18]. If a set of data such as production data were collected, the data could be plotted against any environmental factor in a scatter diagram. The data distribution would be enclosed by a boundary line which separates real data from hypothetical data: there is only a small chance that the data would be found outside such a boundary line. The outermost line is a response to the limiting factor of production being evaluated [19–21]. That is why this study used this approach, rather than stepwise statistical analysis. The highest production will be achieved at the minimum limiting factor, which is presented by the conical boundary line. The projection of point intersection between the boundary line with yield cut-off in abscissa can be used as the threshold criteria of land suitability classes. Yield cut-off is equal to the minimum limit of the FAO criteria [22]: the minimum border of the S1 class is 80% maximum production, and the minimum border of the S2 class is 60% maximum production. The border between S3 and N can be defined using break-even point production, calculated for the commodity being evaluated.

2.2. Methods. This study uses exploratory methods, by analysis of cashew growth regions. Consideration of site selection was based on biogeophysical variability distribution. The study was conducted in 5 provinces in Indonesia, represented by 12 regencies (Bogor Municipality, Bogor Regency, Karawang, and Majalengka in West Java Provice; West Lombok, East Lombok, Central Sumbawa, Bima, and Dompu in West Nusa Tenggara Province; Gunung Kidul in Yogyakarta Province; Wonogiri in Central Java Province; and East Flores in East Nusa Tenggara Province) (Figure 1).

From the 12 regencies, a total of 112 soil and plant samples were taken. The regions studied vary considerably in terms of climate, soil, geological, and geomorphological conditions. In terms of region, they stretch from western Java to eastern part of Nusa Tenggara, Indonesia. Rainfall of the sampled locations varies from 2,500–4,500 mm·year^{-1} in Bogor Regency to 1,486 mm·year^{-1} in East Flores Regency. Soil parent materials vary from granite to gabbro, with geological formations varying from alluvium quarter in Karawang, West Java to sedimentary karstic material in Gunung Kidul, Yogyakarta. The provisional criteria built using data from 2 provinces have been presented previously [23]. The present criteria are the final criteria, developed from more diverse regions and a wider range of data.

In such a diverse environment, field surveys were done to obtain soil properties and crop productivity. Data were taken on land characteristics and plant growth, demonstrating a diversity of land characteristics and production levels. The field study was done from 2007 to 2011: from 2007 to 2009 for 9 regencies and from 2010 to 2011 for the 3 remaining regencies.

Soil samples (0–30 cm depth) were taken for laboratory analysis. All laboratory analysis was conducted in the laboratory of the Department of Soil Science and Land Resources, at Bogor Agricultural University, Indonesia. The soil laboratory analysis method followed the method described by [24]. The parameters analyzed were soil texture (pipette method), cation exchange capacity (CEC) (NH_4OAc method), exchangeable Na, K, Ca, Mg (NH_4OAc, atomic absorption spectrophotometry), soil pH (pH-meter, 1 : 1), organic carbon content (organic-C) (Walkley-Black combustion method), total nitrogen (total-N) (Kjeldahl method), available phosphorous (available-P) (Bray-1 method), and exchangeable potassium (exchangeable-K) (NH_4OAc method). The land characteristics observed in the field included drainage, effective soil depth, surface rocks, and slope. Climatic characteristics were obtained from meteorological stations in each regency.

Crop productivity was measured by units of weights of spindle nuts per tree per year. The data of production per tree per year were obtained from farmers who were asked to measure, after trees in each sampling point were identified and selected.

In the field surveys, plant ages were different for each sample. Therefore, individual plant production data needs to be adjusted according to plant age. An age-adjusted production method can be done by using the following equation [25]:

$$Yt = \ddot{Y} + \left(Yi - \widehat{Y}\right), \quad (1)$$

where Yt = age-adjusted production, Yi = actual production based on observations, $\ddot{Y}$ = general mean, and Y = predicted production depending on age from the model, where the model relation between yield and age $Y = f(t)$, where t = time.

Age-adjusted production was then plotted with land characteristics to construct a scatter diagram and scatter plot of pertinent boundary lines. Boundary lines and equations were constructed from the outermost points so that the lines wrap around the data. For each land characteristic, at least 5 outliers were taken. The boundary equation model was selected according to the most suitable data, based on the highest determination coefficient (R^2). The yield cut-off as a minimum value for the S1 class was 80% of maximum possible production, while the minimum value of the S2 was set at 60% and S3 class was limited by the level of production at the break-even point of cashew production. In previous research [26], the break-even point cashew production level was 24% of maximum production. Projection of the intersection between the boundary line and yield cut-off becomes criteria of land suitability in the relevant class.

We used the 5 as the number of outermost points with the following considerations: (i) to minimize the number of points above the boundary limits and (ii) to maximize the likelihood of developing statistically significant models. The choice of a number of boundary points to estimate a boundary line in one scatter diagram represents a compromise between the two targets of the big group sizes and a high number of boundary points [27]. For the same reason, other researches [28] used 10 points with a sample size of 252, which represented 3.97% of the samples. In our case, we used 5 points in a sample size of 92 or 5.43% of the samples.

A validity test was performed for the accuracy of the resultant land suitability criteria. The validity test was done by using a set of data not used in the preparation of the model, through the assessment of land suitability using the principle of maximum limiting factor, in which the final value of the land suitability classification was determined by the value of the lowest land characteristics. In this research, there were 92 samples used for model development and 20 samples were used for the validity test. The validation samples were selected by stratified random sampling by taken 4 samples each from 5 provinces.

3. Results and Discussion

A summary of measurement results is presented in Table 1. Relationships between cashew production and tree age are presented in Figure 2. Production was correlated with age, although the determination coefficient (R^2) was quite small (Figure 2(a)). The low R^2 was due to environmental factors. The plant growth varies not only due to the age of the plant, but also to other environmental factors. After calibration, age has no effect (Figure 2(b)) and thus, for subsequent analysis, confrontation was done between the data of land characteristics with age-adjusted production.

The distribution of age-adjusted production data shows that the maximum production reaches 90.24 kg·tree^{-1}·year^{-1}. Based on this value, an interval of age-adjusted production for each land suitability class can be obtained, namely, (1) production in the S1 class at >72.19 kg·tree^{-1}·year^{-1}, (2) production in the S2 class between 54.15 and 72.19 kg·tree^{-1}·year^{-1}, (3) production in the S3 class between 21.30 and 54.15 kg·tree^{-1}·year^{-1}, and (4) production in the N class at <21.30 kg·tree^{-1}·year^{-1}.

Land elevation can be used as an indicator of air or soil temperature. The higher the elevation is, the lower the air temperature is. The relationship between air temperature and elevation can be formulated using the Braak formula [29]. According to this reference, Indonesia's lowland temperatures vary between 25–27°C, and the formula used is $T = 26°C - (0.01 \times \text{elevation in meters} \times 0.6°C)$.

Outer boundary lines are constructed based on the data distribution relationships of age-adjusted production with elevation (Figure 3). The pattern of lines showed a trend that

Table 1: Data summary of cashew production and several environmental factors, used for model construction.

No.	Province	N		Age	Production ($kg{\cdot}tree^{-1}$) Actual	Production ($kg{\cdot}tree^{-1}$) Age-adjusted	Soil depth (cm)	Surface rock (%)	Slope (%)	Altitude (m)	Temperature (°C)	Dry month (month)	Rainfall ($mm{\cdot}year^{-1}$)
1	West Java[1]	11	Min	5	0.16	1.62	60.00	0.00	5.00	76.00	25.10	0.00	1,974.00
			Ave	11	4.92	8.37	139.09	4.55	38.91	214.55	25.63	1.82	2,505.09
			Max	24	26.00	18.19	200.00	20.00	120.00	342.00	25.72	3.00	4,100.00
2	Yogyakarta[2]	14	Min	3	0.05	0.02	20.00	0.00	1.00	167.00	27.65	6.00	1,199.56
			Ave	21	2.05	0.40	72.86	4.36	5.93	184.57	27.65	6.00	1,330.94
			Max	38	5.75	7.69	160.00	30.00	23.00	195.00	27.65	6.00	1,403.92
3	Central Java[3]	5	Min	15	0.37	2.04	20.00	0.00	3.00	195.00	27.65	6.00	1,199.56
			Ave	18	18.27	17.49	57.00	5.40	13.20	217.00	27.65	6.00	1,199.56
			Max	30	88.63	75.55	100.00	15.00	22.00	245.00	27.65	6.00	1,199.56
4	West Nusatenggara[4]	23	Min	3	0.18	1.40	10.00	0.00	3.00	15.00	23.30	4.90	831.00
			Ave	11	17.17	20.01	75.96	5.09	16.74	74.20	25.80	6.10	1,114.85
			Max	20	56.28	55.48	120.00	40.00	70.00	285.90	26.30	7.70	1,470.00
5	East Nusatenggara[5]	39	Min	3	0.10	0.01	10.00	0.00	1.00	2.00	25.72	2.00	839.30
			Ave	15	13.21	12.64	70.10	10.49	9.82	85.65	27.14	7.62	1,126.30
			Max	30	73.20	71.43	200.00	80.00	49.00	473.00	27.23	9.00	1,974.00
	Total	92											

[1]Number of samples in each Regency in West Java: Karawang ($n = 4$), Bogor ($n = 3$), and Majalengka ($n = 4$).
[2]Number of samples in each Regency in Yogyakarta: Gunung Kidul ($n = 14$).
[3]Number of samples in each Regency in Central Java: Wonogiri ($n = 5$).
[4]Number of samples in each Regency in West Nusa Tenggara: West Lombok ($n = 6$), East Lombok ($n = 1$), Central Sumbawa ($n = 6$), Dompu ($n = 8$), and Bima ($n = 2$).
[5]Number of samples in each Regency in East Nusa Tenggara: East Flores ($n = 39$).

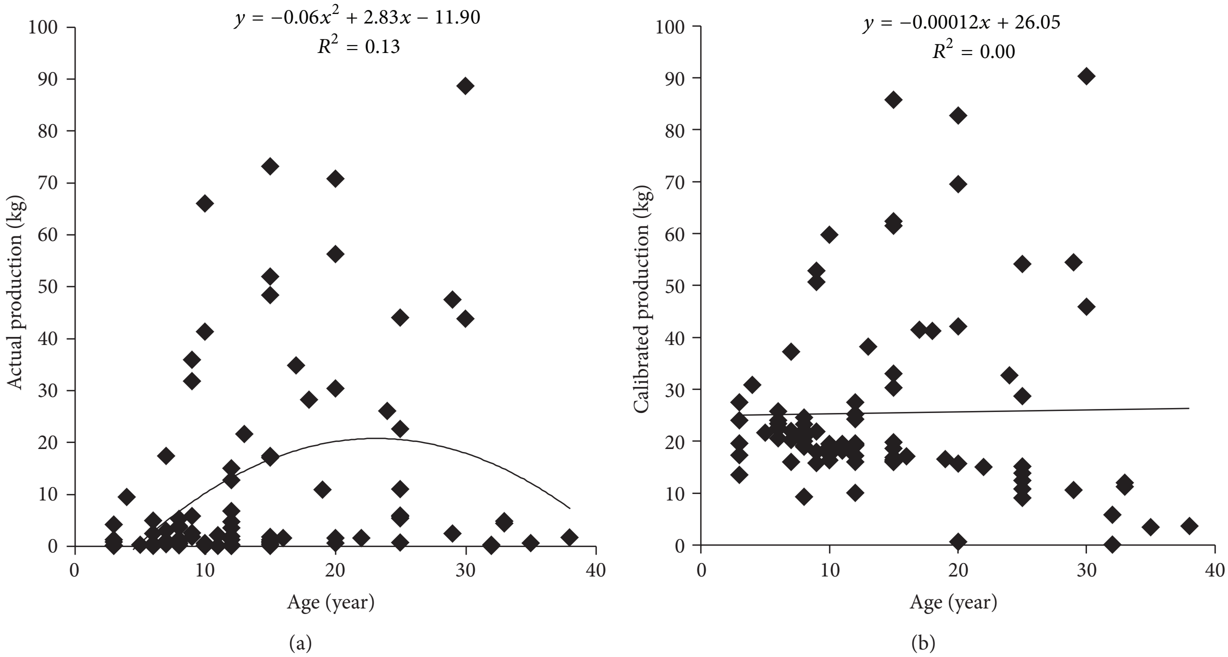

Figure 2: Relationships between age of cashew trees with production: before age-adjusted (a) and after age-adjusted (b).

the higher the elevation, the lower the production. From the projected intersection of the production interval line and the outer boundary, the elevation values which become the limits between the S1 class and the S2 class can be obtained, which is 196 m above mean sea level (a.s.l.), the boundary between the S2 class and the S3 class is 324 m a.s.l., while the boundary between the S3 class and the N class is 456 m a.s.l.

Land characteristics which relate to water availability include rainfall, number of dry months, and number of wet months. The dry and wet months follow the definition currently used in Indonesia [30], in which dry months are those with rainfall <100 mm, while wet months are those with rainfall >200 mm. From data distribution of the relationship between calibrated production and such land characteristics, the outer boundary lines can be drawn, as shown in Figure 3. It appears that the higher the amount of rainfall, in correlation with dry and wet months, the higher the calibrated production, up to a certain extent and then decreases with certain land characteristics.

From the projected intersection between the yield cut-off and the equation model at boundary lines, it is obtained that the amount of precipitation, which becomes limit class between the S1 class and the S2 class, is 987 mm$\cdot$year^{-1} and 2,247 mm$\cdot$year^{-1} as the lowest and highest limits. The limits between the S2 class and the S3 class are 827 and 3,197 mm$\cdot$year^{-1}, and the limits between the S3 class and the N class are 601 and 4,926 mm$\cdot$year^{-1}. For the dry months, the limits between the S1 class and the S2 class are 5 months and 10 months for the lower and upper limits and the limits between the S2 class and the S3 class are 4 months and 11 months, while the limit between the S3 class and the N class is 11 months. For the wet months, the limit between the S1 class and the S2 class is 1 month and 3 months for the lower and upper limits and the limit between the S2 class and the S3 class is 5 months, while the limit between the S3 class and the N class is 8.4 months. This result confirms the result obtained in Mozambique [31], which indicated that management aspect and moisture availability variation are factors that determine cashew yield variability. In such research, temporal variation of available soil moisture explains the yield variability of the cashew nuts by 17%. According to the research done in Keralla, India [32], there was a decline of 52% in Cashew productivity due to the warmest and drought conditions as a result of a decline in rainfall and an increase in temperature.

Land characteristics that affect the land quality of rooting zones are soil effective depth, sand, and clay fraction content, together with silt content which determines the soil texture classes. Texture classes are obtained by overlaying the content of sand, clay, and silt with a texture triangle. The lines forming the outer boundary based on data distribution of land characteristics of rooting zone conditions and their relationship with production are presented in Figure 4. For soil effective depth, the outer boundary shows a trend that the deeper the effective soil depth, the higher the production. For sand and clay fraction contents, the boundary line shows a trend of increased production along with increased sand and clay contents up to a certain extent, which then decreases with increased sand or clay contents.

Based on the projected intersection of yield cut-off and equation at boundary lines, the soil effective depth obtained for limits between S1 class and S2 class is 40 cm below the soil surface (b.s.s.) and the limit between the S2 class and the S3 class is 21 cm b.s.s., whereas the limit between the S3 class and the N class is 7 cm b.s.s.

The clay content as the limit between the S1 class and the S2 class is 12% and 48% as the lower and upper limits,

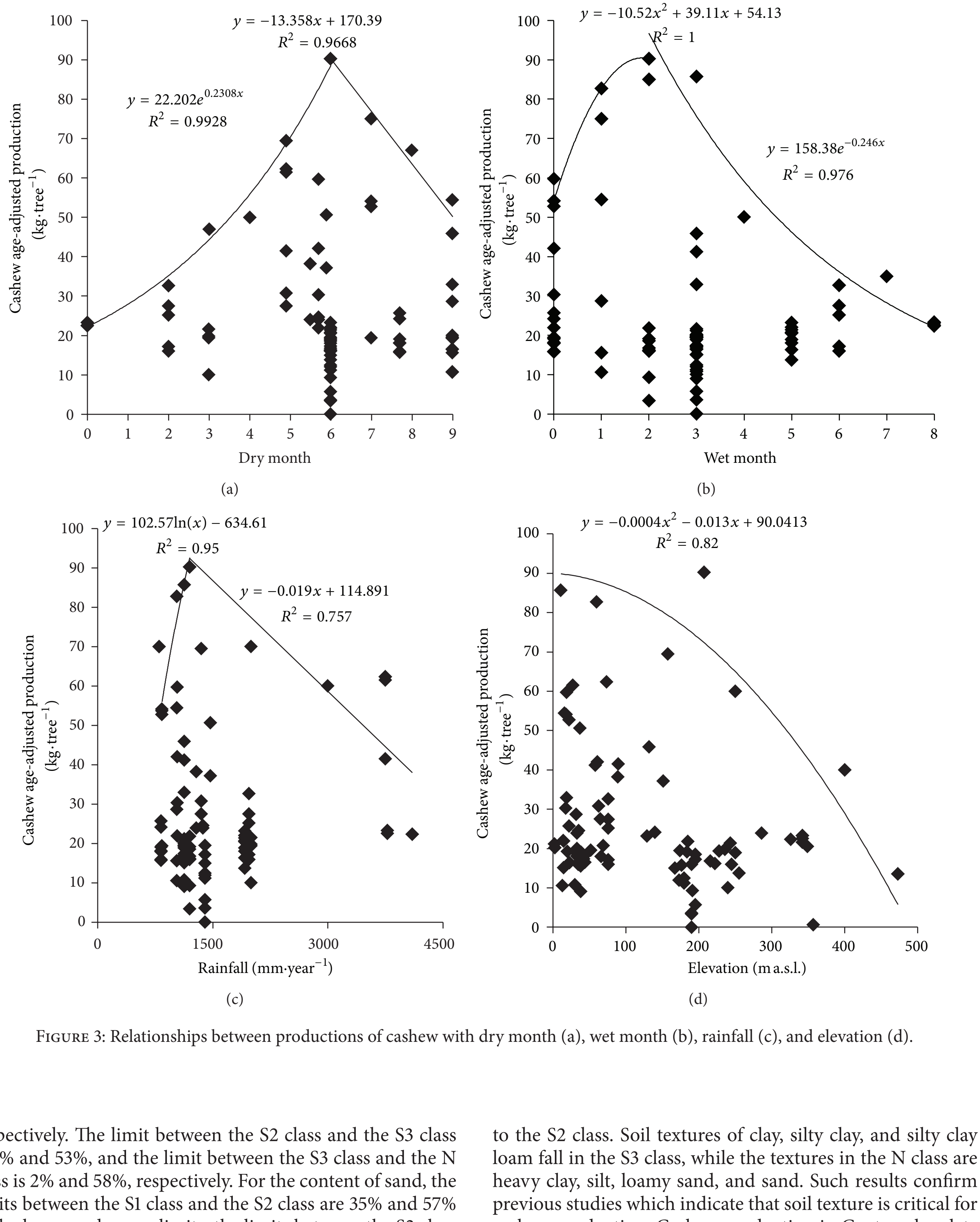

Figure 3: Relationships between productions of cashew with dry month (a), wet month (b), rainfall (c), and elevation (d).

respectively. The limit between the S2 class and the S3 class is 8% and 53%, and the limit between the S3 class and the N class is 2% and 58%, respectively. For the content of sand, the limits between the S1 class and the S2 class are 35% and 57% as the lower and upper limits, the limits between the S2 class and the S3 class are 29% and 62%, and the limits between the S3 class and the N class are 8% and 83%, respectively.

Based on the overlay results, it is obtained that the soil textures of clay loam, sandy clay loam, and loam belong to the S1 class. Soil textures of sandy clay and sandy loam belong to the S2 class. Soil textures of clay, silty clay, and silty clay loam fall in the S3 class, while the textures in the N class are heavy clay, silt, loamy sand, and sand. Such results confirm previous studies which indicate that soil texture is critical for cashew production. Cashew production in Guatemala relate to well-drained soil with a sandy loam texture [33]. It seems that cashew growth thrives in a free-draining, light-textured, deep soil.

Some land characteristics associated with nutrient retention in soil include soil pH, C-organic content, soil CEC, and

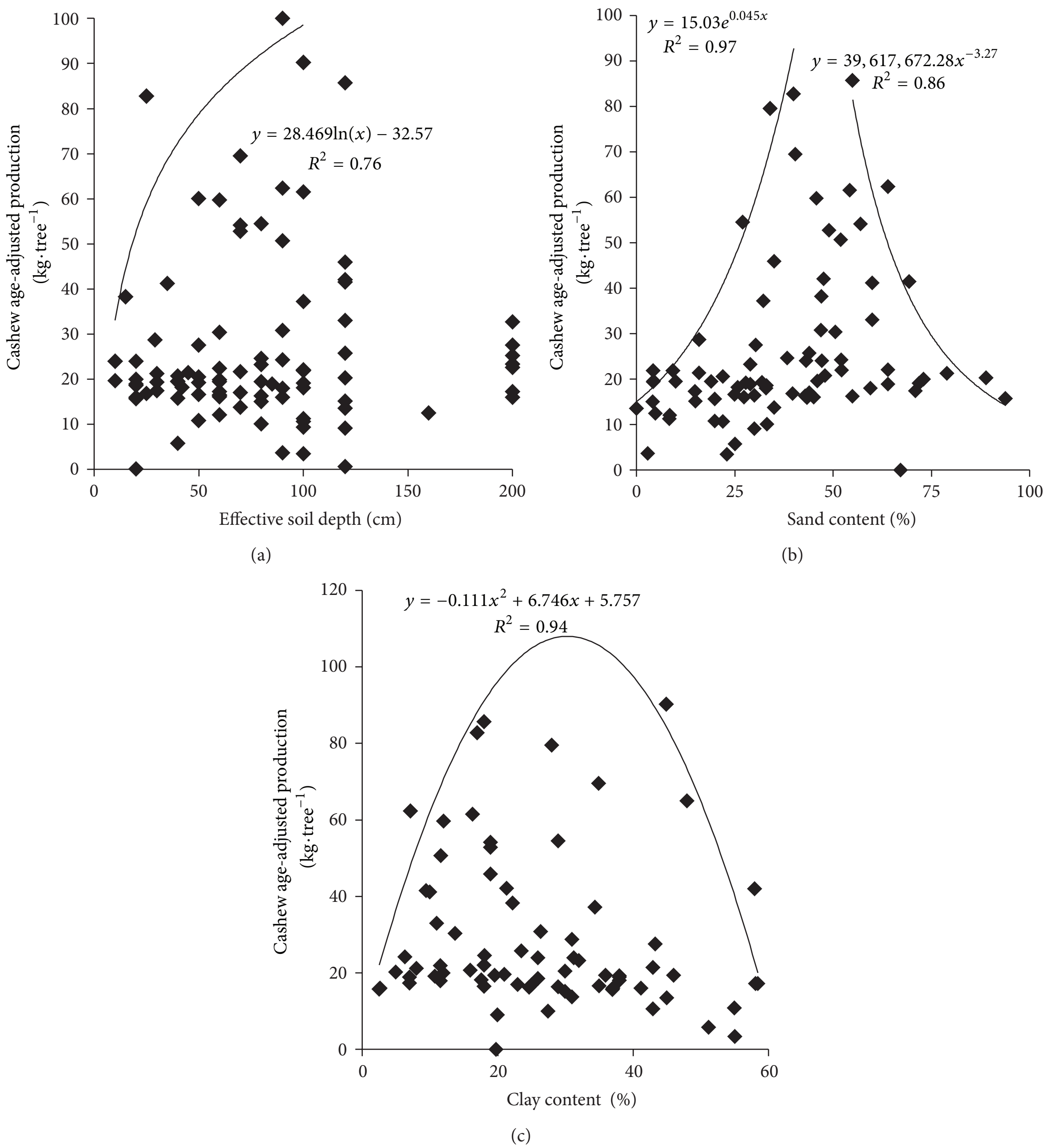

Figure 4: Relationships between productions of cashew with rooting zone condition: effective soil depth (a), sand content (b), and clay content (c).

base saturation. The lines forming the outer boundaries based on data distribution of such land characteristics and their relationship with production are shown in Figure 5.

The projected intersection between yield cut-off and the boundary lines produces soil pH limits between the S1 class and the S2 class at pH levels of 5.4 and 6.4 as lower and upper boundaries and the limits between the S2 class and the S3 class are pH levels of 5.1 and 6.9, while the limits between the S3 class and the N class are pH levels of 4.6 and 7.7. As a comparison, research has reported that cashews grow well in Nigeria within a pH range of 3.0–6.5, while the best growth is obtained between a pH range of 4.5–5.0, pH 4.5 being the optimal [34].

The C-organic content which formed the limit between the S1 class and the S2 class is 0.8%, the limit between the S2 class and the S3 class is 0.5%, and the limit between the S3 class and the N class is 0.1%. The CEC value that became the border between the S1 class and the S2 class is 12.4 cmol(+)·kg^{-1}, the border between the S2 class and the S3 class is 8.5 cmol(+)·kg^{-1}, and the border between the S3 class and the N class is 2.6 cmol(+)·kg^{-1}. The value of base saturation which became the border between the S1 class and

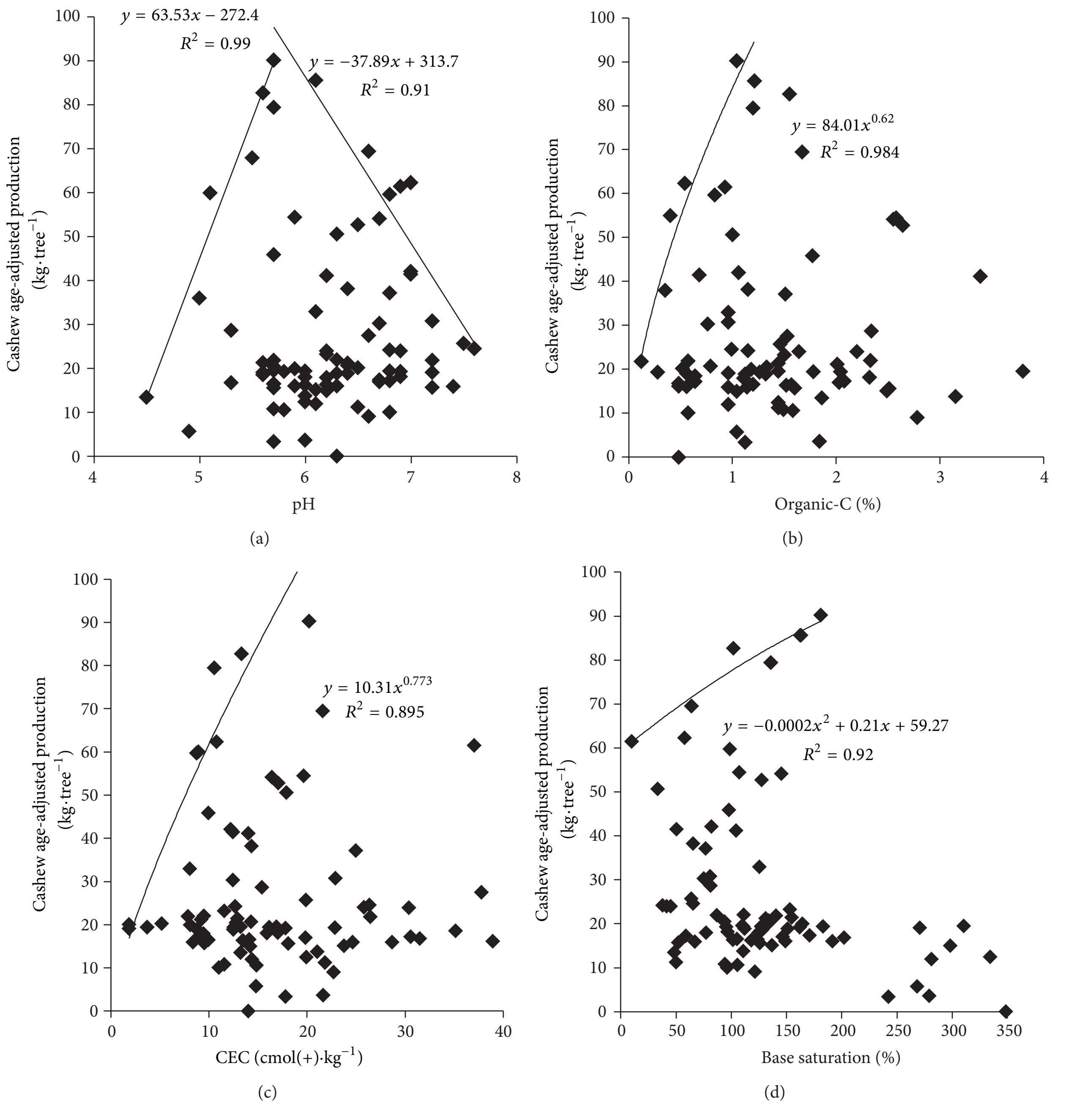

Figure 5: Relationships between cashew age-adjusted productions with soil pH (a), organic-C (b), soil CEC (c), and base saturation (d).

the S2 class is 66%. This means that the S1 class has value of base saturation >66%, while the S2 class has a value of base saturation <66%.

Nutrient availabilities which affect the productivity of cashew nuts include total-N, available-P, and exchangeable-K. The role of these elements is essential for the growth associated with vegetative performance and crop productivity. The boundary lines of the data relationship between the production of cashew with total-N, available-P, and exchangeable-K are shown in Figure 6. Patterns of these boundary lines show a trend of increased production with higher values of total-N, available-P, and exchangeable-K of soil.

From the projected intersection of yield cut-off with the boundary lines, it is found that the level of total-N which limit between the S1 class and the S2 class is 0.07%, the limit between the S2 class and the S3 class is 0.05%, and the limit between the S3 class and the N class is 0.03%. Concentration of available-P which became the limit between the S1 class and the S2 class is 40 ppm, the limit between the S2 class and the S3 class is 11 ppm, and the limit between the S3 class and the N class is 1 ppm. Phosphorus is an essential component of the

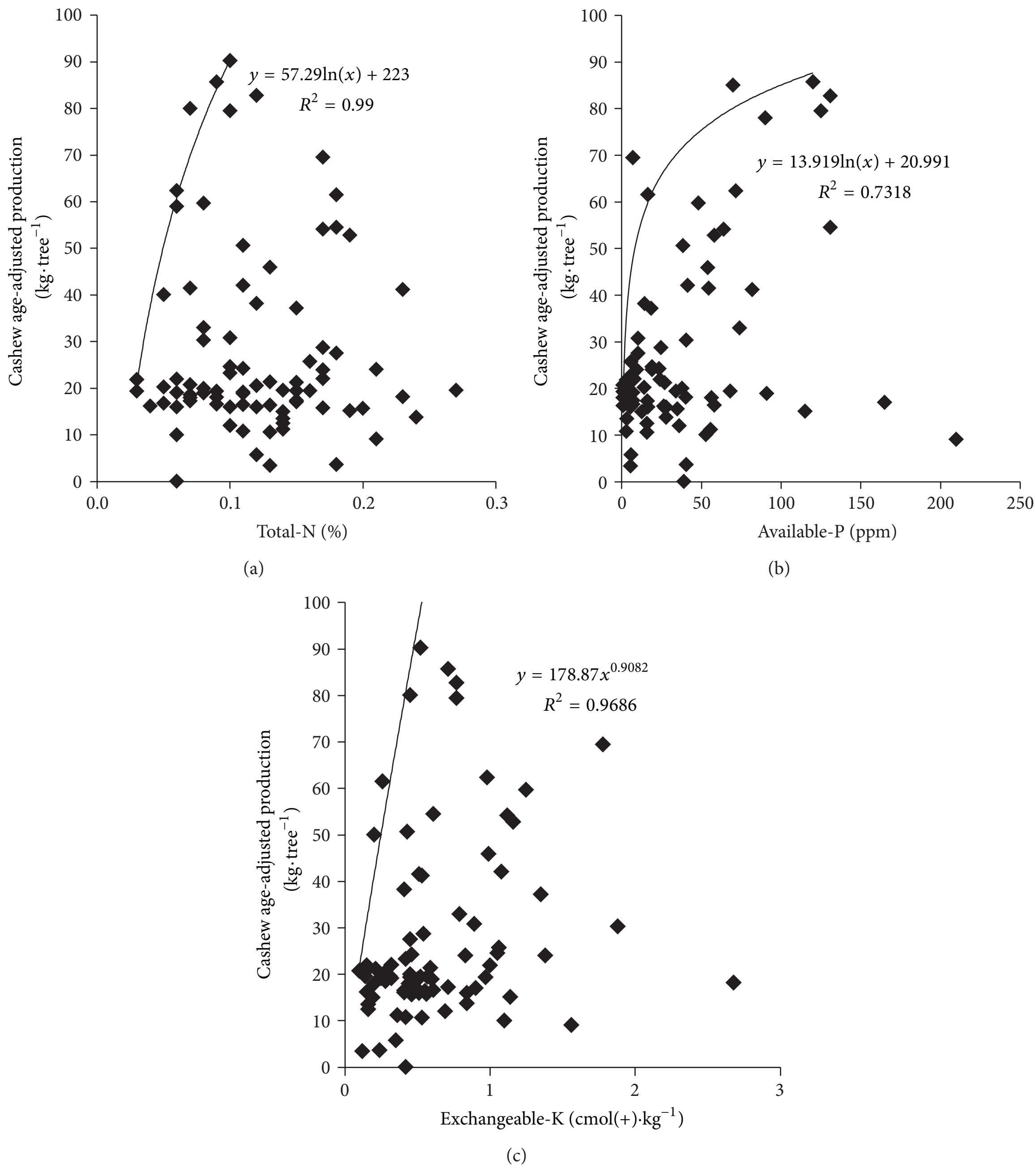

Figure 6: Relationships between cashew productions with nutrient available: total-N (a), available-P (b), and exchangeable-K (c).

genetic material of the cell nucleus. Phosphorus deficiency causes stunting, delayed maturity, and shriveled seeds [35]. Nitrogen appears necessary during the vegetative phase of the cashew tree [36]. Application of a high-nitrogen fertilizer was responsive in this vegetative phase.

The contents of exchangeable-K which became the limit of the S1 class and the S2 class is 0.37 cmol(+)$\cdot$kg^{-1}, the limit between the S2 class and the S3 class is 0.27 cmol(+)$\cdot$kg^{-1}, and the limit between the S3 class and the N class is 0.10 cmol(+)$\cdot$kg^{-1}. In general, in terms of nutrient retention, cashews are less particular in terms of soil type and fertility requirement compared to other crops [37, 38]. As a result of its wide adaptability, cashews can also be grown in very poor-quality soil, and this has characterized its survival and establishment in diverse regions.

The terrain conditions which affect productivity are slope and the amount of rock on the surface. The boundary lines of the data relationship between age-adjusted production with slope and the amount of rocks on the surface are shown in Figure 7. The lines indicate that production decreases with increasing slope or excessive quantities of rocks on the surface.

Based on Figure 7, the limit of slope between the S1 class and the S2 class is 12%, the limit between the S2 class

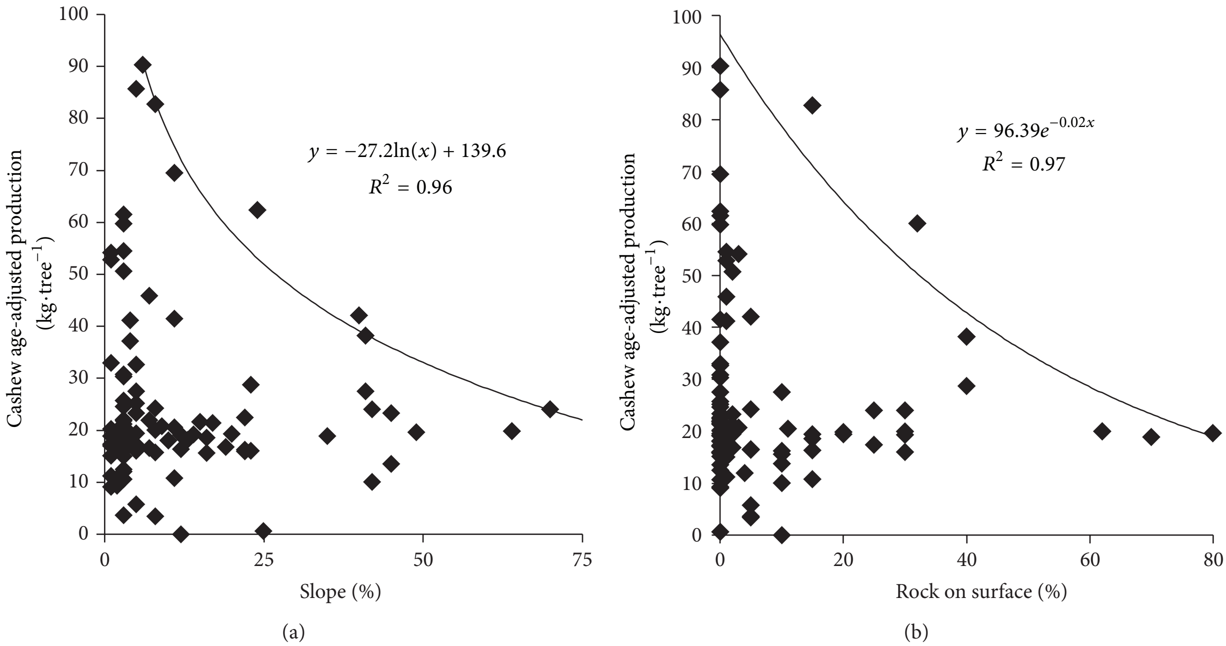

Figure 7: Relationships between cashew productions with terrain conditions: slope (a) and rock on surface (b).

and the S3 class is 23%, and the limit between the S3 class and the N class is 77%. The content of the surface rocks to form the limit between the S1 class and the S2 class is 15% and the limit between the S2 class and the S3 class is 29%, while the limit between the S3 class and the N class is 76%.

Based on the model, developed for any land characteristic, the land suitability criteria for cashew production can at last be established, as presented in Table 2. Land qualities which can not constitute criteria are air temperature, drainage, and Al-toxicity. This is due to the limited distribution of cashew crops in the study areas. Cashew production ranges from a few dozen meters to 470 m a.s.l., and so the temperature range in the study area varies by only 2 to 3°C. Similarly for drainage class, criteria cannot be made, because cashews are generally developed as green plants or grown on degraded lands as conservation plants or to increase the economic value of dry land, so that the distribution of this plant is commonly spread on land with good drainage. In this research, this plant was never found in soil drainage with moderately well or worse. Criteria for Al-toxicity limits could not be determined also due to the distribution of Al saturation which was found in the narrow interval distribution.

The validity test used 20 data sets that were not used in the preparation of the model, which consists of data fields and production characteristics. The data used for validation are presented in Table 3. The results of this validity test indicate that overall land suitability criteria have generated an 80% accuracy rate. This means that as much as 80% of the data tested/generated are valid according to the postulated suitability criteria.

4. Conclusions

This study gives an analyis of the relationship between cashew production and the biophysical aspects of its growth. Pattern of this relationship was then used to define the suitability of cashew within its growth environments.

Analysis of the relationship between cashew production and water availability indicates that, with higher rainfall (over 2,247 mm·year^{-1}), crop productivity decreases. However, conditions of rainfall below 987 mm·year^{-1} also cause low productivity. The number of dry months which are strongly correlated with a level of productivity above 80% is 5 to 10 months.

In terms of the relationship between cashew production and conditions of the root zone of plants, our equation obtained (28.469 $\ln(x)$–32.57) has a fairly high correlation ($R^2 = 0.76$) for the relationship between crop production and effective soil depth. This means that 76% of cashew production variability is influenced by effective soil depth. More effective soil depth of the plant roots resulted in better conditions, with a minimum effective soil depth of 40 cm yielding productivity above 80% (S1 class). Meanwhile, the soil texture which was conducive to crop productivity over 80% of the average production is clay loam, sandy clay loam, and loam, with a determination coefficient >0.86.

Retention of soil nutrients which correlate with the cashew productivity includes soil CEC, organic-C content, and soil pH. In general, by increasing CEC, soil pH tends to be neutral, and the high percentage of organic-C, crop productivity is also higher. Crop productivity over 80% of the average production requires the percentage of organic-C to be

Table 2: Land suitability criteria for cashew.

Land quality/land characteristics	Land suitability class			
	Very suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Unsuitable (N)
Temperature				
Elevation (m a.s.l.)	<196	196–324	324–456	>456
Water availability				
Rainfall (mm)	987–2.247	827–987	601–827	<601
		2,247–3,197	3,197–4,926	>4,926
Dry month (number)	5–10	4-5	<4	
		10-11	10-11	>11
Wet month (number)	1–3	<1		
		3–5	5–8	>8
Rooting media				
Texture	Clay loam, sandy clay loam, loam	Sandy clay, Sandy loam	Clay, silty clay, silty clay loam	heavy clay, silt, loamy sand, sand
Effective depth (cm)	>40	21–40	7–21	<7
Nutrient retention				
CEC (cmol (+)·kg^{-1})	>12.4	8.5–12.4	2.6–8.5	<2.6
pH	5.4–6.4	5.1–5.4	4.6–5.1	<4.6
		6.4–6.9	6.9–7.7	>7.7
Organic-C (%)	>0.8	0.5–0.8	0.1–0.5	<0.1
Base Saturation (%)	>66	<66		
Available nutrient				
Total-N	>0.07	0.05–0.07	0.03–0.05	<0.03
Available-P (ppm)	>40	11–40	1–11	<1
Exchangeable-K (cmol (+)·kg^{-1})	>0.37	0.27–0.37	0.10–0.27	<0.10
Terrain condition				
Slope (%)	<12	12–23	23–77	>77
Surface rock (%)	<15	15–29	29–76	>76

above 0.8%, CEC above 12.4 cmol(+)·kg^{-1}, and soil pH tends to neutral (5.4 to 6.4). The coefficient of determination of the model equations constructed is all >0.89.

For the nutrients available in soil, analysis of the relationship between crop production and contents of soil N, available-P, and exchangeable-K showed a strong to moderate correlation (coefficients of determination of 0.99, 0.79, and 0.97, resp.). With higher levels of N, available-P, and exchangeable-K in soil, productivity also increases. If the levels of total-N are over 0.07%, available-P over 40 ppm, as well as soil exchangeable-K over 0.37 cmol(+)·kg^{-1}, land is able to produce cashew at over 80% of the average productivity.

Some terrain parameters that affect the productivity of cashews are the percentage of surface rocks (R^2 = 0.97) and percent of slope (R^2 = 0.96). With decreasing percentage of surface rocks, cashew productivity increases.

From the models built, the land suitability criteria for cashew production have been constructed. Suitability criteria for cashew production generated from this study are proposed to be applied in the selection of the plantation location.

The criteria have been established through research in 5 (five) provinces (West Java, West Nusa Tenggara, East Nusa Tenggara, Yogyakarta, and Central Java) with different characteristics. Nonetheless, it was realized that the biophysical characteristics across Indonesia vary sufficiently to merit research in 5 provinces. These criteria could be generalized; however, considering the wide range of Indonesian resources, more complete research of other regional biophysical properties would strongly recommended.

New criteria have been drawn up based on the empirical facts of field-specific productivity. Considering the effort that has been undertaken for this study and the data which were used as the base formulation, it is advisable for the widespread use of these criteria in cashew development in Indonesia. To increase cashew productivity, two approaches can be implemented [39], namely, intensification by applying available technologies and development of cashew

Table 3: Data summary of cashew production, used for validity test.

Site code	Age-adjusted Production (kg·tree^{-1})	Land suitability class: According to age-adjusted production	Soil Depth	Surface Rock	Slope	Elevation	Dry month	Wet month	Rainfall	pH	Organic-C	Total-N	Available-P	Exchangeable-K	Base sat.	Clay content	Sand content	CEC	According to land characteristics*	Validation test result**
A1	25.94	S3	S1	S1	S1	S1	S1	S2	S2	S3	S1	S1	S2	S2	S2	S1	S2	S1	S3	1
Al2	22.68	S3	S1	S1	S1	S1	S1	S2	S1	S3	S1	S1	S2	S2	S2	S1	S2	S1	S3	1
B1	19.21	N	S2	S1	S1	S1	S1	S2	S2	S3	S1	S1	S2	S1	S1	N	S3	S2	N	1
F.15	122.43	S3	S1	S1	S1	S1	S1	S3	S1	S1	S1	S1	S3	S1	S1	S1	S1	S1	S3	1
F.28	30.12	S3	S1	S1	S1	S1	S3	S1	S1	S1	S1	S1	S1	S1	S1	S1	S3	S1	S3	1
F.29	26.29	S3	S1	S1	S1	S3	S3	S3	S1	S1	S1	S1	S2	S1	S1	S1	S2	S1	S3	1
F.31	21.72	S3	S1	S1	S1	S1	S3	S1	S1	S1	S1	S1	S3	S1	S1	S1	S1	S1	S3	1
ML1	34.72	S3	S1	S1	S1	S2	S1	S3	S1	S3	S1	S1	S3	S1	S1	S1	S1	S1	S3	1
ML3	52.11	S3	S1	S1	S2	S1	S1	S3	S1	S2	S1	S1	S3	S1	S1	S1	S1	S1	S3	1
O1	21.98	S3	S1	S1	S2	S1	S1	S2	S2	S2	S1	S1	S2	S1	S1	S2	S3	S1	S3	1
PK3	52.95	S3	S1	S1	S3	S2	S2	S3	S3	S3	S1	S1	S2	S1	S1	S2	S3	S3	S3	1
PK4	55.58	S2	S1	S1	S2	S2	S2	S2	S3	S3	S1	S1	S2	S2	S2	S3	S3	S3	S3	0
SA1	29.49	S3	S1	S1	S1	S1	S2	S2	S1	S3	S2	S2	S2	S1	S1	S2	S3	S3	S3	1
Y12	5.88	N	S1	S1	S3	S1	S1	S2	S1	S1	S1	S1	S2	S1	S1	N	S3	S1	N	1
Y14	9.70	N	S1	S1	S2	S1	S1	S1	S1	S2	S2	S1	S2	S1	S1	S1	S1	S1	S2	0
Y16	11.78	N	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1	S3	S1	S1	N	S3	S1	N	1
Y18	19.66	N	S1	S1	S1	S2	S1	S1	S1	0	S2	S3	S2	S1	S1	S1	S2	S1	S3	0
Y19	60.04	N	S1	S1	S1	S2	S1	S1	S1	0	S2	S1	S2	S1	S1	N	S3	S1	N	1
Y27	98.00	S1	S1	S2	S1	S2	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S1	S1	S2	0
Y6	11.28	N	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S3	S2	S2	N	S3	S1	N	1

Note: * using the principle of maximum limitation method.
**1 means valid, where result of land suitability class according to production give the same result with the land suitability class according to land characteristics.
0 means invalid, where result of land suitability class according to production gives the different result with the land suitability class according to land characteristics.

plantation in areas having suitability rates from fair to highly suitable.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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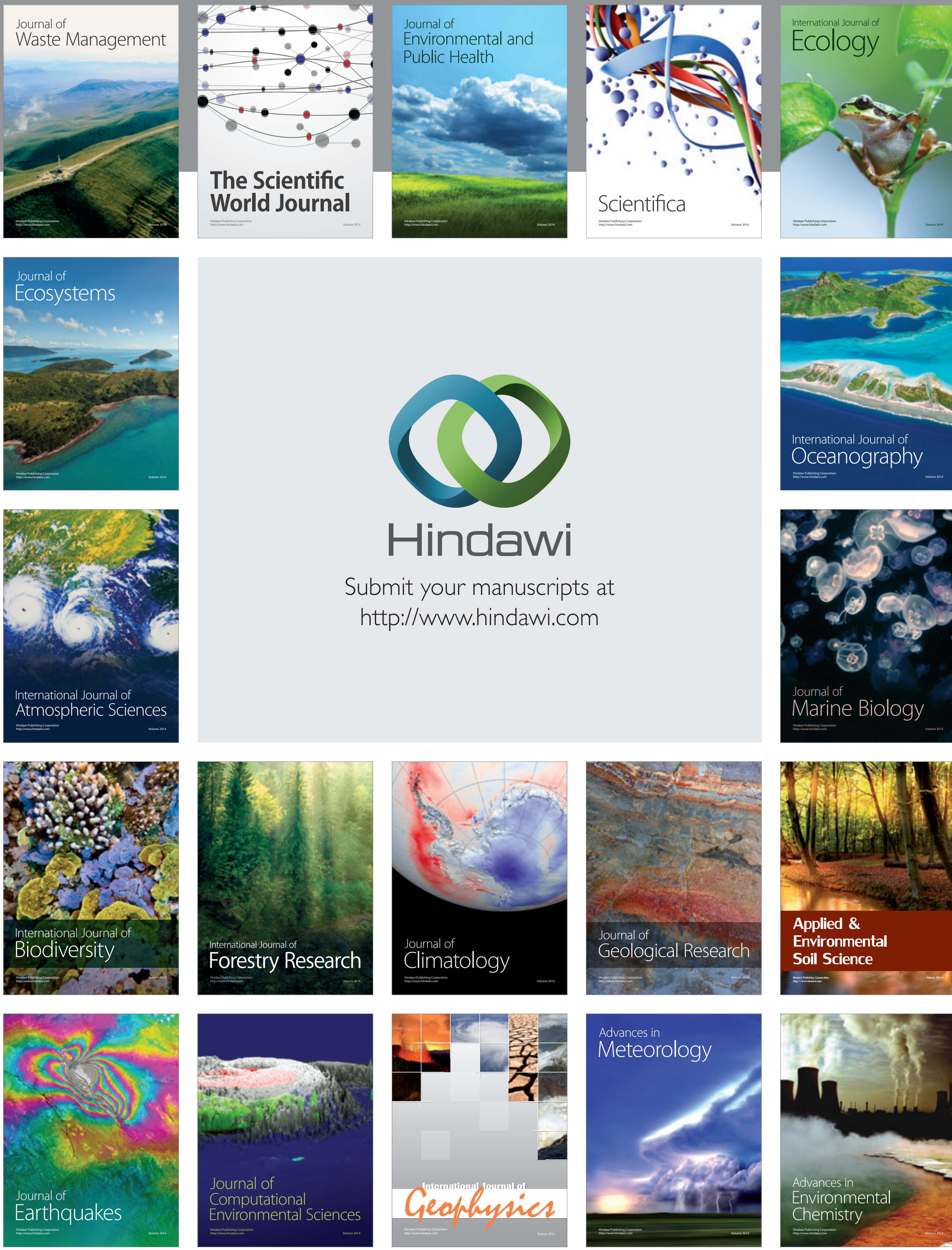
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