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Comparative land suitability analysis for 'lakatan' banana (*musa acuminata*) in Isabela, Philippines

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Abstract: This study presents a land suitability evaluation specifically for 'lakatan' banana *(Musa acuminata)* cultivation in Isabela, Philippines, aiming to optimize yield through targeted soil analysis for alluvial soils under isohyperthermic climatic regime. Simple Limitation Method (SLM), Limitation Method regarding Number and Intensity (LMNI), Parametric Methods (PM) and Analytical Hierarchy Process (AHP) were the methods used for a comparative assessment. The available soil series data for Isabela from the Philippine Rice Research Institute were evaluated against the optimal edaphic requirements for 'lakatan' banana (*Musa acuminata*) cultivation, based on consolidated published studies. The suitability of banana production in Isabela varies significantly depending on the method used. Based on the analyses using SLM and LMNI, majority of soil series were not suitable for banana production; however, when PM (Storie and square-root) and AHP methods (linear and Log) were used, banana production becomes marginally and moderately suitable, respectively. The variation in results primarily stems from the differing methodologies of SLM and LMNI compared to AHP and PM, offering a basis for informed decision-making and guideline development in 'lakatan' banana cultivation.

Keywords: banana cultivation; climate parameters; crop requirements; multi-criteria decision making; multi-method evaluation
Abbreviations: AHP_Analytical Hierarchy Process, LMNI_Limitation Method regarding Number and Intensity, MCDM_Multi-criteria Decision Making, MCE_Multi Criteria Evaluation, pH_potential hydrogen, PM_Parametric Methods, SLM_Simple Limitation Method

Introduction

Banana (*Musa sapientum*) cultivation is a cornerstone agricultural sector in the Philippines known for providing livelihoods to thousands of Filipino farmers in the past decades. Moreover, a substantial revenue through both domestic consumption and international exports can also be attributed to banana farming. (FAO, 2017). The Philippines, being the largest exporter of banana in the region, accounts for 90% of the total export volume from Asia (FAO, 2017). In fact, in 2016, the Philippines produced 8,903,684 metric-tons of banana (PSA, 2017). The demand for bananas, particularly the 'lakatan' variety, is continuously rising due to its nutritional value and versatility.

In the province of Isabela, located in the northern Philippines, banana farming, specifically the 'lakatan' variety, has emerged as an increasingly important source of livelihood for local communities. (PSA, 2014). 'Lakatan' banana farming has gained prominence in Isabela due to several reasons. First, bananas are highly marketable commodities both domestically and internationally. Second, Isabela's geographical location and favorable climate provide suitable conditions for banana cultivation. The province's climate is characterized by abundant rainfall and moderate temperatures throughout the year, making it conducive to banana growth. Lastly, Isabela's rich volcanic soil offers favorable conditions for nutrient uptake and plant growth.

Despite the presence of favorable environmental conditions, the suitability for banana farming varies across different areas in Isabela. Variations in soil fertility, drainage, topography, temperature, and rainfall patterns across the province significantly impact the success and productivity of banana farms. Bananas prefer freely drained, deep and fertile loamy soils, but can be cultivated on a wide range of soil types following proper agro-management. The presence of swelling clay and high bulk density can lead to poor soil drainage, which adversely affects crop yield. Bananas grow well in pH range of 4.5 to 8.2 (Kadao et al., 2003). The potential for bananas to produce year round is best expressed when water is abundant and the daily temperatures are in the range of 20-30 degrees Celsius (Van den Bergh et al., 2012). Hence, a systematic land suitability analysis is essential to identify the most suitable areas for banana growing, taking into account these critical factors.

Land suitability evaluation is the systematic assessment of land characteristics to determine their appropriateness for specific uses. Recent developments in assessing soil characteristics to determine land suitability include automatic data acquisition of soil condition with the help of a sensor to lessen the time and manual work in testing a soil if it is suitable for planting (Tolentino, et al., 2020). In the context of this study, land suitability analysis made use of available soil series data for Isabela from the Philippine Rice Research Institute. These data were evaluated against the optimal edaphic requirements for 'lakatan' banana (*Musa acuminata*) cultivation, based on various consolidated published studies. This process helps in the comparison of potential benefits of various land uses and, in its simplest form, helps identify the most suitable lands for particular purposes. Moreover, it aids in sustainable land management by ensuring that land resources are used efficiently and appropriately (Pan & Pan, 2012; Halder, 2013; Yalew at al., 2016). The primary objective of land evaluation is achieving optimum usage from each land and soil with assessment physical, social and economic phases (Sys and Verheye, 1974). The land suitability evaluation consists of the analysis of data relating to soils, topography, drainage, climate and weather conditions, during an effort to match the land characteristics with crop requirements (Zabihi et al., 2015; Zhang et al., 2015).

Table 1. Weights of criteria generated using the pairwise comparison matrix developed by Goepel, 2018.

Criterion	Linear	Log
No. of dry months	26.34%	21.89%
Annual ave. rainfall	28.42%	22.97%
Slope	3.54%	6.55%
Soil drainage	16.58%	16.54%
Flooding hazard	13.42%	14.44%
Soil texture	6.54%	9.37%
Soil depth	5.16%	8.24%

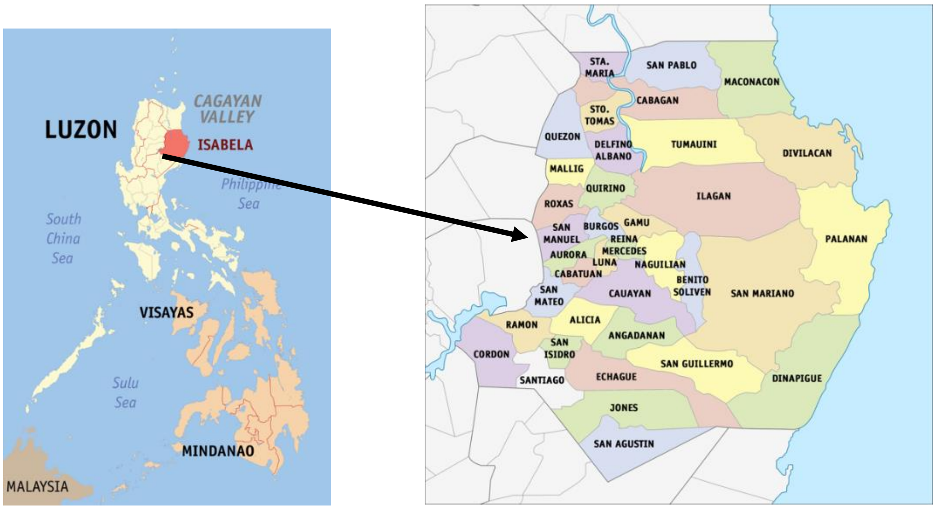

Figure 1. Location map of the study area

Table 2. Land suitability classes of the different soil series in Isabela, Philippines based on different methods.

			PM		AHP	
Soil Series	SLM	LMNI	Storie	Square root	Linear	Log
Alaminos	N1cf	N1cf	S3	S2	S1	S1
Annam	N1ct	N2t	S3	S3	S2	S2
Bago	N1cf	N1cf	S3	S2	S2	S2
Bantog	N1c	N1c	S3	S2	S2	S2
Bigaa	N1cf	N1cf	S3	S2	S2	S2
Cauayan	N1cf	N1cf	S1	S1	S1	S1
Faraon	N2s	N2ts	N1	S3	S2	S2
Guinbalaon	N1cf	N1cf	S3	S2	S1	S1
Ilagan	N1c	N1c	S3	S3	S2	S1
Quingua	N1c	N1c	S2	S2	S2	S1
Rugao	N1c	N1c	S3	S2	S2	S1
San Juan	N2s	N2s	S3	S2	S2	S2
San Manuel	N1c	N1c	S2	S1	S2	S1
Sibul	N2s	N2s	N1	S3	S2	S2
Sta. Rita	N1c	N1c	S3	S2	S2	S2
Tagulod	N2w	N2w	S3	S2	S2	S2

SLM-Simple Limitation Method, LMNI-Limitation Method regarding Number of Intensity, AHP-Analytical Hierarchy Model, c-climate, t-terrain, w-soil wetness, s-rooting condition, f-fertility

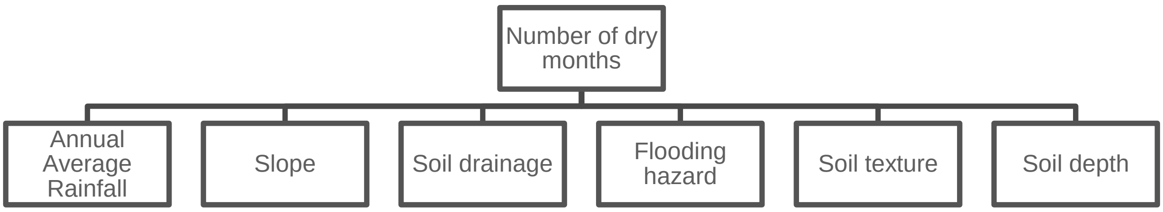

Figure 2. Selected criteria for suitability evaluation.

Table 3. Climate characteristics of Isabela, Philippines from Weatherspark.com.

Climatic characteristics (c)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ave. Temp. (^{0}C)	26°	27°	28°	29°	29°	28°	27°	27°	27°	27°	27°	27°
Ave. Low Temp (^{0}C)	23°	24°	24°	25°	25°	25°	24°	24°	24°	24°	24°	24°
Ave. Rainfall (mm)	52.0	41.8	35.8	44.3	92.4	194.2	206.0	202.9	176.6	173.8	126.8	88.6

Table 4. Soil characteristics and Land Qualities of Isabela, Philippines from PhilRice.

	Terrain (t)	Soil Wetness (w)		Rooting Conditions (s)		Nutrient Availability (f)				
SOIL SERIES	Slope (%)	Soil drainage	Flooding hazard	Soil texture	Soil depth (cm)	Soil pH	N level	P level	K level	CEC
Alaminos	18-30	Good	None	fC, CL	D	4.5-5.5	M	VL	VL	VL
Annam	30-50	Good	None	SiCL, C	M-D	5.5-6.0	M	L	M	M-H
Bago	3-8	Poor	Slight	SC	VD	6.0-7.0	H	L	L	L-M
Bantog	0-3	Poor	Moderate	vfC	D-VD	7.0-7.5	H	M	M	M
Bigaa	0-3	Poor	Slight	fC	D-VD	5.5-6.5	L-M	L	L	M
Cauayan	8-18	Moderate	None	SiL, CL	D-VD	4.5-5.5	M	L	L	L
Faraon	30-50	Good	None	C	VS	6.5-7.0	H	M	M	H
Guinbalaon	18-30	Good	None	SiC	D	5.5-6.0	M-H	M	L	L
Ilagan	8-18	Good	None	C	M	5.0-6.0	M	L	M	H
Quingua	0-3	Good	Moderate	SiL, SiC	D-VD	7.5-8.0	M	L	M	H
Rugao	3-8	Moderate	None	C	D-VD	4.5-7.5	M	L	M	H
San Juan	8-18	Moderate	None	hSC, SCL	VS	5.5-9.0	M	L-H	H	L-H
San Manuel	0	Good	Moderate	L, SiL, S	D-VD	5.5-6.5	H	M	M	M
Sibul	18-30	Good	None	hC	S	5.5-6.0	M	L	L	M
Sta. Rita	0	Poor	Slight	vfC, CL	M	6.5-7.0	H	M	M	H
Tagulod	0-3	Poor	Severe	C	D-VD	6.5-7.0	H	VL	L	L-M

***Legend**: **Soil texture:** fC-fine clay, SiCL-Silty clay, C-clay, SC-Sandy clay, vfC-Very fine clay, fC-fine clay, SiL-Silty loam, CL-Clay loam, SiC-Silty clay, hSC-heavy sandy clay, SCL-Sandy clay loam, L-Loam, S-Sand, hC-heavy clay. **Soil depth**: VD-very deep, D-deep, M- moderate, S-shallow, VS-very shallow. **NPK & CEC**: VL-very low, L-low, M-medium, H-high*

Table 5. Crop requirement, classes and scaled value, limits and degree for suitable assessment of banana in Isabela, Philippines.

Criteria	Classes and scaled values						References
SLM	S1		S2	S3	N1	N2	
LMNI	0	1	2	3	4		
PM	100-95	95-85	85-60	60-40	40-20	20-0	
Climatic characteristics (c)							
Annual Ave. Temp (OC)	25-27	-	28-29 24-23	30-32 22-19	-	>32 <19	Fiegalan et al., (2017)
Annual Ave. Low Temp (OC)	>20	20-15	15-8	8-2	-	<2	Sys et al., (1993)
No. of dry months (<75mm)	0	1	1.1-2.0	2.1-3.0	3.1-4.0	>4	Fiegalan et al., (2017)
Annual Ave. rainfall (mm)	>18000	1800 - 1500	1500 - 1250	1250-1000	-	<1000	Fiegalan et al., (2017)
Terrain (t)							
Slope (%)	0-4	4-8	8-16	16-30	30-50	>50	Sys et al., (1993)
Soil Wetness (w)							
Soil drainage	good	-	moderately	Poor	-	poor not drainable	Naidu et al., (2006)
Flooding hazard	None	-	Slight	Moderate	-	Severe	Sys et al., (1993)
Rooting Conditions (s)							
Soil texture	L,SiCL, CL,SiL	SL, S,	SC, SCL	SiC, fC, vfC	LS, SL, fLS	hC	Fiegalan et al., (2017)
Soil depth (cm)	Very deep	-	deep	moderate	shallow	Very shallow	Naidu et al., (2006)
Nutrient Availability (f)							
Soil pH	6.4-5.8 6.4-7.0	5.5-5.6 7.0-7.5	5.6-5.2 7.5-8.0	5.2-4.5 8.0-8.2	<4.5	>8.2	Sys et al., (1993)
N level	High	Medium	Low	Very low	-	-	Fiegalan et al., (2017)
P level	High	Medium	Low	Very low	-	-	Fiegalan et al., (2017)
K level	High	-	-	Medium	Low – Very low	-	Fiegalan et al., (2017)
CEC	High	Medium	Low	Very low	-	-	Fiegalan et al., (2017)

Table 6. Organization connection of key informants.

Organization
Binhi, Inc
King's Orchard
East-West Seed

Table 7. Summary of the consistency ratio and other relevant indexes needed for data validation.

Consistency Index	Linear	Log
Lambda (λ)	7.089	7.050
Geometric consistency index (CI)	0.04	0.02
Random index (RI)	1.41	1.41
Consistency ratio (CR)	0.011	0.006

Table 8. Index values for the different suitability classes.

Value Range	Suitability class
0.75 – 1.0	Highly suitable (S1)
0.50 – 0.75	Moderately suitable (S2)
0.25 – 0.50	Marginally suitable (S3)
0 – 0.25	Not suitable (N)

The purpose of this study is to evaluate the land suitability of the different soil series in the province of Isabela, Philippines for 'lakatan' banana cultivation using SLM, LMNI, Parametric Methods (Storie and square-root) and AHP method (Linear and Log). By conducting a systematic analysis of soil and climate parameters, this research aims to identify areas within the province that are most suitable for sustaining profitable and sustainable banana production. The findings of this study will provide valuable insights and guidelines for farmers, policymakers, agricultural planners and agriculturists to make informed decisions regarding the allocation of land for banana farming.

Results and discussion

The right suitability is essentially a challenge of producing crop yield with relatively low inputs, as well as a matter of crop requirements and the influence of soil and site characteristics upon the crop, according to Vink's (1960) report. Finding a piece of land appropriate for a certain crop involves two key stages in the identification of favorable characteristics on the property. In this study, information on the crop requirements for banana was carefully gathered from a variety of publications, while data on the land characteristics of the various soil series in Isabela were obtained from PhilRice (Philrice, n.d.). Then, the linear and logarithmic analytical hierarchy processes (AHP), the simple limitation method (SLM), the limitation method regarding number and intensity (LMNI), and the Storie and square-root parametric approaches were used. The most and least limiting parameters employed in the computation of the parametric techniques were selected based on the weights of the selected criteria determined by the pairwise comparison (Table 1).

SLM and LMNI Method

The evaluations based on SLM and LMNI yielded similar suitability classifications, both indicating that the entire province of Isabela is not suitable for banana cultivation. (Table 2). This is mainly because of the limitation in the number of dry months in which the whole province experiences a minimum of 4 months dry spell. Additionally, areas with Faraon and San Juan soil series, as well as Sibul and Tagulod, present more serious limitations for banana cultivation. The Faraon and San Juan series are characterized by very shallow soils, while Sibul has unfavorable soil texture and Tagulod is affected by flooding hazards. The limitation on dry spell can be adressed by irrigation during the dry months with the province's very good irrigation system. Meanwhile, the limitation related to fertility, especially potassium, can be addressed by chemical and organic fertilizers.

PM method

The parametric, the Storie and square-root methods obtained a slightly different result. Land suitability evaluation using Storie yielded a more conservative results than the square-root method. This is because the Storie method assigns the greatest weight to the most limiting factor, whereas the square-root method places more emphasis on the least limiting factor. The results obtained by the parametric square-root methods are probably more realistic, as suggested by comparison with other reports (Movahhedi, 1993; Ghasemi Dehkordi, 1994; Sarvari & Mahmoudi 2001; Jafarzadeh & Atabakazar, 2004; Jafarzadeh et al., 2005; Jafarzadeh & Abbasi, 2006; Shahbazi & Jafarzadeh, 2004) in which different methods were applied in different parts of the country for the same crops. Its reliability was even increased by using AHP to make a better judgement based on expert opinion on identifying the most and the least limiting factors for land suitability evaluation which is the most crucial part in the parametric methods of land suitability evaluation. The parametric Storie method suggests that most of the soil series in Isabela were marginally suitable for banana production, with Faraon and Sibul soil series as not suitable while Cauayan, Quingua and San Manuel soil series were highly suitable. On the other hand, the parametric square-root method indicates that most of the soil series in Isabela has a moderate suitability for banana production, with Annam, Faraon, Ilagan and Sibul soil series as marginally suitable while Cauayan and San Manuel were highly suitable.

AHP method
The AHP analytical hierarchy process is used as one of the multi-criteria decision-making tools (Multi-criteria Decision Making – MCDM) or Multi Criteria Evaluation – MCE. A pairwise comparison was used to generate the weights of the seven (7) selected criteria using the AHP calculator provided by Goepel (2018). The scaled values of the different criteria on the other were obtained using the values provided by Sys et al. (1993). Furthermore, to obtain the suitability classification rating, Sys et al. (1993) equation was used, and the final result is presented in Table 2. A high similarity on the obtained suitability classes were observed between the AHP linear and logarithmic transformed scale values. However, more soil series were rated highly suitable using AHP logarithmic (Alaminos, Cauayan, Guinbalaon, Ilagan, Quingua, Rugao, and San Manuel) than using AHP linear (Alamino, Cauayan, Guinbalaon).

Materials and methods

Lakatan banana
The Lakatan banana (Musa acuminata, AAA group) is one of the most popular dessert bananas in the Philippines due to its appealing aroma, firm texture and sweet taste. Botanically, it belongs to the Musaceae family and falls under the genus Musa. As a triploid (AAA genome) cultivar, it is derived solely from Musa acuminata and does not have genetic contribution from Musa balbisiana, which means it is seedless and reproduces through suckers. Lakatan banana plants are herbaceous perennials with tall, upright pseudostems that can reach up to 2 to 3 meters in height. The leaves are long, wide, and easily torn by strong winds, which is typical of banana plants. The inflorescence, often referred to as the banana heart, emerges from the center of the plant and consists of rows of flowers—female flowers appear first and are followed by male flowers toward the end of the spike. The fruits are elongated, slightly curved, and turn yellow-orange when ripe. The peel is relatively thin but firm, and the pulp inside is creamy, sweet, and aromatic, which makes Lakatan highly favored for fresh consumption. Due to its parthenocarpic nature, the fruit develops without fertilization and is typically seedless (PCARRD-DOST, 2009).

Study area
The study area covered the entire province of Isabela, situated in the Cagayan Valley region occupying the northeastern section of Luzon (Figure 1). Isabela province is the second largest province in the Philippines in terms of land area with 13,102.05 square kilometers or 5,058.73 square miles (Placeandsee, 2023). It has 34 municipalities and 1,055 barangays populated by 1,697,050 individuals according to the 2020 census (Philatlas, 2023).
Agriculture is the biggest industry in Isabela. It is the country's top producer for corn contributing 21% of the annual national yellow corn production and the second highest rice-growing province producing 15% of the aggregate national rice production on an annual basis. Isabela also produces high value crops such as tobacco, coffee, mango and banana.

Climatic characteristics
The climatic characteristics of Isabela influence various aspects of the region, including agriculture. The distinct wet and dry seasons, coupled with the warm temperatures, contribute to the region's agricultural productivity, particularly in rice, corn and other high value crop cultivation. However, the occurrence of heavy rainfall during the wet season can also pose challenges in terms of flooding.
Isabela experiences a relatively high and consistent temperature throughout the year. The average annual temperature ranges from 25 to 30 degrees Celsius. The warmest months are typically April and May, with temperatures sometimes exceeding 35 degrees Celsius (Table 3).
Isabela has distinct wet and dry seasons. The wet season generally starts in May and extends until October or November, coinciding with the southwest monsoon (locally known as "habagat"). During this period, the region receives the majority of its annual rainfall. The average annual precipitation in Isabela is approximately 1,700 to 2,500 millimeters. The heaviest rainfall is typically observed in August and September (Table 3)

Soil characteristics and land qualities
To obtain reliable soil data, the available soil survey reports were inspected and based on this, ten (10) representative soil profiles were chosen for a more detailed investigation within different land units (Table 4).

Crop Requirements
The crop requirements of banana with respect to climate, landscape and soil were summarized in Table 5 according to Sys et al. (1993). The simple Limitation Method (SLM), the Limitation Method regarding Number and Intensity (LMNI) and two Parametric Methods (PM), namely, the square-root and Storie methods (Sys et al., 1991) were used to land classification. Analytical Hierarchy Process (AHP) was also done to determine the weights of the seven (7) most important criteria for banana.

Analytical Hierarchy Process (AHP)
Expert information on banana crop was collected with an interview to key informants detailed in Table 6. They were chosen according to their knowledge and professional experience on banana production.
This study established 7 crucial criteria based on the growth requirements of banana (PCARRD, 1988) which are presented in Figure 2.

The key informants' assessments were used to derive the relative importance of one criterion to another using the AHP (Goepel, 2018). The procedure consists of three major steps: generation of the pairwise comparison matrix for each hierarchal level using different scale, the standard weights of the criteria (Table 1), and the consistency ratio (CR) estimation (Malczeski, 1999). The resulting CR values were below 0.10 evidence that the pairwise comparison matrix had a reasonable level of consistency and that the weight values were valid for the research (Table 7).

The four-class system for suitability was used in this study adapted from FAO (1976), as follows: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). Table 3 gives the assigned scaled values to each criterion for reclassification according to their attribute values in each of the four suitability classes. The limits and degree for suitability assessment of banana were determined based on a thorough review of the available literature (reference in Table 3) and key informants' opinions.
A summarized process was done by applying a weight (Table 5) to each reclassified criterion, followed by a summation of the results to yield a suitability rating based on linear and logarithmic method:

$$S = \Sigma(wi * xi)$$

where *S* is the land suitability index, *wi* the weight of criterion *i*, and *xi* is the reclassified scaled value of criterion *i*. Each soil series got a total score that is categorized according to the value range (adapted from Sys et al., 1991) of the index (Table 8).

Simple Limitation Method (SLM)

The use of Simple Limitation Method (SLM) in land suitability evaluation is based on identifying and categorizing the limitations or constraints that affect the suitability of a specific land area for a particular land use. This approach provides a simplified and systematic way to assess the factors that may restrict or hinder the successful implementation of a desired land use. By selecting and evaluating relevant factors such as soil characteristics, topography, climate, water availability, and fertility, the SLM helps to identify the limitations associated with each factor and assign them to limitation classes based on their degree of impact. The SLM allows for a clear understanding of the constraints that may affect land suitability and provides a basis for decision-making regarding land use planning and management. Although the SLM is a simplified approach, it provides valuable insights into the limitations of a land area, allowing stakeholders to make informed choices about land use options, interventions, and appropriate land management practices. However, it is important to consider that the SLM has its limitations and may not capture all the complexities of land suitability. Therefore, it is often used as an initial assessment method, and more advanced techniques can be employed for a more comprehensive evaluation.

Limitation Method regarding Number and Intensities (LMNI)

The Limitation Method regarding Number and Intensity (LMNI) is a comprehensive approach used in land suitability evaluation to assess both the quantity and severity of limitations that impact the suitability of a land area for a specific land use. This method recognizes that the presence and intensity of multiple limitations can significantly affect land suitability. The methodology evaluates, in the first place, the climatic characteristics, regrouped according to radiation, temperature, rainfall and humidity. For each climatic characteristic group, the most severe limitation determines the suitability of climatic class, which is subsequently used as the corresponding limitation level for the total land evaluation. The evaluation is carried out by comparing the actual land characteristics with the limitation levels defined by the crop requirement tables (Table 3). This method is more difficult than SLM, but the results accuracy is more honest, because it considers the land with several limitations of the same level as belonging to a lower-class land than with only a single limitation of the same level.

Parametric Method (PM)

The Parametric Method in land suitability evaluation is a quantitative approach that involves assigning numerical values to various factors or criteria influencing land suitability and using mathematical models to assess the overall suitability of a land area for a specific land use. This method utilizes parameters and thresholds to determine the suitability of a land area based on numerical rating of different limitation level of land characteristics according to a numerical scale between the maximum (normalized as 100%) and the minimum value. Factors such as soil characteristics, climate, topography, water availability, and fertility are assigned numerical values that reflect their importance and influence on land suitability. These values are then used in mathematical models or algorithms to calculate a suitability index or score for the land area. The parametric method allows for a more precise and quantitative assessment of land suitability, facilitating objective decision-making processes. In our case, the indices were calculated following two alternative procedures:

The Storie method *(Storie, 1976)*: The index was taken as a product of individual ratings:

$$I = A\ x\ \frac{B}{100}\ x\ \frac{C}{100}\ x\ \ldots$$

where *I* is the specified index and *A, B, C* etc. are different rating given for each property.

Square-root method *(Khiddir, 1986):*

$$I\ =\ Rmin\ x\ \sqrt{\frac{B}{100}\ x\ \frac{C}{100}\ x\ \ldots}$$

where Rmin is the minimum rank.

Conclusion

Depending on the technique employed, the suitability of banana production in Isabela varies substantially. All of the soil series were not suitable for banana production based on the findings of SLM and LMNI, but employing parametric methods (Storie and square-root) and AHP methods (linear and Log) banana production generally becomes marginally and moderately suitable, respectively.

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