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LAND SUITABILITY EVALUATION FOR OIL PALM PRODUCTION IN CROSS RIVER STATE, NIGERIA

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ABSTRACT
The properties of soils in an area are defined by the interaction between lithology and other factors of soil formation. Of the five factors of soil formation, climate is most important in the control of the distribution of crops in Nigeria, and oil palm is not an exception. The study was carried out to evaluate the suitability of land in Cross River State for oil palm production, and make appropriate soil management recommendations for improved production. Eight slope transitions were identified and two soil profile pits were sunk in each transition. Sixteen profile pits were used for the study. Currently, the well-drained high elevation soils are moderately suitable (S_2) for oil palm cultivation; however, most of the well-drained soils in the higher elevation ranges in the southern agricultural zone are potentially highly suitable (S_1). The central and southern agricultural zones are more suitable for oil palm cultivation. The poorly drained and low elevation areas in the three zones are not economical for the cultivation of oil palm and should be put to the cultivation of sugar cane and paddy rice.

Key words: land Suitability, oil palm, rainforest, Cross River

INTRODUCTION
Land is the basis for agriculture and other rural land uses, and comprises the physical environment; soils, climate, vegetation, topography, hydrology, and other natural resources to the extent that these affect the potential for land use. To achieve sustainable management of soil resources, detailed studies through the processes of soil characterization and land evaluation for the land use type must be considered (Esu, 2004). Land suitability evaluation appraises and groups specific types of land in terms of their absolute or relative suitability for a specified kind of use (FAO, 1976). It is a simple avenue to combat the problems caused by land use as many a time, soils are not comparatively used for the purpose that best suits their properties. Land users rather focus on the availability of land, with less emphasis on its fitness.

Through soil mapping, analysis and categorization put data obtained from resource inventory into a form that is useful to farmers by evaluating the mapping units for diverse land use types. Land use planning seeks to evaluate and assess land as a basis for decisions involving land use to reconcile competing demands for land and reduce incidences of soil degradation (Ameztegui *et al*., 2016). In a bid to increase productivity and satisfy the increasing demands for food by a geometrically increasing population, farmers are made to continuously cultivate tracts of land by mechanized systems. This practice has led to a severe depletion in their fertility status. Soil degradation and fertility depletion are the frontline reasons for the decline of food production, hunger, and malnutrition in sub-Saharan Africa (Sanchez and Uehara, 1980).

Land suitability classification attempts to solve problems that are associated with land degradation, and the wrong allocation of land to uses. It is the actual or potential fitness of a given tract of land for a defined use and takes into account the economic and sociopolitical factors during land evaluation. Land suitability classification is applied to clearly defined land uses (Idoga *et al*. 1995), and may be done based on the present status of the tract of land or after minor improvements. Topographic characteristics, climatic conditions as well as the quality of soil in an area are the most important determinant parameters of land suitability evaluation (Al-Mashreki *et al*. 2010). The aim of land suitability evaluation is to find out parcels of land that best support commonly grown crops based on the physical and chemical properties of the soils and make recommendations for improved yield.

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Beyond critical ranges, crops cannot be expected to yield satisfactorily unless special precautionary measures are taken into consideration (Ande, 2011). The majority of oil palm roots are found within the first 30.00-60.00 cm of the soil surface, firm anchorage of adult palms of more than 8.00 m of height can only be assured in deep soil (> 90.00 cm) with rainfall of ≥ 2,000.00 mm per year, friable soil consistency, sandy clay loam to loamy textures with insignificant amounts of gravels, good water and nutrient storage (Mutert, 1999).

Oil palm is one of the most important and widely distributed tree crops in Cross River State. The crop is totally useful, with almost zero level of waste. The kernel and mesocarp oils of oil palm are edible and useful in the cosmetic industry; the fibrous stem is a source of fuel, fresh palm wine, and manure; its fronds are important roofing materials; while its kernel shell and empty bunches are sources of fuel, mulching materials, and manure (Ofem *et al.,* 2016; Okolo *et al.,* 2019). Most importantly, oil palm cultivation and processing require little skills and so can be cultivated by the rural farmer with little supervision. The study was carried out to evaluate the suitability of land in Cross River State for oil palm production, and to make appropriate soil management recommendations for limiting soil properties in order to improve production.

MATERIALS AND METHODS

Description of the Study Area

The study is located in Cross River State, Nigeria. Cross River State is located within latitudes 5°32′ and 4°27′ N, and longitudes 7°50′ and 9°28′ E. The state is bordered by Benue State in the North-East, Ebonyi and Abia States in the West, Akwa Ibom State in the South-West, and the Atlantic ocean and the Cameroons in the South and East, respectively. Three locations were selected; Ishibori, Agoi Ibami and Mfamosing in Ogoja, Yakurr and Akamkpa Local Government Areas found in the northern, central, and southern agricultural zones, respectively. The Oban-Obudu hills form the basement complex of Cross River State and are made up of Precambrian Schist and Gneiss with intrusives of igneous rocks (Ekwueme, 1987). The sedimentary limestone of Cretaceous and Tertiary ages in Cross River State is common in the Ikom depression (Mamfe rift) and Calabar flank, and is often intercalated with shale, siltstone, and fine-grained sandstone (Fatoye and Gideon, 2013; Ofem *et al.,* 2020). The current study is focused on the soils developed on limestone across the three agricultural zones in Cross River State.

Cross River State is characterized by a humid tropical climate and has distinct wet and dry seasons which vary slightly in duration and location. Drier and hotter climates characterize the Ishibori area, compared to Agoi Ibami and Mfamosing. In the Koppen climate classification system, the areas qualify as a tropical moist climate with an average temperature that exceeds 18°C in all months and precipitation of over 1,500.00 mm per year. Rainfall amounts vary from 1,251.00 to 3,348.00 mm per year in Ishibori to 1,760.00-3,771.00 mm per year in the Agoi Ibami and Mfamosing areas. Temperature varies slightly from 23 to 34°C in Ishibori to 22.6 to 32°C in Agoi Ibami and Mfamosing (Sambo *et al*., 2016). The state has a multi-vegetational system. Its vegetation ranges from the mangrove swamps in the Southern coastal areas through the tropical rainforests in the southern uplands (Eni *et al*. 2011) and central areas of the State to the southern guinea savannahs in the northern parts of the State (Fon *et al*., 2014). Montane parkland dominates the Obudu-Obanliku plateaux. Cocoa (*Theobroma cacao*), oil palm (*Elaeis guineensis*), gmelina (*Gmelina arborea*), rubber (*Hevea brasiliensis*), sesame (*Sesamum indicum*) and neem (*Azadirachta indica*) are tree crops commonly grown at commercial scale. Food crops include maize (*Zea mays*), cassava (*Manihot esculenta*), yam (*Dioscorea* sp.) and rice (*Oryza sativa*), as well as vegetables like cucumber (*Cucumis sativus*), okra (*Abelmoschus esculentus*), and watermelon (*Citrullus lanatus*).

Field and Laboratory Studies

Digital elevation models (DEMs) of the study locations were obtained from USGS Explorer SRTM 1 arc-second Global (http://earthexplorer.usgs.gov/) at a resolution of 30.00 m. Using Arc GIS (ESRI, US) software, the DEMs were used to delineate slope transition from high to low elevations. Two transitions were identified in Ishibori (IH1, IH2), three each in Agoi Ibami (AI1, AI2, AI3), and Mfamosing (MF1, MF2, MF3). Two profile pits were randomly sited and dug in each of the eight slope transitions to represent the soils. The soil samples were air-dried under laboratory conditions, ground and passed through a 2.00 mm mesh of sieves. Fifty-three soil samples were collected from the 16 soil profile pits and used for physical and chemical analysis.

Particle size analysis was performed by the Bouyoucos hydrometer method using sodium hexametaphophate as the dispersing agent. Soil pH (H_2O) was determined potentiometrically in a 1:2.5 soil:water suspension. Organic C was determined by the Walkley and Black wet oxidation method, while exchangeable Ca^{2+}, Mg^{2+}, K^+ and Na^+ were extracted using 1N NH_4OAc (pH 7.0). Atomic absorption spectrophotometry and flame photometry were used for the determination of exchangeable Ca^{2+} and Mg^{2+}, and exchangeable K^+ and Na^+, respectively. Exchangeable sodium percent was determined by expressing the ratio of exchangeable sodium and cation exchange capacity as a percentage. Similarly, base saturation was obtained by expressing the sum of exchangeable bases as a percentage of the cation exchange capacity. The laboratory analysis were carried out as outlined by Soil Survey Staff (2014).

Land Suitability Evaluation Procedures for Oil Palm Production

The pedons were placed in suitability classes by comparing the oil palm requirement information in Table 1 to primary and secondary data (Table 2). The most limiting factor was assumed to determine the overall suitability ratings in accordance with Liebig's law of minimum. For the parametric (square root method) method, each limiting characteristic was rated for all the pedons as shown in Table 3.

The index of productivity (IP) for each pedon was computed using the equation:

$$IP = A\sqrt{\frac{B}{100} \times \frac{C}{100} \ldots \frac{E}{100}};$$

where A is overall lowest characteristic rating; B, C… E are lowest characteristic rating for each land quality group except the land quality group of which A characteristic is a member.

For the purpose of this research, the land quality groups; climate (c), topography (t), wetness (w), physical characteristics (s), soil fertility (f) and alkalinity (n) were used. Since there are often strong correlations within a land quality group, only one member with the least rating in each of c, t, w, s, f and n was used to calculate the IP. The IP was calculated for actual and potential productivity and presented in Table 4. In potential productivity, properties that are easily altered by soil management procedures (soil pH, BS and organic carbon) were masked.

RESULTS AND DISCUSSIONS

Land Suitability Evaluation for Oil Palm Cultivation

Land characteristics of the area are corrected to 100.00 cm depth and presented in Table 2. These characteristics, in comparison with values in Table 1 gave rise to the suitability classes and scores in Table 3. Furthermore, aggregate suitability scores for each pedon were calculated and presented in Table 4.

Land Requirements for Oil Palm

Climate

Temperature and rainfall characteristics were evaluated for climate quality. In Cross River State, these characteristics were optimum for the cultivation of oil palm (Table 3), with suitability scores ranging from S_1 (94.00) to S_1 (100.00) for mean annual temperature and mean annual rainfall. Climate did not constitute a limitation for the cultivation of oil palm. Near optimum climate was reported for oil palm cultivation in Nigerian Institute for Oil Palm Research by Ogunkunle (1993), while Ofem *et al.* (2016) reported that the climate in Biase was highly suitable for oil palm. According to the study, much of Nigeria is climatically not suitable for its cultivation. Consequently, southern Nigeria particularly Cross River State has been found to have a comparative advantage over other zones in Nigeria for the cultivation of oil palm, probably because of its favourable climate. However, the climate is not a sole determinant of land quality or suitability for oil palm cultivation.

Topography

The topography of the study areas was highly suitable for oil palm cultivation with a score of S_1 (100.00) in all the locations.In the Biase area, Ofem *et al.* (2016) reported none to slight limitations in topography.

Wetness

Wetness land quality was represented by drainage and flooding. Soils in higher elevation ranges were well-drained and free of flooding. For instance, drainage and flooding characteristics had ratings greater than S_1 (97.00). However, the lowest elevation ranges (IH2, AI3, MF3) were most affected by flooding and drainage. Suitability class scores for these low elevation ranges were N_1 (35.00 to 37.00) for flooding characteristics and S_3 (50.00) to N_1 (38.00) for drainage characteristic. These characteristics cause severe limitations to oil palm cultivation in the low elevation ranges. The foodplain soils of River Niger have been reported to be highly suitable for rice but moderately for oil palm cultivation (Ukabiala, 2022). This further indicates that poorly drained soils are less suitable for oil palm cultivation.

Soil physical characteristics

Soil physical quality was represented by soil texture, coarse fraction (CF) and soil depth. Soil texture was optimum and did not constitute a major limitation in the three agricultural zones for the cultivation of oil palm with a suitability class score of S_1 (90.00 to 98.00). Such optimum soil textures (Tables 2) and scores (Table 3) may reduce drainage and increase nutrients and moisture retention. However, a slight limitation was observed for CF in mapping unit IH1.

This further down-graded its suitability class score to S_2 (76.00-80.00), resulting in slight oil palm cultivation limitations. Other mapping units were optimum with a suitability class score of S_1 (89.00-100.00) for the cultivation of oil palm and no significant limitation. Soil depth was optimum for the well-drained soils in high elevations (irrespective of the agricultural zones) with suitability class scores of S_1 (88.00-100.00) and without a limitation. However, soils in the low elevation ranges were limited by the high water table resulting in suitability class scores of S_3 (40.00-48.00) and N_1 (30.00-31.00) with severe limitations.

Potential soil fertility

Included in the potential soil fertility were chemical properties that were not easily altered (e.g., CEC, Mg:K ratio and exchangeable sodium percent). The entire soils were optimum in terms of CEC with a suitability class of S_1 (88.00-100.00) except AI2P2, which witnessed slight limitation and was rated S_2 (80.00). Similarly, the Mg:K ratio and exchangeable sodium percent were optimum in the entire soils with a suitability class score of S_1 (100.00) (see Table 3).

Current soil fertility

Current soil fertility refers to chemical fertility when properties that are easily altered are taken into consiration alongside the requirements for potential fertility, including base saturation, soil pH and organic carbon.

Table 1: Land use requirements for suitability classes for oil palm cultivation (limitation-parametric method of evaluation)

Class, degree of limitation and rating scale						
Land	S1 (highly suitable)		S2 (moderately suitable)	S3 (marginally suitable)	N1 (currently not suitable)	N2 (permanently not suitable)
Characteristics	0.00	1.00	2.00	3.00		4.00
	100.00-95.00	95.00-85.00	85.00-60.00	60.00-40.00	40.00-25.00	25.00-0.00
Suitability to land use	High	Moderate	Marginal	Currently		Permanently
Climate (c)						
MAR (mm per year)	> 2000.00	2000.00-1700.00	1700.00-1450.00	1450.00-1250.00	-	< 1250.00
MAT (ºC)	> 25.00	25.00-22.00	22.00-20.00	20.00-18.00	-	< 18.00
Topography (t)						
Slope (%)	0.00-4.00	4.00-8.00	8.00-16.00	16.00-30.00	> 30.00	-
Wetness (w)						
Flooding	Fo (No flooding limitation)	Fo (No flooding limitation)	F1 Slight limitation; no longer than 1 to 2 months	F2 Moderate limitation; 2 to 3 months of flood in every 5 to 10 years	- -	F3 Severe limitation; Every year, 2 to 4 months of flood
Drainage	Imperfect	Moderate well	Moderate well	Poor; aeric	Poor; drainable	Very poor; not drainable
Physical characteristics (s)						
Texture	L,SCL,CL	CL, SCL, L	C, SCL	SCL-LfS	-	C, SC
CF (%)	0.00-15.00	15.00-35.00	35.00-55.00	55.00-75.00	-	> 75.00
Soil depth (cm)	> 150.00	150.00-120.00	120.00-100.00	100.00-80.00	-	< 80.00
Soil fertility (f)						
CEC (cmol kg^{-1})	> 10.00	8.00-10.00	6.00-8.00	< 6.00	-	-
BS (%)	> 35.00	20.00-35.00	> 20.00	-	-	-
pH (H_2O)	7.2-7.0, 7.2-7.5	7.0-6.2, 7.5-8.0	6.2-5.8, 8.0-8.2	5.8-5.5, 8.2-8.5	< 5.5	> 8.5
Mg:K	> 3.50	>3.50	2.00-3.50	1.00-2.00	-	-
Organic C (%)	> 1.50	1.50-0.80	0.80-0.40	< 0.40	-	-
Alkalinity (n)						
ESP (%)	0.00-15.00	15.00-25.00	25.00-35.00	35.00-45.00	-	> 45.00

Source: Sys *et al*. (1993). MAR - mean annual rainfall, MAT - mean annual temperature, CF - coarse fragment, CEC - cation exchange capacity, BS - base saturation, ESP - exchangeable sodium percent; L - loam, SCL - sandy clay loam, CL - clay loam, C - clay, LfS - loamy fine sand, SC - sandy clay

Table 2: Land characteristics data for the soils

Pedons	MAR (mm yr^{-1})	MAT (ºC)	Slope (%)	Flooding	Drainage	Texture	CF (%)	Depth (cm)	CEC (cmol kg^{-1})	BS (%)	Mg:K	pH	OC (%)	xNa (cmol kg^{-1})	ESP (%)
IH1P1	1983.00	27.90	6.30	Fo	MWD	SCL	53.00	195.00	30.60	25.30	45.60	6.00	0.50	0.02	0.09
IH1P2	1983.00	27.90	5.00	Fo	WD	SL	40.30	150.00	32.60	26.00	39.30	6.80	1.60	0.05	0.17
IH2P1	1983.00	27.90	4.00	F3	PA	SCL	16.70	145.00	26.80	34.70	37.90	6.10	1.27	0.04	0.16
IH2P2	1983.00	27.90	4.00	F3	PD	SL	19.70	87.00	36.50	35.00	25.70	5.60	5.57	0.09	0.26
AI1P1	2258.00	27.00	5.30	Fo	WD	SL	0.70	200.00	16.70	20.70	13.80	6.30	0.50	0.03	0.22
AI1P2	2258.00	27.00	3.50	Fo	WD	SL	8.00	180.00	16.70	26.70	17.70	6.40	0.55	0.03	0.23
AI2P1	2258.00	27.00	5.20	Fo	WD	SL	8.00	120.00	26.30	18.90	7.30	6.40	0.54	0.02	0.09
AI2P2	2258.00	27.00	2.00	Fo	WD	SL	32.30	132.00	7.70	55.30	21.80	6.20	0.42	0.03	0.44
AI3P1	2258.00	27.00	4.00	F3	PA	LS	11.50	80.00	8.40	21.40	9.50	5.30	1.25	0.02	0.28
AI3P2	2258.10	27.00	4.50	F3	PD	LS	13.70	124.00	20.50	15.60	23.30	6.60	0.26	0.02	0.12
MF1P1	2894.10	27.20	4.00	Fo	WD	SL	11.30	121.00	20.90	30.10	17.40	6.10	0.55	0.02	0.12
MF1P2	2894.10	27.20	4.00	Fo	WD	SL	13.80	153.00	11.90	16.50	12.20	5.60	1.00	0.04	0.37
MF2P1	2894.10	27.20	2.00	Fo	WD	SL	24.80	161.00	44.50	20.90	42.60	5.40	1.50	0.05	0.12
MF2P2	2894.10	27.20	5.60	Fo	WD	LS	5.00	200.00	28.50	8.30	9.50	5.70	1.20	0.05	0.20
MF3P1	2894.10	27.20	0.88	F3	PA	SL	0.00	48.00	40.00	21.00	27.40	6.60	0.88	0.03	0.08
MF3P2	2894.10	27.20	4.00	F3	PA	LS	14.30	49.00	16.50	34.10	4.40	6.20	1.71	0.03	0.21

Source: Sambo *et al*. (2016). MAR - mean annual rainfall, MAT - mean annual temperature, CF - coarse fragment, ESP - exchangeable sodium percent, xNa - exchangeable sodium, MWD - moderately well drained, WD - well drained, PA - poor aeric, PD - poor drainable, Fo - no flooding, F3 - severe (every year of 2 to 3 months of flood), SCL - sandy clay loam, SL - sandy loam, LS - loamy sand

Table 3: Suitability classification and scores of the pedons for oil palm cultivation

Pedons	MAR (mm year^{-1})	MAT (°C)	Slope (%)	Flooding	Drainage	Texture	CF (%)	Depth (cm)	CEC (cmol kg^{-1})	*BS (%)	*pH	*OC (%)	Mg:K	ESP (%)
IH1P1	S_1 (94.00)	S_1 (100.00)	S_1 (91.00)	S_1 (100.00)	S_1 (97.00)	S_1 (98.00)	S_2 (76.00)	S_1 (100.00)	S_1 (100.00)	S_1 (88.00)	S_2 (82.00)	S_2 (72.00)	S_1 (100.00)	S_1 (100.00)
IH1P2	S_1 (94.00)	S_1 (100.00)	S_1 (92.00)	S_1 (100.00)	S_1 (97.00)	S_1 (96.00)	S_2 (80.00)	S_1 (100.00)	S_1 (100.00)	S_1 (89.00)	S_1 (93.00)	S_1 (100.00)	S_1 (100.00)	S_1 (100.00)
IH2P1	S_1 (94.00)	S_1 (100.00)	S_1 (95.00)	N_1 (35.00)	S_3 (50.00)	S_1 (98.00)	S_1 (92.00)	S_1 (90.00)	S_1 (100.00)	S_1 (98.00)	S_2 (84.00)	S_1 (90.00)	S_1 (100.00)	S_1 (100.00)
IH2P2	S_1 (94.00)	S_1 (100.00)	S_1 (95.00)	N_1 (35.00)	N_1 (38.00)	S_1 (96.00)	S_1 (89.00)	S_3 (48.00)	S_1 (100.00)	S_1 (100.00)	S_3 (58.00)	S_1 (100.00)	S_1 (100.00)	S_1 (100.00)
AI1P1	S_1 (100.00)	S_1 (100.00)	S_1 (94.00)	S_1 (100.00)	S_1 (100.00)	S_1 (96.00)	S_1 (100.00)	S_1 (100.00)	S_1 (100.00)	S_1 (85.00)	S_1 (87.00)	S_2 (72.00)	S_1 (100.00)	S_1 (100.00)
AI1P2	S_1 (100.00)	S_1 (100.00)	S_1 (97.00)	S_1 (100.00)	S_1 (100.00)	S_1 (96.00)	S_1 (98.00)	S_1 (100.00)	S_1 (100.00)	S_1 (89.00)	S_1 (90.00)	S_2 (75.00)	S_1 (100.00)	S_1 (100.00)
AI2P1	S_1 (100.00)	S_1 (100.00)	S_1 (94.00)	S_1 (100.00)	S_1 (100.00)	S_1 (96.00)	S_1 (98.00)	S_1 (88.00)	S_1 (100.00)	S_2 (80.00)	S_1 (90.00)	S_2 (75.00)	S_1 (100.00)	S_1 (100.00)
AI2P2	S_1 (100.00)	S_1 (100.00)	S_1 (100.00)	S_1 (100.00)	S_1 (100.00)	S_1 (96.00)	S_1 (90.00)	S_1 (90.00)	S_2 (80.00)	S_1 (100.00)	S_1 (86.00)	S_2 (70.00)	S_1 (100.00)	S_1 (100.00)
AI3P1	S_1 (100.00)	S_1 (100.00)	S_1 (95.00)	N_1 (37.00)	S_3 (50.00)	S_1 (90.00)	S_1 (97.00)	S_3 (40.00)	S_1 (88.00)	S_2 (83.00)	N_1 (35.00)	S_1 (89.00)	S_1 (100.00)	S_1 (100.00)
AI3P2	S_1 (100.00)	S_1 (100.00)	S_1 (94.00)	N_1 (37.00)	N_1 (38.00)	S_1 (90.00)	S_1 (95.00)	S_1 (87.00)	S_1 (100.00)	S_2 (70.00)	S_1 (90.00)	N_1 (30.00)	S_1 (100.00)	S_1 (100.00)
MF1P1	S_1 (100.00)	S_1 (100.00)	S_1 (95.00)	S_1 (100.00)	S_1 (100.00)	S_1 (96.00)	S_1 (97.00)	S_1 (89.00)	S_1 (100.00)	S_1 (90.00)	S_2 (84.00)	S_2 (75.00)	S_1 (100.00)	S_1 (100.00)
MF1P2	S_1 (100.00)	S_1 (100.00)	S_1 (95.00)	S_1 (100.00)	S_1 (100.00)	S_1 (96.00)	S_1 (96.00)	S_1 (100.00)	S_1 (100.00)	S_2 (70.00)	S_3 (58.00)	S_1 (90.00)	S_1 (100.00)	S_1 (100.00)
MF2P1	S_1 (100.00)	S_1 (100.00)	S_1 (100.00)	S_1 (100.00)	S_1 (100.00)	S_1 (96.00)	S_1 (92.00)	S_1 (100.00)	S_1 (100.00)	S_1 (85.00)	S_3 (56.00)	S_1 (100.00)	S_1 (100.00)	S_1 (100.00)
MF2P2	S_1 (100.00)	S_1 (100.00)	S_1 (93.00)	S_1 (100.00)	S_1 (100.00)	S_1 (90.00)	S_1 (99.00)	S_1 (100.00)	S_1 (100.00)	S_3 (40.00)	S_3 (60.00)	S_1 (93.00)	S_1 (100.00)	S_1 (100.00)
MF3P1	S_1 (100.00)	S_1 (100.00)	S_1 (100.00)	N_1 (36.00)	S_3 (50.00)	S_1 (96.00)	S_1 (100.00)	N_1 (30.00)	S_1 (100.00)	S_1 (86.00)	S_1 (90.00)	S_1 (85.00)	S_1 (100.00)	S_1 (100.00)
MF3P2	S_1 (100.00)	S_1 (100.00)	S_1 (95.00)	N_1 (36.00)	S_3 (50.00)	S_1 (90.00)	S_1 (96.00)	N_1 (31.00)	S_1 (100.00)	S_1 (93.00)	S_1 (86.00)	S_1 (100.00)	S_1 (100.00)	S_1 (100.00)

MAR – mean annual rainfall, MAT - mean annual temperature, CF - coarse fragment, BS - base saturation, OC - organic carbon, ESP - exchangeable sodium percent;
S_1 - highly suitable, S_2 - moderately suitable, S_3 - marginally suitable, N_1 - currently not suitable, N_2 - permanently not suitable, CEC - cation exchange capacity, *chemical properties that are easily altered.

Table 4: Aggregate suitability and classification of the pedons for oil palm cultivation

	IH1P1	IH1P2	IH2P1	IH2P2	AI1P1	AI1P2	AI2P1	AI2P2	AI3P1	AI3P2	MF1P1	MF1P2	MF2P1	MF2P2	MF3P1	MF3P2
Potential																
Parametric	S_2 (69.20)	S_2 (73.30)	S_3 (31.40)	N (22.90)	S_1 (92.00)	S_2 (72.40)	S_1 (85.30)	S_1 (75.90)	N (21.40)	S_3 (33.50)	S_1 (86.70)	S_1 (93.10)	S_1 (92.00)	S_1 (86.80)	N (18.00)	N (18.10)
Non-parametric	S_2s	S_2s	S_3w	S_3ws	S_1	S_1	S_1	S_1	S_3ws	S_3w	S_1	S_1	S_1	S_1	S_3ws	S_3ws
Current																
Parametric	S_2 (57.20)	S_2 (69.10)	S_3 (28.80)	N (17.50)	S_2 (68.40)	S_2 (72.40)	S_2 (68.20)	S_2 (66.40)	N (13.10)	N (16.50)	S_2 (69.00)	S_2 (55.40)	S_2 (53.70)	S_3 (36.60)	N (16.60)	N (16.80)
Non-parametric	S_2sf	S_2s	S_3wf	N_1wsf	S_2f	S_2f	S_2f	S_2f	N_1wsf	N_1wf	S_2f	S_2f	S_2f	S_3f	N_1ws	N_1ws

Source: Ogunkunle (1993). Definition of suitability classes: S1 (100.00-75.00), S2 (74.00-50.00), S3 (49.00-25.00), N (24.00-0.00);
S_1 - highly suitable, S_2 - moderately suitable, S_3 - marginally suitable, N_1 - currently not suitable, N_2 - permanently not suitable;
s - physical soil limitation, w - wetness limitation, f - fertility limitation

Base saturation was optimum in the entire soils with a suitability class score of S_1 (85.00-100.00) except for soils in AI2P2, AI3P1, AI3P2 and MF1P2 (S_2; 70.00-83.00) and MF2P2 (S_3; 40.00) which had slight and severe limitations. Soil pH was optimum in IH1P2, AI1P1, AI1P2, AI2P1, AI2P2, AI3P2, MF3P1 and MF3P2 with suitability class scores of S_1 (86.00-93.00) and without obvious limitations to oil palm cultivation. Similarly, IH1P1, IH2P2 and MF1P1 were moderately suitable (S_2) and rated from 82.00 to 84.00, with slight limitation caused by soil pH, while other soils were moderately or severely limiting in pH and rated either as S_3 (56.00-60.00) or N_1 (35.00). Organic carbon was adequate for most of the soils with suitability class scores of S_1 (85.00-100.00). Slight limitation was observed for IH1P1, AI1, AI2 and MF1P1, and a moderately suitable class (S_2) obtained. However, AI3P2 was not suitable (N_1; 30.00) in terms of organic carbon for oil palm cultivation. By the requirements of Sys *et al.* (1991), organic carbon was slight to severely limiting for oil palm cultivation, especially in the central agricultural zone.

Major Limitations to Suitability for Oil Palm Cultivation

In most of the areas in Cross River State, climate (temperature and rainfall), slope as well as soil characteristics such as Mg:K ratio, exchangeable sodium percent, texture, CF and CEC were optimum or nearly so for oil palm cultivation. The loss of K may cause severe loss in oil palm yield (Ogunkunle, 1993). The ratio of Mg:K in the soils was optimum, hence the moderately (S_2) to highly (S_1) suitable soils for oil palm cultivation except in the soils affected by wetness (IH2, AI3, MF3) or soil pH and base saturation. Sandy loam to sandy clay loam textures were obtained. Sandy clay loam texture has been recommended for optimum oil palm cultivation (Sys, 1985). Such textural class encourages soil water holding capacity, particularly in the upper 30.00 cm, where more oil palm roots are concentrated (Omoti and Ataga, 1982). Sandy and gravelly soils, when combined with poor fertility, cannot be suitable for oil palm cultivation (Ogunkunle, 1993). In the soils of Biase in Cross River State, Ofem *et al.* (2016) reported that pH (H2O), cation exchange capacity, K mole fraction and exchangeable potassium were major limitations. High rainfall (> 2000.00 mm per year), as well as sandy loam to loamy sand textures, may have been responsible for the sub-optimum base saturation in some of the soils.

Soil depth and wetness properties (drainage and flooding) were also optimum in the well-drained high elevation ranges of the soils and grossly limiting in the low elevation ranges; hence the sub-optimal drainage and flooding condition for oil palm cultivation. With unfavorable wetness condition and shallow depth, a soil can be barely suitable for oil palm cultivation. This was the case in IH2P2, AI3 and MF3. Base saturation, organic carbon and CEC were sub-optimum for oil palm cultivation in most of the soils and optimum in a few of them. When base saturation and soil pH become marginal or sub-optimum, the soil may not be economically favourable for oil palm cultivation.

Suitability Classes

Suitability classification and scores of individual pedons are presented in Table 3. The aggregate rating was done for current and potential suitability using the parametric and non-parametric methods and summarized in Table 4. In Table 3, all the pedons in the well-drained high elevation ranges (IH1, AI1, AI2, MF1, MF2) were suitable for oil palm cultivation, but to varying degrees. On the other hand, pedons in the low elevation ranges (IH2, AI3 and MF3) were either marginal or not suitable for oil palm cultivation.

Parametric Method

With the parametric method, nine (9) pedons (IH1P1, IH1P2, AI1P1, AI1P2, AI2P1, AI2P2, MF1P1, MF1P2, MF2P1) were moderately suitable (S_2) and only one (MF2P2) was marginally suitable (S_3) for soils in the high elevation ranges, currently. Furthermore, five pedons (IH2P2, AI3P1, AI3P2, MF3P1, MF3P2) in the poorly drained low elevation ranges were not suitable (N) and only one (IH2P1) was marginally suitable (S_3) for oil palm cultivation. Potentially, the pedons were more suitable with seven pedons (AI1P1, AI2P1, AI2P2, MF1P1, MF1P2, MF2P1, MF2P2) being highly suitable (S_1) and three pedons (IH1P1, IH1P2, AI1P2) being moderately suitable (S_2) in the well-drained high elevation ranges. In the poorly drained soils in the low elevation ranges, most of the pedons were not suitable (N), while only IH2P1 and AI3P2 were rated as marginally suitable (S_3).

The distribution of the entire slope transitions as well as their current and potential suitability classes by the parametric approach are as presented in Figs. 1 to 6. For soils in the northern agricultural zone, potential land suitability indicates that, 285.19 ha (42%) met the requirements for placement into land suitability class S_2 (moderately suitable), while 375.15 ha (55.2%) was classified as S_3 (marginally suitable) and only 18.76 ha (2.8%) was N (not suitable) for oil palm cultivation out of a total land area of 679.10 ha.

In the soils of central agricultural zone, potential land suitability indicates that 98.92 ha (35.4%) of the entire area was classified as highly suitable (S_1) for oil palm cultivation, while 88.36 ha (31.6%) was moderately suitable (S_2) and 74.37 ha (26.6%) was marginally suitable (S_3). Furthermore, only 18.09 ha (6.4%) of the entire 279.74 ha was not suitable (N) for oil palm cultivation. Currently, 185.53 ha (66.3%) was classified as moderately suitable (S_2) for oil palm cultivation, while 94.25 ha (33.7%) was not suitable for oil palm cultivation out of the total land area of 279.78 ha. This suggests that good soil management procedures will upgrade a great proportion of the area. This is compared to the area occupied by not suitable class (6.4%) in the potential suitability.

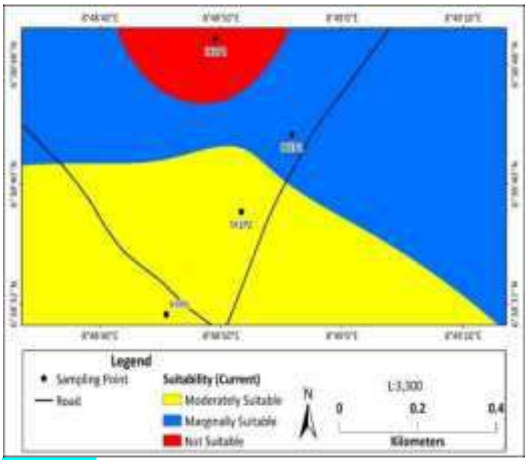

Figure 1: Distribution of current land suitability classes in the northern agricultural zone

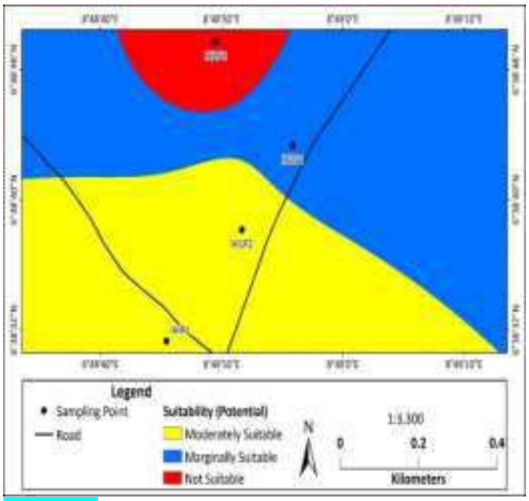

Figure 2: Distribution of potential land suitability classes in the northern agricultural zone

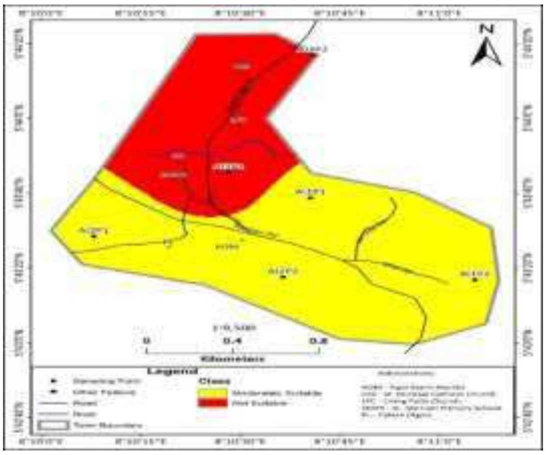

Figure 3: Distribution of current land suitability classes in the central agricultural zone

The studied soils in Mfamosing occupied a total area of 2201.65 ha; 1806.68 ha (S_1; 82.1%) of this area was highly suitable for oil palm cultivation, while only 394.97 ha (S_3; 17.9%) was marginally suitable, potentially. This area of coverage was obtained after land management procedures may have been applied. Currently, 826.34 ha (S_2; 37.5%) of the total area

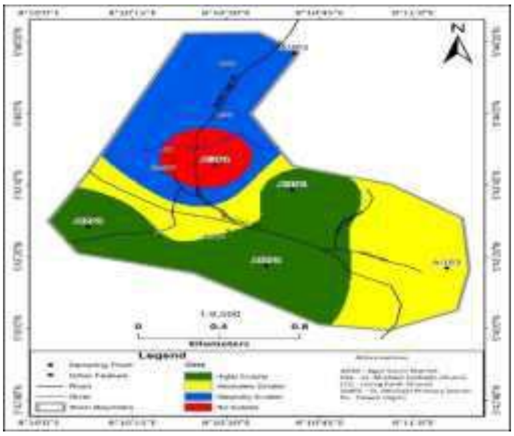

Figure 4: Distribution of potential land suitability classes in the central agricultural zone

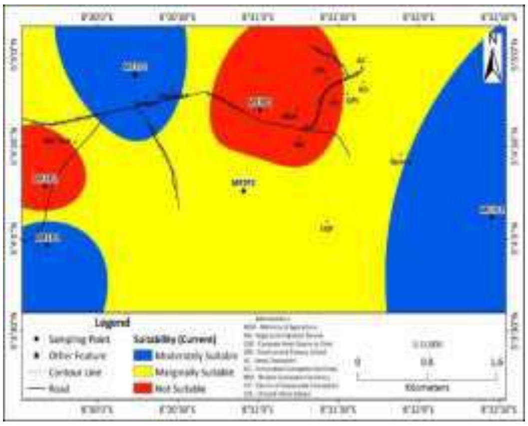

Figure 5: Distribution of current land suitability classes in the southern agricultural zone

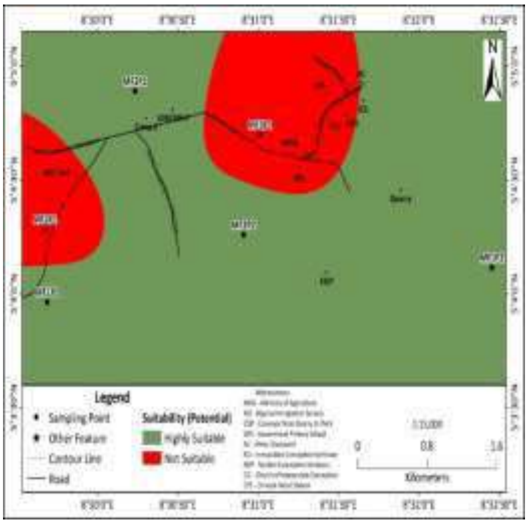

Figure 6: Distribution of potential land suitability classes in the southern agricultural zone

(2201.65 ha) was moderately suitable (S_2), while 1129.96 ha (51.3%) was marginally suitable (S_3) and 245.38 ha (11.2%) was not suitable for the cultivation of oil palm. Again, it was observed that a good percentage of soils that were currently rated marginally suitable (S_3) were later upgraded, potentially to highly suitable (S_1) mainly because the limiting properties were easily removed fertility limitations.

According to Ogunkunle (1993), the efficiency of each method (parametric and non-parametric) of land evaluation depends on the relevance of the most limiting characteristic to oil palm cultivation. Consequently, where the climate, soil physical condition or CEC is identified as the most limiting property, the non-parametric system may be most accurate (Ogunkunle, 1993). In this way, a limiting soil characteristic determines crop performance and reduces the effect of other soil properties. If soil depth or wetness is unsuitable as in the case of IH2, AI3 and MF3, then the land is unsuitable irrespective of the suitability status of soil chemical or other land qualities. If easily amended chemical properties are rather limiting, the parametric method may be a better approach (Ogunkunle, 1993). On this premise, the non-parametric method may be preferred in the low elevation soils of IH2, AI3 and MF3, while the parametric method is adopted for the well-drained soils in the upland of IH1, AI1, AI2, MF1 and MF2.

Non-Parametric Method

By the non-parametric approach, the soils were more suitable for oil palm cultivation, potentially; more than it was obtained by the parametric method. This was made possible only after the removal of limitations except in situations where the main limitation was caused by soil physical characteristics such as CF (IH1), depth or wetness (IH2, AI3, MF3). In these situations, the cost implication of removing such limitation may be more than the risk in cultivating with such limitations, if the land use type is changed to a more suitable one. For instance, in IH1P1 organic carbon content was rated S_2 (72.00) and constituted a major limitation (though slightly), while CF was rated S_2 (76.00). The IH1P1 was, therefore, classified as S_2sf, currently. Potentially, the organic carbon content of the soil may be improved by the use of organic soil amendments such as animal droppings, plant residues, compost, etc. In an earlier study, Ofem *et al.* (2016) reported that organic carbon was highly suitable for oil palm cultivation. However, it becomes difficult to remove limitations caused by CF; hence, its rating as S_2s, potentially. Similarly, the slight limitation caused by soil pH (S_2; 84) in IH2P1 can be removed by liming, while poor wetness condition may be removed by the installation of appropriate drainage facilities. This, however, is financially tasking and may not be economically feasible, especially for tree crops. The soil qualified as S_3wf (limitation due to 'f' can be removed), currently and as S_3w, potentially. The suitability class (S_3) did not change as the main limitation (wetness) was not removed in the long run. In forest and fallow plots in South-East Nigeria, Asadu *et al.* (2020) rated soil properties except cation exchange capacity as highly suitable for oil palm cultivation (currently).

For each of IH2P2 (N_1wsf), AI3P1 (N_1wsf), AI3P2 (N_1wf), MF3P1 (N_1ws) and MF3P2 (N_1ws), the soils were either limited by wetness (w), depth (s), soil pH, base saturation or organic carbon (f); currently. Potentially, all the soils were upgraded to S_3ws as fertility limitations due to pH may be removed by liming, suitable mineral fertilizer (to remove limitation due to base saturation) and organic soil amendments like compost and animal droppings (to remove limitation due to organic carbon). On the other hand, AI1P1, AI1P2, AI2P1, AI2P2, MF1P1, MF1P2 and MF2P1 were classified as S_2f in the land suitability subclass, while MF2P2 was classified as S_3f, currently. Interestingly, all the soils were limited by one kind of fertility characteristic or the other. It would therefore be easier to remove limitations due to organic carbon by the use of poultry droppings, compost or by reducing bush burning and spreading palm fronds between the rows of oil palm trees. Limitations due to soil pH and base saturation may be removed by the careful use of liming materials and suitable mineral fertilizers. The soils were therefore upgraded to highly suitable class (S_1).

Ranking the pedons for oil palm cultivation by their scores using the parametric approach (Table 3) indicated that the best 10 pedons were well-drained and found in higher elevation ranges, while the worst six of them were poorly drained, located in the lowest elevation range and influenced by regular flooding. This suggested that, wetness quality (drainage and flooding) was a major constraint to oil palm cultivation in the poorly drained soils of Cross River State. Though the tracts of land had not degraded to permanently not suitable subclass, it is recommended that the land use type of the soils in the lowest elevation range (IH2, AI3, MF3) be changed and used for more water tolerant crops. This is so because of the expenses that may be incurred during the installation of drainage facilities, if it must be used for the cultivation of oil palm. The economic implication of the installation may outweigh the benefits that will accrue from the installation process.

CONCLUSION

The study was to evaluate the suitability of land in Cross River State for for oil palm production, and make appropriate soil management recommendations for improved production. Land suitability evaluation for oil palm cultivation in Cross River State indicates suitability classes ranging from S_1 to S_2, S_3 and N by the parametric and non parametric approaches. In the northern agricultural zone, the parametric approach indicated that potentially, 42% of the soils were S_2 and 55.2% were S_3, while only 2.8% were not suitable for oil palm cultivation. For the central agricultural zone potentially, 35.4% of the soils were S_1, while 31.6% were S_2 and 26.6% were S_3. However, only

6.4% of the soils were N for oil palm cultivation. Currently, 66.3% of the soils were S_2, while 33.7% were N for the land use. In the southern agricultural zone, the parametric approach indicated that 82.1% of the soils were potentially S_1, while only 17.9% were S_3. The potential suitability classes witnessed significant improvement from the current suitability which indicated 37.5%, 51.3% and 11.2% for S_2, S_3 and N, respectively. Land suitability for oil palm cultivation increased from the northern to central and southern agricultural zone, a trend that is similar to the increase in the amount of rainfall. The poorly drained soils in the low elevations are not economical for cultivation with oil palm. The land use type should therefore be changed to crops like sugar cane and paddy rice which thrive better under such conditions.

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