Land Suitability Evaluation for Improvement of Banana/Plantain Production in Bayelsa State, Southern Nigeria

Abstract

With climate change affecting the world, increasing population requires improved soil resource assessment, management and environmentally friendly use of land to support food security. Bayelsa State is known to be one of topmost producers of banana/plantain but the escalating climate change variability in Nigeria has heightened irregular rainfall patterns, exacerbating land degradation resulting in more severe floods and erosion reducing land available for banana/plantain cultivation. Hence, this land suitability evaluation of some communities land situated on the lower Niger River plain of Bayelsa State through field study approach supported by laboratory analysis. Land suitability classes were determined by matching land characteristics with plant growth requirements. Apart from ELM3 and TFN3 considered not suitable (N2) due to annual flooding, the actual land suitability of the remaining sixteen SMUs marginally suitable (S3). The inhibiting characteristics affecting land suitability for plantain/banana production included high rainfall, annual flooding, poor drainage, low CEC and low organic carbon. Improvement efforts recommended included dredging of the river systems,elaborate drainage structure, fertilization and application of organic manure/organic fertilizer. Potential suitability classes arrived at following improvement efforts included not suitable (N2) for ELM3 and TFN3, and moderately suitable (S2) for ELM1, ELM2, ODN1, ODN2, ODN3, TFN1, TFN2, ODI1, ODI2, ODI3, KRM1, KRM2, KRM3, NDU1, and NDU2 as well asmarginally suitable for NDU3. The flood plain soils of Bayelsa State will have moderately suitable (S2) potential <u>for plantain/banana production provided the relevant improvement efforts are carried out.</u>

Suitability evaluation, Banana/Plantain, Production, Bayelsa State, Southern Nigeria

Introduction

The rising global population necessitates the environmentally sustainable use of land to ensure food security, particularly in the face of the current climate change crisis [1]. Dickson et al. [2], highlight that nearly all food consumed by humans, except for marine-sourced products, is grown on land, which underscores the need for sustainable land management practices. Failures in past and present agricultural development programs in many Sub-Saharan African (SSA) nations have been attributed to inadequate soil management [3]. Soil degradation can severely hinder food supply, especially in small-scale agricultural systems [4]. Addressing this issue requires improved soil resource assessment and management of agricultural soil potential [5]. In a study on the capability of Bayelsa State soils,[6], emphasized that modern agriculture necessitates that farmers have a comprehensive understanding of soil nutrient status and other chemical and physical characteristics to make informed decisions. Therefore, integrating land suitability evaluation into soil characterization and classification studies before crop cultivation and other agricultural land uses is crucial {[1],[2]}. Bhaskar et al. [1] further emphasize that many land capability and soil suitability assessments fail to account for soil geographical variations and essential characteristics, which are vital for addressing site-specific land use concerns. Evaluating land suitability requires considering factors such as drainage, texture, soil depth, nutrient retention (including pH and cation exchange capacity), alkalinity, erosion risk, and flood/inundation potential. For banana cultivation, [1] reported that the effective soil depth should exceed 125 cm, with optimal growing conditions including a mean temperature of 26.67°C and an average annual rainfall of 120 to 150 cm. Similarly, [7] recommend an effective soil depth greater than 100 cm, a temperature range of 20-23°C, and an average annual rainfall of 125-175 cm for banana cultivation.

In Africa, plantains and bananas contribute over 25 percent of the carbohydrate intake for more than 700 million people. In Nigeria, plantains flourish in the southern regions due to the tropical and humid climate, with production occurring in states such as Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Abia, Imo, Lagos, Oyo, and Ondo, among others. Plantains produce fruit throughout the year, making them a dependable staple food, especially in developing nations like Nigeria, where there are significant challenges with food storage, preservation technology, and transportation. Year-round fruiting plantains, which can grow in various soil types, are processed into flour and snacks that are highly popular among Nigeria's youth. Currently, Nigeria's plantain flour production stands at 25,000 metric tonnes (MT) against a demand of 125,000MT, leaving a deficit of 98,900MT, as reported by the Bill and Melinda Gates Foundation (Business Day).

Plantains thrive in tropical regions with warm temperatures, ample sunlight, and sufficient moisture, providing optimal growth conditions. However, tropical soils are often unsuitable for plantain cultivation due to poor nutrient content, susceptibility to diseases, and a lack of reliable planting materials. Recently, the availability of plantains in markets and households has been compromised by climate change and increased annual flooding in the southern Nigerian plantain-growing regions. States like Bayelsa, once leading producers, have seen a decline in plantain production due to climate change and flooding of previously cultivated areas. The increasing climate change variability in Nigeria has resulted in irregular rainfall patterns, worsening land degradation, and more severe floods and erosion. Nigeria, being among the top ten countries most vulnerable to climate change, has faced escalating environmental challenges (Wikipedia https://en.wikipedia.org). Addressing the declining plantain production and market situation is critical, thus the need for this soil suitability evaluation of some lower Niger River plain communities in Bayelsa State, Nigeria, which were previously leading in plantain production.

Materials and Methods

2.1 Description of the Study Area

The study was carried out on some communities of the lower Niger River Plain in Bayelsa State,
Southern Nigeria which was known for plantain/banana production. The area lie between latitude 05° 22' 03.9" N and 04° 59' 08.9" N and longitude 006° 30' 21.1" E and 006° 06' 54.1" E. Niger Riverflows southward, breaking into Forcados and Nun Rivers. Whereas, the Forcados River demarcates Bayelsa State and Delta State on the western border, the Nun River runs north and south down the middle of the Bayelsa State, remaining the most direct tributary of the Niger. From Bayelsa State's territory, several rivers issue into the Atlantic Ocean, namely, the Ramos, Dodo, Pennington, Digatoru, Middleton, Koluama, Fishtown, Sangana, the Nun, Brass, St. Nicholas, Santa Barbara and Sombreiro (Fig. 1). Annual rainfall is between 2000 and 4000 mm, spreading over 8 to 10 months while temperature is fairly constant with a maximum of 30°C. The Relative humidity is comparatively uniform, averaging over 80 % all over the state.

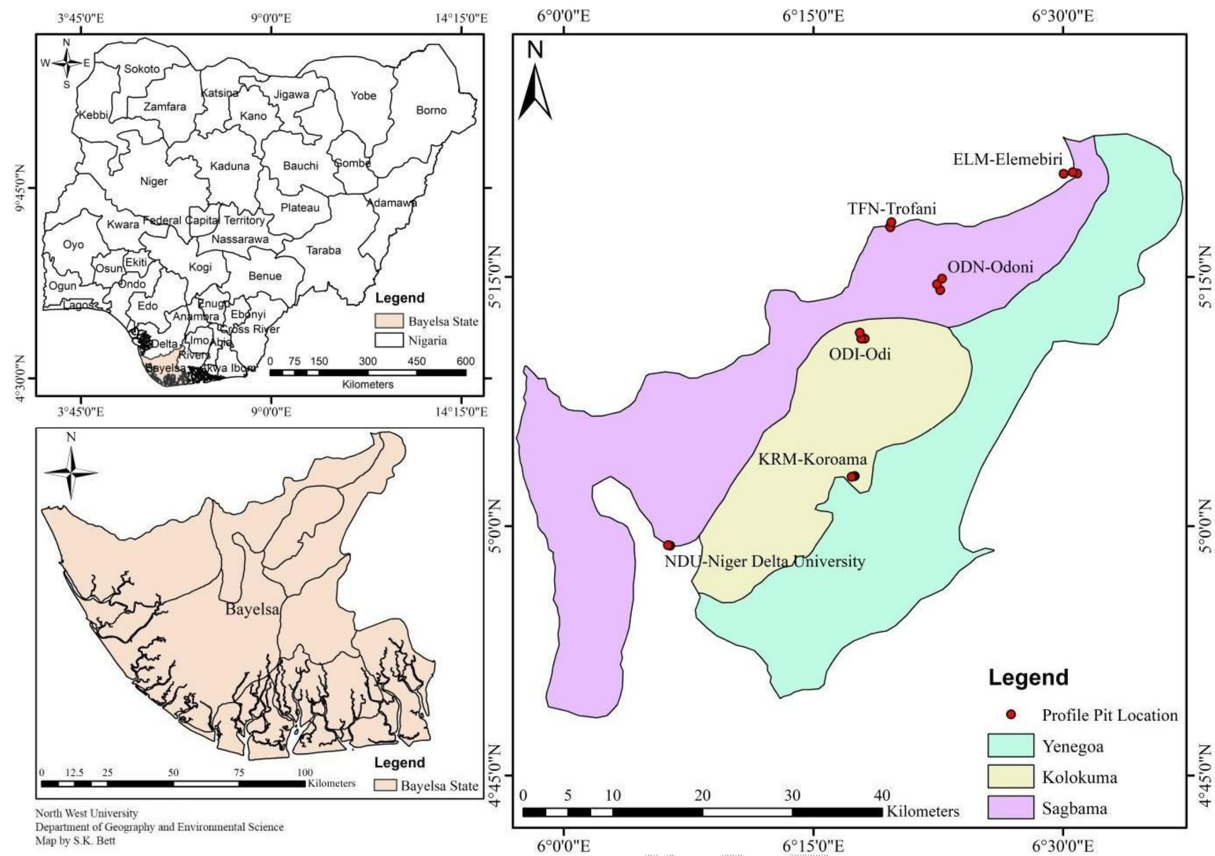

Fig 1: Map of Bayelsa State showing study locations and Rivers linked to the Atlantic Ocean
(source: Dickson, 2018)

The natural vegetation is tropical rainforest with much of the original vegetation degraded or altered. Banana/plantain are produced on the levee crestand levee slope, and sometime levee slope. On Table 1 is presented the area covered by the SMUs.

Table 1: Soil Sampling Units, Profile Pit Location and Land Area

Study Location	Sampling Unit	Geo-reference of Profile Pit	No. of Profile Pits	Land Area (Hectares)	Land Area (%)
Elemebiri	ELM1	N 05° 21′11.5″E 006° 30′02.2″	1	29.08	2.4
	ELM2	N 05° 21′12.4″ E 006° 30′51.3″	1	21.25	1.7
	ELM3	N 05° 21′22.6″E 006° 30′51.3″	1	162.14	13.3
Odoni	ODN1	N 05° 14′12.4″E 006° 22′37.2″	1	89.94	7.4
	ODN2	N 05° 14′33.3″E 006° 22′25.5″	1	52.10	4.3
	ODN3	N 05° 14’ 53.3″E 006° 22′43.4″	1	90.57	7.4
Trofani	TFN1	N 05° 18′01.5″E 006° 19′36.0″	1	87.61	7.2
	TFN2	N 05° 17′58.6″, E 006° 19′37.1″	1	51.50	4.2
	TFN3	N 05° 18′17.1″, E 006° 19′41.2″	1	148.51	12.2
Odi	ODI1	N 05° 11′17.4″E 006° 18′04.6″	1	142.49	11.7
	ODI2	N 05° 11′17.1″, E006° 17′52.3″	1	65.06	5.3
	ODI3	N 05° 11′38.7” ″E 006° 17′47.0″	1	138.65	11.4
Koroama	KRM1	N 05° 02′59.9″, E 006° 17′28.8″	1	13.18	1.1
	KRM2	N 05° 02′59.2″,E 006° 17′26.9″	1	10.65	0.9
	KRM3	N 05° 02′58.1″, E 006° 17′14.0″	1	21.43	1.8
Niger Delta University	NDU1	N 04° 58′49.1″E 006° 06′23.7″	1	24.05	2.0
	NDU2	N 04° 58′49.9″, E 006° 06′17.5″	1	7.53	0.6
	NDU3	N 04° 58′50.5″, E 006° 06′15.7″	1	60.53	5.0

Source: Dickson, 2018

2.2 Procedures

Six different locations, Elemebiri, Odoni, Trofani, Odi, Koroama and Niger Delta University Wilberforce Island were selected for this study. Surface (0-15cm) and (15-30cm) soil samples were collected at 100 m intervals on the land types encountered (viz. upper slope or levee crest, middle slope or levee slope and lower slope or floodplain) using soil auger which alsoserved as mapping units.The soil mapping units were designated ELM1, ELM2 and ELM3 for Elemebiri, ODN1, ODN2 and ODN3 for Odoni, TFN1, TFN2 and TFN3 for Trofani, ODI1, ODI2 and ODI3 for Odi, KRM1, KRM2 and KRM3 for Koroama and NDU1, NDU2 and NDU3 for Niger Delta University Teaching and Research Farm. As a result of land form differentiations and differences in texture, colour, soil depth, gravel content, landscape segments in each location wereseparated into three mapping units, making a total of eighteen mapping units. Details of the field procedures are as presented in [9] and [10].

2.3 Soil site suitability

The FAO framework for land evaluation and rainfed farming norms {[11,[12]} was applied to assess soil suitability, with SMUs classified into suitability classes by aligning their characteristics with established requirements. The criteria for plantain/banana suitability [6] were used, and the land was logically classified into highly suitable (S1),moderately suitable (S2), marginally suitable (S3), currently not suitable (N1), and not suitable (N2) based on soil and site attributes as detailed in Table 2. The land characteristics considered included rainfall, mean annual temperature, slope, wetness, drainage, texture, and volume of coarse soil materials with depth, fertility, ECEC, base saturation, and organic carbon, among others. The overall suitability classes were determined by the most limiting characteristics of each SMU. Soils classified as S1 have no significant barriers to long-term use for a specific purpose. Soils in the S2category have moderate to substantial constraints for long-term application of a particular use, while soils in the S3 category have serious constraints for sustained application of a specific use. On the other hand, soils in the N1 category have severe limitations and cannot be used for plantain/banana cultivation unless significant remedial measures are undertaken, and soils in the N2 category are unsuitable for plantain cultivation.

Table 2: Land use requirements for Banana/plantain cultivation (Djaenudin et al., 2003)

Land Quality/Characteristics	S1	S2	S3	N1	N2
1 Climate (c)					
Annual rainfall (mm)	1250-1750	1750-2000	2000-2500	›2500	-
		1000-1250	750-1000	‹750	-
Temp. (°C)	23-27	27-30	30-40	›40	
		18-20	15-18	‹15	-
2 Topography (t)					
Slope (%)	‹8	8-16	16-30	›30	
3 Wetness (w)					
Flooding	F0	F1	F2	F3	
Drainage	Good	Mod. Poor		very poor, Rapid	-
	Moderate		Poor, mod. Rapid		
4 Soil physical characteristics (s)					
Texture (surface)	fine, slightly Fine, medium	-	slightly coarse	Coarse	-
Coarse fragments (%) 0-10cm	‹15%	15-35	35-55	›55	-
Depth (cm)	›100	75-100	50-75	‹50	-
5 Fertility (f)					
CEC (cmol/kg)	›16	≤			
Base saturation (%)	›35	20-35	‹20		
OC (g/kg) 0-15cm	›1.2	0.8-1.2	‹0.8		
pH-$H_2$0	5.0-6.0	4.5-5.0	‹4.5		
		6.0-7.5	›7.5		
Salinity (ds/m)	‹4	4-6	6-8	›8	

Source: Dickson, 2018

3.0 Results and Discussion

3.1 Suitability of the Soils for plantain Cultivation

Land suitability evaluation as defined by [13] “is the assessment of a land to obtain information related to land potential for specific uses” andsuch evaluation could end up inactual land suitability and potential suitability classes. Actual suitability class is based on the assessment of the land under current conditions [14] while potential land suitability is based on estimated land conditions after land improvement [15].

In this study, annual rainfall and annual temperature under climatic variables were the most limiting characteristics to plantain/banana cultivation. In the conversion table (Table 2), 1,250-1750 mm mean annual rainfall is the highly suitable range for banana/plantain cultivation whilethe area receives 2000-4000 mm annual rainfall. Therefore, all the SMUs fall short of the highly suitable rainfall range and were placed in the marginally suitable (S3) class. Since rainfall in Bayelsa State in most years exceed the optimum rainfall requirement for banana/plantain cultivation,it interfere with the growth process. High rainfall have both direct and indirect impact on growth and yield quality. Rainfall damages plants and even trigger the development of diseases. Where high rainfall is accompanied by high humidity, emergence of Black Sigatoka disease (*Mycosphaerellafijiensis*) could occur which causes damage to plantain/banana leaves[16] and Bayelsa State experiences high rainfall and high humidity of over 80%. Indirectly, leaching of soil nutrients have been attributed to high rainfall [16] and also high rainfall may affect run-off and the rate of erosion [17].

A temperature range of 23-27 C is considered highly suitable for banana/plantain cultivation in the conversion table (Table 2) and the temperature of the SMUs was within 23-30 C and they were placed in the S1 suitability class. Mujiyo [15] reported that banana/plantain growth is good at 25-30 C and there is likelihood of slow maturation at lower temperatures, even damaging plants. The slope of the areas the SMUs occupy was less than 3% (highly suitable) and they allocated to the S1 suitability class.

Table 3: Land Suitability Evaluation of Soil Mapping Units for Plantain/Banana Cultivation

	SMU																	
Land quality/characteristic	ELM1	ELM2	ELM3	ODN1	ODN2	ODN3	TFN1	TFN2	TFN3	ODI1	ODI2	ODI3	KRM1	KRM2	KRM3	NDU1	NDU2	NDU3
Climate (c)																		
Annual rainfall (mm)	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3	S3
Mean annual Temp. (° C)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Topography (t)																		
slope (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Wetness (w)																		
Flooding	S1	S1	N2	S1	S1	S2	S1	S1	N2	S1	S1	S2	S1	S1	S2	S1	S1	S3
Drainage	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S2	S1	S1	S2	S1	S1	S3
Soil physical characteristics (s)																		
Texture	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Coarse frags. (%) 0-10cm	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Depth (cm)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Fertility (f)																		
CEC (cmol/kg)	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2
Base saturation (%)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
pH-H20	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
OC (%)	S1	S3	S2	S2	S1	S1	S2	S3	S2	S2	S2	S1	S1	S3	S2	S1	S1	S1
Salinity (ds/m)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Limiting Characteristics	Cf	Cff	cf2	Cf	Cf	Cwf	Cf	Cf	cf2	Cf	cf	cwf	cf	Cf	cwf	cf	cf	cwf
Aggregate suitability	**S3**	**S3**	**N2**	**S3**	**S3**	**S3**	**S3**	**S3**	**N2**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**S3**	**N1**

C=climate; t=topography; w=wetness; s=soil physical properties; f=fertility; N1- presently not suitable but potentially suitable. (**Source: Dickson, 2018)**

The impact of wetness, drainage and flooding on the locations differ and posed limitation to banana/plantain cultivation in certain locations. When flooding was considered in evaluating the SMUs suitability for plantain/banana cultivation, ELM1, ELM2, ODN1, ODN2, TFN1, TFN2, ODI1, ODI2, KRM1, KRM2, NDU1, and NDU2 fell into the S1 suitability class, ODN3, ODI3 and KRM3 into the S2 suitability class, NDU3 in the N1 suitability class while ELM3 and TFN3 which suffer annual flooding from Niger and Forcados Rivers, respectively, were placed in the N2 category. Using drainage as a requirement, ELM1, ELM2, ELM3, ODN1, ODN2, TFN1, TFN2, TFN3, ODI1, ODI2,KRM1, KRM2, NDU1, and NDU2 were allocated to the S1 suitability class, ODN3, ODI3 and KRM3 into the S2 suitability class and NDU3 into the N1 suitability class.

For soil physical characteristics (texture, coarse fragments and depth), all were within the highly suitable range and were placed in the S1 suitability class (Table 3) for plantain/banana cultivation. According to [15], a soil depth >150 cm is suitable for plantain/banana cultivation. According to [18], deep soil condition enable roots to develop properly

Cation exchange capacity (CEC) and organic C are the fertility characteristics that were most limiting, affecting the SMUs differently. The SMUs CEC values, fall short of being allocated to the highly suitable class (16 cmol/kg) but eligiblefor the S2 suitability class. The organic Cvalues as recorded for ELM1, ODN2, ODN3, ODI3, KRM1, NDU1, NDU2 and NDU3 were within the highly suitable (S1) range, ELM2, ODN1, TFN1, TFN3, ODI1, OD12 and KRM3 in the moderately suitability (S2) range and ELM2, TFN2 and KRM2 in the marginally suitability (S3) range. Using base saturation, pH and salinity as requirements, all SMUs were entitled to be allocated to the highly suitable (S1) class. Since the most limiting characteristics dictate the actual or aggregate suitability class, all the SMUs were placed in the marginally (S3) suitability class (Table 3). The limiting characteristics were rainfall, temperature, flooding, drainage, CEC and organic carbon.

3.2 Potential Land Suitability

Potential land suitability is assessed by estimating land conditions after implementing land improvements [15]. Table 4 presents recommendations for land management, formulated based on land characteristics limiting suitability in the SMUs. Following post-improvement, the potential land suitability remained unsuitable (N) for ELM3 and TFN3, marginally suitable (S3) for NDU3, and moderately suitable (S2) for other SMUs. Rainfall requirements for all SMUs exceeded the optimal levels for plantain/banana cultivation, leading to nutrient loss through leaching, increased erosion risk, and waterlogging, which inhibits oxygen supply to plant roots. An elaborate drainage structure is recommended to manage excess rainfall and prevent waterlogging {[16],[15]}. Biopores can be installed to store water in the soil, absorb surface runoff, and reduce erosion and nutrient loss [19].

Six SMUs (ELM3, ODN3, TFN3, ODI3, KRM3, and NDU3) experience extreme annual flooding issues, necessitating measures to avoid crop damage from flooding. The others are not completely exempted from flooding. Due to climate change and the continuous deposition of alluvial materials by the Niger River's annual floods, the river systems have become so shallow and flat. Several rivers originating from Bayelsa State, including Ramos, Dodo, Pennington, Digatoru, Middleton, Koluama, Fishtown, Sangana, Nun, Brass, St. Nicholas, Santa Barbara, and Sombreiro, discharge into the Atlantic Ocean. Plantain/banana cultivation occurs on the levee crest, levee slope, and sometime flood plain, most of which are subject to flooding depending on the flood volume. To enhance production, the thirteen river systems need to be dredged to deepen them formore accommodation of water. This dredging process is costly and requires government intervention at the state or national level.

Organic-C content and CEC in most of the SMUs are either marginal or moderate and for optimum plantain/banana growth, improvement efforts need to be carried out. As organic food products are becoming more prominent, the application of organic manure/ fertilizer should be encouraged. In addition,other nutrient sources should be supplied to increase the nutrient retentive capacities of the SMUs. Furthermore, bush burning and measures that accelerate loss of organic matter need to be discouraged.

Table 4. Improvement Effort and Potential Land Suitability for each SMU

SMU	Inhibiting factor	Improvement effort	Potential Land Suitability
ELM1	rainfall,, CEC	Elaborate drainage Fertilization	Moderately suitable S2
ELM2	rainfall, CEC, organic C	Elaborate drainage Fertilization Avoidance of bush burning, organic manure/fertilizer application	Moderately suitable S2
ELM3	rainfall, flooding CEC, organic C	Elaborate drainage Elaborate drainage structure, dredging of the river systems Fertilization Avoidance of bush burning, Organic manure/fertilizer application	Not suitable N2
ODN1	rainfall, CEC, organic C	Elaborate drainage Fertilization Avoidance of bush burning, organic manure/fertilizer application	Moderately suitable S2
ODN2	rainfall, CEC	- Elaborate drainage Fertilization Avoidance of bush burning, organic manure/fertilizer application	Moderately suitable S2
ODN3	rainfall flooding, drainage, CEC	Elaborate drainage Elaborate drainage structure, dredging of the river systems Fertilization Avoidance of bush burning, organic manure/fertilizer application	Moderately suitable S2
TFN1	rainfall, CEC,	- Elaborate drainage Fertilization Avoidance of bush burning, organic manure/fertilizer application	Moderately suitable S2
TFN2	rainfall, CEC, organic C,	Elaborate drainage Fertilization Avoidance of bush burning, organic manure/fertilizer application	Moderately suitable S2
TFN3	rainfall, flooding, drainage, CEC, organic C	Elaborate drainage Elaborate drainage structure, dredging of the river systems Fertilization Avoidance of bush burning, organic manure/fertilizer application	Not suitable N2
ODI1	rainfall, CEC,	Elaborate drainage Fertilization	Moderately suitable S2

	organic C	Avoidance of bush burning, organic manure/fertilizer application	
ODI2	rainfall, CEC, organic C	Elaborate drainage Fertilization Avoidance of bush burning,organic manure/fertilizer application	Moderately suitable S2
ODI3	rainfall, flooding, drainage, CEC	Elaborate drainage Elaborate drainage structure, dredging of the river systems Fertilization Avoidance of bush burning, organic manure/fertilizer application	Moderately suitable S2
KRM1	rainfall, CEC	Elaborate drainage Fertilization Avoidance of bush burning, organic manure/fertilizer application	Moderately suitable S2
KRM2	rainfall, CEC	Elaborate drainage Fertilization Avoidance of bush burning, organic manure/fertilizer application	Moderately suitable S2
KRM3	rainfall, flooding drainage CEC, organic C	Elaborate drainage dredging of the river systems Elaborate drainage structure, Fertilization Avoidance of bush burning, organic manure/fertilizer application	Moderately suitable S2
NDU1	rainfall, CEC	Elaborate drainage Fertilization Avoidance of bush burning, organic manure/fertilizer application	Moderately suitable S2
NDU2	rainfall, CEC	Elaborate drainage Fertilization Avoidance of bush burning, organic manure/fertilizer application	Moderately suitable S2
NDU3	rainfall, flooding, drainage, CEC	Elaborate drainage Elaborate drainage structure, dredging of the river systems Fertilization Avoidance of bush burning, organic manure/fertilizer application	Moderately suitable S3

4.0 Conclusion

Bayelsa State, known for its significant plantain/banana production in southern Nigeria, has considerable potential for agricultural improvement if appropriate land management measures are implemented. Achieving potential land suitability necessitates addressing the identified limiting land characteristics through comprehensive evaluation and targeted solutions. This study identified rainfall, flooding, wetness/drainage, CEC, and organic carbon as critical limiting factors. Recommended land improvement strategies include the construction of elaborate drainage systems, dredging of river systems, application of organic manure and fertilizers, and the avoidance of practices that deplete soil organic matter. Many of these measures are beyond the capacity of individual farmers, necessitating intervention from state and federal governments to support the improvements, especially the dredging of the river systems.

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