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Land Suitability Evaluation Study for Oil Palm (*Elais Guineensis*) and Rubber (*Hevea Brasiliensis*) Cultivation in Esan North East Local Government Area of Edo State, Nigeria

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ABSTRACT: This study was done in Esan North East LGA of Edo Nigeria to assess the suitability of the LGA for oil palm and rubber cultivation. Methodology involved rigid grid systematic soil survey at a semi-detailed scale, which produced eight (8) mapping units. Suitable guidelines specific for each crop were used in establishing suitability of the land for oil palm and rubber. The result revealed that mapping units 1, 3, 4, 6 and 7 (82.31%) were marginally suitable (S3) for oil palm and rubber by limitation method; marginally suitable for oil palm (S3) but moderately suitable (S2) for rubber by parametric method. Mapping unit 2 (5.64%) was marginally suitable (S3) for oil palm but not suitable (N) for rubber by both methods; mapping unit 8 (4.52%) was marginally suitable (S3) by both methods; mapping unit 5 (7.52%) was not suitable (N) for oil palm by both methods, marginally suitable (S3) by limitation method, and moderately suitable (S2) by parametric method for rubber cultivation. Major limitation to cultivation of oil palm and rubber in the study area is climate, therefore, management practices such as supplementary irrigation; even though it is expensive would solve the challenge of moisture stress in the study area.

Keywords: Esan North East, Mapping unit, Oil palm, Rubber, Suitability

Introduction

To achieve sustainable management of soil resources, detailed studies through soil characterization and suitability for land use type must be done. Land suitability evaluation involves the appraisal and grouping of a specific type of land in terms of its absolute or relative suitability for a specific type of use (Ofem *et al*., 2022). A comprehensive suitability evaluation involves assessing various factors such as climate, soil properties, topography and socio-economic conditions to determine the optimal areas for cultivation and to enhance productivity.

Land suitability studies attempts to solve problems associated with land degradation and wrong allocation of land to specific use (Dent and Young 1981; Agbogun *et al*., 2021). It is the process of estimating the potential of land for alternative types of use. Land suitability classification gives information on the actual or potential fitness of a given piece of land for a defined use, and considers the economic and socio-political factors (FAO, 1976; Okunsebor *et al*., 2021).

Oil palm and rubber are two of the most economically significant crops in Nigeria, playing a crucial role in the agricultural and industrial sectors. These crops are not only vital for domestic consumption but also for export, contributing significantly to the nation's economy. Due to the tremendous advantages of oil palm and rubber in boosting both industrial and economic development, attempts have been made to increase their production especially in the Southern part of Nigeria where a good portion of the soils are of coastal plain sands origin.

Esan North East local government area is located in the southern part of Nigeria where oil palm and rubber are produced. However, the production of these crops has been affected by various challenges such as land characteristics, land degradation, low yield, and inadequate infrastructure. It is worthy of note that the absence of information on the appropriate location to be used for production of the crops (oil palm and rubber) is also a major challenge in the state. Although some researchers including Okunsebor *et al*. (2021) have made efforts to address these challenges, findings from such investigations cannot be applied to the entire state since the study areas are only portions in localized communities.

To address these challenges properly, it is important to conduct a comprehensive suitability study on the soils in Esan North East LGA, to identify suitable areas for oil palm and rubber cultivation in the local government and provide recommendations on best management practices. This study aims to bridge the knowledge gap by conducting a thorough suitability evaluation for oil palm and rubber production in the local government. Findings from this study are expected to inform policy makers, local farmers, and investors, thereby fostering the growth and development of oil palm and rubber industries in Esan North East LGA and contributing to the overall agricultural advancement of Edo state and Nigeria at large.

Materials and methods

This study was conducted in Esan North East Local Government Area of Edo state. The site lies within Latitudes 06°40' N and 06°55' N and Longitudes 06°15' E and 06°30' E. It occupies a land area of about 34, 293.1 ha (342.93 square kilometers) and an estimated population of about 195,757 (National Population Commission, 2022).

The study area has two major towns: Uromi which consists of 19 villages (Amedokhian, Arue, Awo, Efandion, Egbele , Eguare-Uromi, Eko-Ibadin, Eror, Ewoyi , Idumoza, Ivue, Obeidu, Onewa, Ubierumu Ne- Oke, Ubierumu Ne- Uwa Ukoni, Unuwazi, Utako and Uwalo); and Uzea which consists of five (5) villages (Ebun, Ebunle, Ewoiki, Olinlin and Uroh).The site is bordered by Etsako Central LGA by the North, Esan South East LGA by the South, Igueben LGA by the West and Esan Central LGA by the East; as shown in the location map (Fig. 1).

The study area is characterized by a tropical climate with an average annual rainfall amount of 1540 mm, mean temperature of 31°C and mean annual relative humidity ranging from 30.50 to 94.00% (Weppa-Wanno Farms, 2018). The rainy season is from April to October, while the dry season starts in early November and ends by March. The rainfall pattern is bimodal with peaks in July and August. However, there is a short spell in mid-August which is accompanied by few thunder storms.

The soils of Esan North East were formed from three major parent materials: IMSH- clay, shale with lime stone - Imo shale formation of the Eocene tertiary formation; BASH- clay, clay stone and shale, mainly from Bende Amaki formation of the Eocene Tertiary formation; LSR- Lignite, clay stone and clay, from lignite formation of the Oligocene Miocene tertiary formation (culled from geological map of Nigeria).

On aggregate level, the topography is a terrace, with the highest point in Uromi at 460 m ASL, gradually tapering towards Eko-Ibadin at 254 m ASL, with a steep slope towards Uzea that settled at 32 m ASL.

Generally, the area falls within the rain forest vegetation zone of the Nigeria vegetation map (F.G.N., 2002) and it includes tall forest trees, perennial crops such as oil palm, rubber, plantain, banana; arable crops such as cassava, maize, and so on.

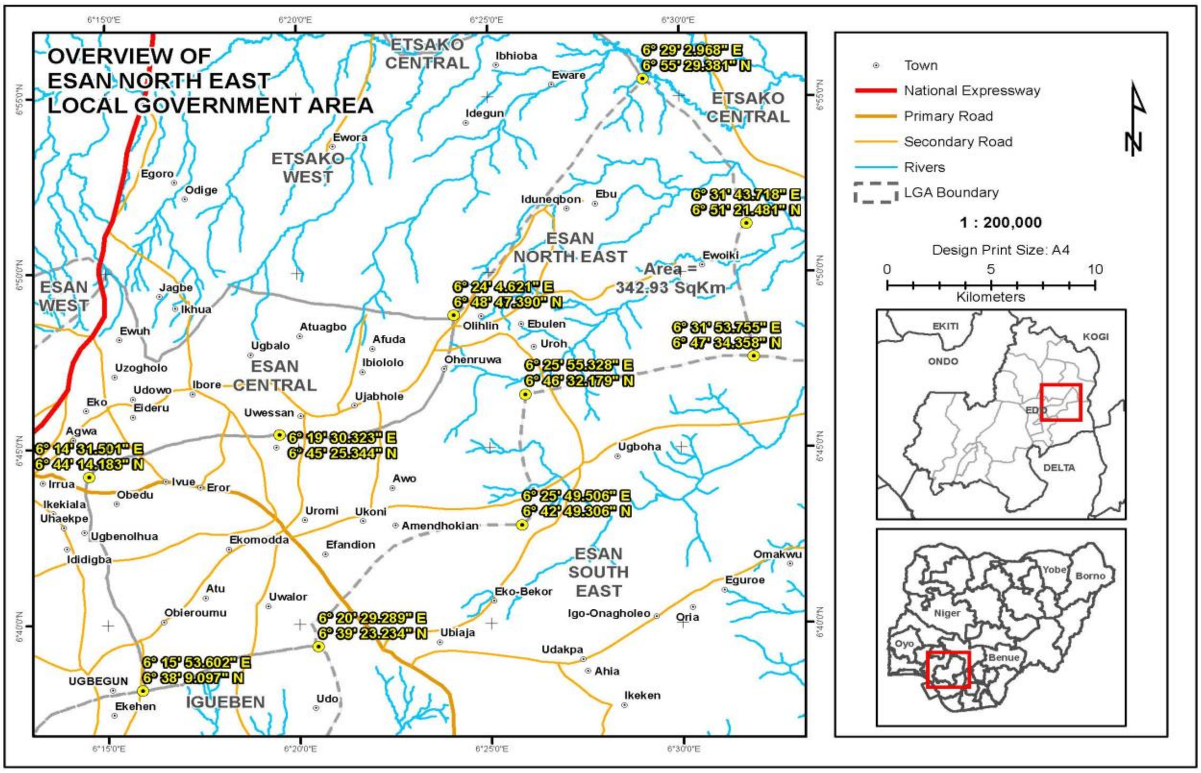

Fig. 1: Location map of Esan North East LGA ***Source***: Edo GIS Office (2020)

Field studies: Field studies involved rigid grid soil survey at a semi-detailed scale (one observation point per 50 hectares) according to Dent and Young (1981). Auger borings were done at regular intervals of 1000 m along traverses. Auger samples were examined at depth intervals of 0-30, 30-60, 60-90 and 90-120 cm respectively. The samples were described morphologically on the field (soil colour with the aid of Munsell soil colour chart (Munsell, 1994), texture and consistency by feel, presence or absence of mottles, mottle colour, presence or absence of concretions, effective soil depth, slope properties and drainage conditions). Areas with similar properties and characteristics such as slope position, texture, drainage condition and colour were grouped to produce the various soil modal classes; eight (8) modal classes were delineated. Each identified modal class was represented by a modal class profile which was described and sample (for routine analysis) according to FAO (2006). Routine samples were collected from three points in each horizon to form a composite sample.

Laboratory analyses: Routine soil samples collected from each pedon were air-dried, passed through a 2 mm sieve mesh and crushed with mortar and pestle; samples for carbon and Nitrogen determination were further sieved with a 0.5 mm sieve. The sieved samples were analysed for some physical and chemical properties. Particle size distribution was determined by the hydrometer method (Gee and Or, 2002) after the removal of organic matter content with hydrogen peroxide and dispersion with sodium hexametaphosphate (IITA, 1979). Available P was determined by Bray-1 method (Olsen and Sommers, 1982). The pH was determined with glass electrode pH meter in soil: soil and water at ratio 1:1 (Maclean, 1982). Exchangeable Bases (Na, K, Ca and Mg) were extracted with neutral normal ammonium acetate (NH_4OAC at pH 7.0); Na and K were determined by flame photometer while Ca and Mg were determined by atomic absorption spectro photometer (Thomas, 1982). Total N was determined by Macro Kjedhal method (Bremner, 1996). Exchangeable Acidity was determined by titration method (Anderson and Ingram, 1993). Organic Carbon was determined by Walkley-Black method (Page *et al*, 1982). Effective Cation Exchange Capacity (ECEC) was obtained by the summation of Exchangeable Bases and Exchangeable Acidity (Tan, 1996). Base Saturation was calculated by dividing the sum of Exchangeable Bases (Na, K, Ca and Mg) by the ECEC and multiplying the quotient by 100.

Statistical analysis: Statistical analysis was done with GENSTAT (8.1) version. Variability of soil properties of horizons within the pedons was determined using coefficient of variation (CV). Coefficient of variation was ranked according to the procedure of Wilding *et al.* (1994) where:

CV < 15% = Low Variation (LV)

15% ≥CV ≤ 35% = Moderate Variation (MV)

CV > 35% =High Variation (HV)

Soil map: Soil map of the study area was produced at a semi-detailed scale, based on the field observation and laboratory results.
Soil classification: Soils of the identified mapping units were classified according to USDA soil taxonomy (Soil Survey Staff, 2014) based on their morphological, physical and chemical properties.
Land evaluation: Land evaluation was done by using both limitation and parametric (index of productivity) (Storie, 1976; Ogunkunle, 1993) methods of the FAO (1976) framework for rain fed agriculture. Pedons were placed in suitability classes by matching their characteristics/qualities with the established requirements for oil palm and rubber production provided by Sys (1985) as modified by Oko-oboh *et al*. (2018) for oil palm, and Bhermana *et al*. (2013) for rubber. Aggregate suitability class of a pedon (aggregate suitability) was obtained by picking the poorest or most limiting characteristic of the pedon. The land qualities considered for evaluation of oil palm and rubber were climate (c), topography (t), wetness (w), soil physical characteristics (s) and fertility characteristics (f). Parametric method was done by calculating the index of productivity using the Square root model (Storie, 1976). Scores were given to the land qualities of each pedon and index of productivity was calculated using the formula:

$$IPc = \underset{(c)}{A}\sqrt{(\underset{(t)}{B}/100 * \underset{(w)}{C}/100 * \underset{(s)}{D}/100 * \underset{(f)}{E}/100)} \text{-------(Eq. 2) (Sys 1985)}$$

where IPc = index of productivity, √ = square root, A is the overall least characteristic rating, B,C----E is the least rating characteristic for each land group quality;
c = climate, t = topography, w = wetness, s = slope, f = fertility.

Each characteristic was first rated as follows:

Extent of limitation	Range	Suitability class
No limitation	100-85	S1
Moderate limitation	84-60	S2
Severe limitation	59-40	S3
Very severe limitation	39-0	N

Source: Ogunkunle (1993)

The index of productivity for each pedon was expressed from the rating of each characteristic of the land qualities of each group, using the lowest rating.
Index of productivity was rated into classes as follows:

Range	Suitability class
100-75	Highly suitable (S1)
74-50	Moderately suitable S2
49-25	Marginally suitable S3
24-0	Non suitable (N)

Source: Ogunkunle (1993)

Pedons were placed in suitability classes by comparing their land qualities and characteristics with the guideline. The suitability class of a pedon (aggregate suitability) is that indicated by the most limiting (poorest) characteristics of that pedon (FAO, 1984). Suitability classes were indicated in descending order of usefulness as S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable) and N (not suitable).

Results

Some physical and chemical results of the pedons are shown in tables 1 and 2. The study area had colours ranging from red to yellowish brown (2.5YR, 5YR, to 7.5YR). Textural class for pedons 1, 7 and 8 was Sand – Loamy sand in surface horizons but Sandy loam in pedons 2,3,4,5 and 6; while that of sub-surface horizons varied from sandy loam to clay (except for pedons 7 and 8 with sandy clay loam texture). Structure at surface horizon for most of the pedons was very fine sub-angular blocky except for pedon 8 (single grain crumb) while subsurface horizons for all the pedons had medium sub-angular blocky structure. Root abundance for surface horizons was few in pedon 5, many in pedon 7, common in pedons 1and 3, and ranged from few to many in pedons 2, 4, 6 and 8 while for sub surface horizons, it was few in pedons 2, 3, 4, 6, 7 and 8; ranged from few to common in pedon 1 and nil in pedon 5.
Sand fraction was highest among particle size fractions with means ≤ 570 gkg^{-1} ≥ 808 gkg^{-1} and had variation (≤ 11.10 gkg^{-1} ≥ 29.30 gkg^{-1}) ranging from low (pedons 7 and 8) to medium (pedons 1, 2, 3, 4, 5 and 6) which confirms the heterogeneity of parent material in the study area. Silt fraction had the least values with means ≤ 17.50 gkg^{-1} ≥ 134 gkg^{-1} and variation (≤ 13.6 gkg^{-1} ≥ 73.90 gkg^{-1}) ranging from low (pedon 8) – medium (pedons 2, 4 5) – high (pedons 1,3,6 and 7). Sand fraction was highest among particle size fractions with means

≤ 570 gkg^{-1} ≥ 808 gkg^{-1} and had variation (≤ 11.10% ≥ 29.30%). Silt fraction had the least values with means ≤ 17.50 gkg^{-1} ≥ 134 gkg^{-1} and variation (≤ 13.6% ≥ 73.90%). Clay fraction had means ≤ 164.00 gkg^{-1} ≥ 392.00 gkg^{-1} and variation ranging from ≤ 38.70% ≥ 68.80%. Means of soil pH varied from ≤ 4.49 to ≥ 6.09 in all the pedons; coefficient of variation for soil pH ranged from ≤ 1.10% to ≥ 18.2%. Organic carbon content had means ranging from ≤ 0.38 gkg^{-1} to ≥ 8.20 gkg^{-1}; coefficient of variation ranged from ≤ 38.70% to ≥ 68.80%. Means of Nitrogen ranged from ≤ 0.04 gkg^{-1} to ≥ 0.35 gkg^{-1}, with variation ranging from ≤ 51.30% to ≥ 120.90%. Means of ECEC (clay) ranged from ≤ 24.20 $cmolkg^{-1}$ to ≥ 40.00 $cmolkg^{-1}$; coefficient of variation ranged from ≤ 50.1% to ≥ 79.90%. Mean values for base saturation varied from ≤ 69.10% to ≥ 94.60%; while coefficient of variation ranged from ≤ 1.80% to ≥ 26.50% in the study area.

Table 1: Some morphological properties of the study area

Pedon	Horizon Design	Depth (cm)	Colour (moist)	Texture	Roots Abundance	Structure	Boundary form
1	A_p	0-11	2.5YR3/2	Loamy Sand	Very fine common	Very fine Single grain crumb	Smooth-Clear
	Bt	11-30	2.5YR4/6	Sandy clay Loam	Very fine common	Fine Sub-Angular blocky	Smooth-Gradual
	Bth	30-67	2.5YR5/6	Sandy clay	Very fine few	Medium/coarse Sub-Angular blocky	Smooth-Diffuse
	Bt_2	67-108	2.5YR5/6	Sandy clay	-	Medium/coarse Sub-Angular blocky	Smooth-Diffuse
	Bt_3	108-144	2.5YR5/8	Sandy clay	-	Medium Sub-Angular blocky	Smooth-Diffuse
	Bt_4	144-180	2.5YR5/8	Sandy clay	-	Fine Sub-Angular blocky	
2	A_p	0-16	2.5YR3/2	Sandy Loam	Fine many	Very fine Sub-Angular blocky	Smooth-Clear
	AB	16-63	2.5YR4/6	Sandy clay	Medium few/coarse very few	Fine/Medium Sub-Angular blocky	Smooth-Diffuse
	Bw1	63-113	2.5YR4/8	Sandy clay	Coarse very few	Medium Sub-Angular blocky	Smooth-Diffuse
	Bw2	113-176	2.5YR4/8	Sandy clay	Fine very few	Fine Sub-Angular blocky	-
	A	0-12	2.5YR3/2	Sandy Loam	Medium common	Very Fine Sub-Angular blocky	Smooth-Clear
3	BA	12-40	2.5YR4/4	Sandy Loam	Medium common	Very Fine Sub-Angular blocky	Smooth-Diffuse
	Bt1	40-90	2.5YR4/8	Clay	Fine- few	Fine Sub-Angular blocky	Smooth-Diffuse
	Bt2h	90-141	2.5YR4/8	Sandy clay	Fine- very few	Fine Sub-Angular blocky	Smooth-Diffuse
	Bt3h	141-177	2.5YR4/8	Clay	-	Medium Sub-Angular blocky	-
4	A_p	0-18	7.5YR3/2	Lomy Sand	Fine many	Very Fine Sub-Angular blocky	Smooth-Clear
	A	18-45	5YR4/3	Sand	Medium many	Very Fine Sub-Angular blocky	Smooth-clear
	AB	45-67	5YR4/6	Clay	Medium few	Fine Sub-Angular blocky	Smooth-Diffuse
	Bth	67-105	5YR5/6	Clay	Fine few	Fine Sub-Angular blocky	Smooth-Diffuse
	Bthc	105-145	5YR5/6	Clay	Fine few	Fine Sub-Angular blocky	-
5	Ap	0-10	7.5YR3/2	Sandy Loam	Fine many/ Coarse few	Very fine Single grain crumb	Smooth-diffuse
	A	10-21	7.5YR5/4	Sandy Loam	Fine many/Coarse few	Fine Sub-Angular blocky	Smooth-clear
	Bt1hc	21-63	7.5YR5/6	Clay	Very fine-very few	Fine massive granular	Smooth-diffuse
	Bt2c	63-140	7.5YR5/6	Sandy Clay	-	Fine massive granular	-
	Ap	0-24	7.5YR3/2	Loamy Sand	Fine many/Medium coarse	Very Fine Sub-Angular blocky	Smooth-clear
6	A	24-37	7.5YR4/3	Sandy loam	Fine common	Very Fine Sub-Angular blocky	Smooth-clear
	AB	37-68	7.5YR4/6	Loamy Sand	Fine few	Fine Sub-Angular blocky	Smooth-Diffuse
	Bt	68-120	2.5YR4/6	Sandy Clay	Fine very few	Fine Sub-Angular blocky	Smooth-Diffuse
	Bt2h	120-160	2.5YR4/8	Sandy Clay	-	Fine Sub-Angular blocky	Smooth-Diffuse
	Bt3	160-190	2.5YR5/6	Sandy Clay	-	Fine Sub-Angular blocky	-
	A_p	0-10	5YR3/2	Loamy Sand	Fine many	Very Fine Sub-Angular blocky	Smooth-Clear
7	A	10-32	2.5YR4/4	Sandy Loam	Fine many	Very Fine Sub-Angular blocky	Smooth-Diffuse
	Bw_1	32-80	2.5YR4/6	Sandy Clay Loam	Fine few	Fine Sub-Angular blocky	Smooth-Diffuse
	Bw_2	80-137	2.5YR4/6	Sandy Clay Loam	Medium few	Fine Sub-Angular blocky	Smooth-Diffuse
	Bw_3h	137-192	2.5YR4/6	Sandy Clay Loam		Fine Sub-Angular blocky	
	A_p	0-17	5YR3/3	Sand	Medium many	Very fine Single grain crumb	Smooth-Clear
8	A	17-48	5YR5/6	Sand/Loamy Sand	Medium common/fine many	Very fine Single grain crumb /Fine Sub-Angular blocky	Smooth-Diffuse
	AB	48-98	5YR6/6	Loamy Sand	Fine few	Fine Sub-Angular blocky	Smooth-Diffuse
	Bt	98-133	5YR6/6	Sandy clay loam	Fine few	Fine Sub-Angular blocky	Smooth-Diffuse
	Bth	133-182	5YR6/6	Sandy clay loam	Very Fine few	Fine Sub-Angular blocky	-

Table 2: Some physical and chemical properties of the study area

Pedon ID	Horizon Depth (cm)	Horizon ID	pH H_2O	E µS/cm	Org. C	O.M	N	Av. P	Ca	Mg	Na	K	Al	H	ECEC (Soil)	CEC	ECEC (Clay)	BS (%)	Sand	Silt	Clay	Textural Class
					← gkg^{-1} →			mgk^{-1}	← cmolkg^{-1} →										← gkg^{-1} →			
				06.72760°N', 006.27085°E; 422 m ASL																		
	0-11	Ap	4.75	13.00	12.30	21.10	2.97	13.26	4.14	1.03	0.67	0.16	0.00	0.80	6.46	10.72	49.69	88.19	840.00	30.00	130.00	LS
1	11-30	Bt1	6.06	10.00	4.90	8.40	1.20	4.45	3.65	0.96	0.70	0.22	0.00	0.60	6.13	18.14	23.57	89.76	690.00	50.00	260.00	SCL
	30-67	Bt2h	4.34	05.00	5.90	10.10	1.40	4.31	4.17	0.93	0.70	0.14	0.00	0.80	6.74	26.54	13.76	88.19	500.00	10.00	490.00	SC
	67-108	Bt3	4.86	04.00	4.10	7.10	1.00	2.03	3.04	0.89	0.61	0.14	0.00	1.20	5.88	25.40	11.76	79.52	490.00	10.00	500.00	SC
	108-144	Bt4	4.38	05.00	2.30	3.90	0.60	4.84	2.84	0.90	0.63	0.13	0.00	0.80	5.30	25.28	10.82	84.92	490.00	20.00	490.00	SC
	144-180	Bt5	6.60	02.00	1.60	2.80	0.40	4.60	2.53	0.90	0.65	0.22	0.00	0.80	5.10	24.56	10.63	84.34	510.00	10.00	480.00	SC
		Mean	5.16	6.5.00	0.52	1.18	0.13	5.56	3.40	0.94	0.66	0.17	0.00	0.83	7.010	21.80	20.50	85.80	587.00	21.70	392.00	
		Cv	18.2	63.60	74.00	80.40	72.6	69.80	20.40	5.70	0.56	24.50	23.00	23.60	10.80	28.20	79.90	4.30	24.90	73.90	40.30	
		Ranking	MV	HV	HV	HV	HV	HV	MV	LV	LV	LV	MV	MV	LV	MV	HV	LV	MV	HV	HV	
				06.64651°N, 006.27185°E; 294 m ASL																		
2	0-16	Ap	4.76	19.00	3.20	5.50	0.08	12.87	7.67	1.04	0.69	0.19	0.00	0.80	10.39	9.60	59.06	92.30	810.00	20.00	170.00	SL
	16-63	AB	4.44	8.00	5.90	10.15	0.14	2.42	4.84	0.96	0.67	0.16	0.00	0.60	7.23	22.52	17.68	91.77	570.00	20.00	410.00	SC
	63-113	Bw1	4.15	8.00	3.20	5.50	0.09	2.73	4.04	0.89	0.82	0.56	0.00	0.40	6.71	27.10	13.69	94.35	470.00	10.00	520.00	SC
	113-176	Bw2	4.62	7.00	3.00	5.20	0.73	2.96	2.38	0.86	0.87	0.54	0.00	0.60	5.25	21.54	56.72	88.59	570.00	20.00	410.00	SC
		Mean	4.49	10.50	0.38	0.66	0.26	5.20	4.7	0.94	0.76	0.36	0.00	0.60	7.40	20.20	37.00	92.60	605.00	17.50	378.00	
		Cv	5.90	54.20	36.20	35.80	120.90	97.00	46.70	8.40	12.80	59.90	27.20	27.20	29.20	37.00	66.40	3.30	23.90	28.60	39.10	
		Ranking	LV	HV	HV	HV	HV	HV	HV	LV	LV	HV	MV	MV	MV	HV	HV	LV	MV	MV	HV	
				06.67810°N , 006.29832°E; 359 m ASL																		
3	0-12	A	4.85	28.00	9.20	15.82	0.22	23.23	4.25	1.01	0.74	0.18	0.00	1.0	7.18	12.16	39.94	86.13	780	40	180	SL
	12-40	BA	4.04	6.00	0.90	1.53	0.02	4.99	2.62	0.76	0.67	0.14	0.00	2.6	6.79	9.80	41.00	53.81	800	10	190	SL
	40-90	Bt1	4.68	6.00	2.30	3.95	0.06	3.12	2.68	0.76	0.69	0.16	0.00	2.6	7.90	27.30	14.91	54.38	450	20	530	C
	90-141	Bt2h	4.52	5.00	5.10	8.77	0.12	3.43	2.87	0.81	0.79	0.21	0.00	2.2	6.88	26.26	16.06	59.37	470	40	490	SC
	141-177	Bt3h	4.90	5.00	9.00	15.48	0.22	2.96	2.65	0.77	0.70	0.22	0.00	0.4	4.74	29.60	8.92	91.63	450	20	530	C
		Mean	4.60	10.00	2.10	3.70	0.13	7.60	3.01	0.82	0.62	0.28	0.00	1.76	6.70	21.00	24.20	69.10	590.00	26.00	384.00	
		CV	7.50	100.70	178.70	178.5	71.30	116.9	23.20	13.00	36.90	85.40	23.00	57.00	17.60	44.20	62.60	26.50	31.00	51.60	47.50	
		Ranking	LV	HV	HV	HV	HV	HV	MV	LV	HV	HV	LV	HV	MV	HV	HV	MV	MV	HV	HV	
				06.88249°N, 006.45096°E; 74 m ASL																		
4	0-18	Ap	5.24	13.00	3.20	5.50	0.09	13.34	4.46	0.92	0.77	0.21	0.00	0.40	6.75	6.60	61.36	94.12	730	160	110	SL
	18-45	A	4.63	16.00	2.40	4.13	0.06	4.37	3.63	0.93	0.80	0.25	0.00	0.40	6.01	8.82	37.56	93.41	710	130	160	SL
	45-67	AB	4.16	5.00	3.40	5.85	0.08	3.74	3.71	1.01	0.70	0.18	0.00	1.14	6.80	7.66	20.61	82.37	530	140	330	SCL
	67-105	Bth	4.47	7.00	5.20	8.94	0.13	2.81	3.49	0.91	0.69	0.18	0.00	0.6	5.87	22.28	14.32	53.37	430	160	410	C
	105-145	Bthc	4.40	4.00	1.73	2.98	0.42	1.87	3.79	0.90	0.74	0.17	0.00	0.4	5.60	26.96	14.31	93.38	450	130	420	C
		Mean	4.58	9.00	1.19	5.50	0.16	5.20	3.82	0.93	0.20	0.74	0.00	0.59	6.21	14.50	29.60	83.30	570.00	134.00	286.00	
		CV	8.90	58.30	41.00	41.00	96.00	88.70	9.90	4.70	16.50	6.30	54.5	54.50	8.70	65.30	67.90	20.90	24.90	13.60	50.10	
		Ranking	LV	HV	HV	HV	HV	HV	LV	LV	MV	LV	HV	HV	LV	HV	HV	MV	MV	LV	HV	
				06.85489°N, 006.47786°E; 60 m ASL																		
5	0-10	Ap	5.53	28.00	13.1	22.50	0.32	105.85	9.01	1.06	0.70	0.21	0.00	0.60	11.58	13.00	68.12	94.78	760	70	170	SL
	10-21	A	4.53	9.00	5.80	9.90	0.76	10.14	3.89	0.95	0.78	0.36	0.00	0.40	6.37	9.66	37.47	93.77	740	90	170	SL
	21-63	Bt1hc	4.83	12.00	8.60	14.80	0.21	8.58	4.18	1.02	0.77	0.25	1.40	0.60	10.22	28.96	19.65	60.38	420	60	520	C
	63-140	Bt2c	5.07	4.00	5.40	9.30	0.13	4.52	4.54	1.04	0.79	0.83	0.00	0.40	7.15	20.86	18.82	94.42	510	110	380	SC

Pedon ID	Horizon Depth (cm)	Horizon ID	pH H_2O	E µS/cm	Org. C			O.M	N								Av. P	Ca	Mg			Na	K
					← gkg^{-1} →			mgk^{-1}	← cmolkg^{-1} →										← gkg^{-1} →				
		Mean	4.99	13.20	8.20	14.10	0.35	32.0	5.40	1.01	0.41	0.76	0.35	0.50	8.80	18.10	36.00	85.80	608.00	82.00	310.00		
		CV	8.70	78.30	43.10	43.20	79.20	152.2	44.70	4.70	69.20	5.40	200.00	23.10	28.00	47.60	64.00	19.80	27.80	26.90	55.30		
		Ranking	LV	HV	HV	HV	HV	HV	HV	LV	HV	LV	HV	HV	MV	HV	HV	MV	MV	MV	HV		
				06.81487°N , 006.43285°E; 148 m ASL																			
6	0-24	Ap	6.08	3.00	2.40	4.10	0.06	57.25	7.36	1.00	0.70	0.19	0.00	0.60	9.85	8.32	65.87	93.88	830	20	150	SL	
	24-37	A	5.92	7.00	1.40	2.40	0.01	17.47	3.82	0.84	0.73	0.22	0.00	0.60	6.21	4.98	69.00	90.34	870	40	90	LS	
	37-68	AB	5.42	13.00	2.30	3.90	0.06	9.20	3.23	0.82	0.78	0.34	0.00	0.4	5.57	7.28	42.87	92.80	830	40	130	SL	
	68-120	Bt1	5.07	13.00	1.10	1.90	0.03	13.49	3.35	0.84	0.71	0.21	0.00	0.4	5.51	20.88	13.44	92.70	570	20	410	SC	
	120-160	Bt2h	5.40	5.00	2.40	4.10	0.06	11.06	3.68	0.83	0.70	0.15	1.40	0.60	5.96	20.32	15.28	89.97	590	20	390	SC	
	160-190	Bt3	5.24	5.00	1.40	2.40	0.03	5.54	3.97	0.86	0.78	0.19	0.00	0.40	6.00	26.32	11.76	93.35	470	20	510	SC	
		Mean	5.52	7.70	1.83	3.13	0.04	19.00	4.24	0.87	0.22	0.73	0.23	0.50	6.52	14.70	36.00	92.70	740.00	26.70	280.00		
		CV	7.10	56.40	32.50	32.10	51.30	100.80	36.70	7.80	30.00	5.20	244.90	21.90	25.40	60.50	73.30	1.80	22.70	38.70	63.40		
		Ranking	LV	HV	MV	MV	HV	HV	HV	LV	MV	LV	HV	MV	MV	HV	HV	LV	MV	HV	HV		
				06.79178°N , 006.44225°E; 112 m ASL																			
7	0-10	Ap	6.18	39.00	4.7	8.10	0.11	17.94	7.73	1.01	0.75	0.19	0.00	0.40	10.08	7.12	91.64	95.99	830.00	60.00	110.00	LS	
	10-32	A	6.07	18.00	2.70	4.60	0.06	6.01	4.26	0.90	0.69	0.16	0.00	0.60	6.61	10.42	37.79	90.97	770.00	40.00	190.00	SL	
	32-80	Bw1	5.99	6.00	0.20	0.30	0.02	3.04	4.73	0.91	0.79	0.41	0.00	0.40	7.23	13.56	26.78	94.51	720.00	10.00	270.00	SCL	
	80-137	Bw2	6.10	5.00	0.60	1.00	0.01	2.03	4.89	0.90	0.70	0.17	0.00	0.40	7.06	16.70	21.39	94.28	650.00	20.00	330.00	SCL	
		Mean	6.09	15.00	3.40	5.90	0.08	6.50	5.22	0.93	0.25	0.74	0.00	0.40	7.50	13.50	40.00	94.60	722.00	32.00	246.00		
		CV	1.10	96.00	103.90	104.6	101.90	100.0	27.20	5.1	44.40	6.10	35.40	35.40	19.10	36.60	75.50	2.40	11.10	60.10	38.70		
		Ranking	LV	HV	HV	HV	HV	HV	MV	LV	HV	LV	MV	MV	MV	HV	HV	LV	LV	HV	HV		
					06.72400°N, 006.43356°E; 132 m ASL																		
8	0-10	Ap	5.95	18.00	8.90	15.30	0.22	25.97	4.75	0.96	0.67	0.17	0.00	0.40	6.94	8.06	69.4	94.28	920.00	30.00	50.00	S	
	10-32	A	5.45	7.00	3.20	5.50	0.08	5.77	3.61	0.82	0.65	0.16	0.00	0.60	5.84	8.60	38.93	89.78	870.00	30.00	100.00	LS	
	32-80	AB	5.31	5.00	1.10	1.90	0.03	6.01	3.32	0.79	0.66	0.13	0.00	1.20	6.09	10.50	29.00	80.33	850.00	40.00	100.00	LS	
	80-137	Bt	5.15	2.00	0.70	1.20	0.02	5.54	3.19	0.76	0.69	0.16	0.00	1.80	6.60	15.24	22.00	72.74	690.00	10.00	300.00	SCL	
	137-182	Bth	5.30	2.00	15.90	27.30	0.39	5.30	3.07	0.77	0.69	0.14	0.00	2.00	7.68	18.96	28.44	60.85	710.00	20.00	270.00	SCL	
		Mean	5.43	6.80	6.00	10.20	0.15	9.70	3.59	0.82	0.15	0.67	0.00	1.20	6.63	12.30	37.60	79.60	808.00	26.00	164.00		
		CV	5.70	97.20	108.20	108.1	106.10	93.50	19.00	9.90	10.80	2.70	58.90	58.90	11.00	38.20	50.10	16.80	12.60	43.90	68.80		
		Ranking	LV	HV	HV	HV	HV	HV	MV	LV	LV	LV	HV	HV	LV	HV	HV	MV	LV	LV	HV		

Table 3: Summary of soil classification for all the pedon

Pedon	USDA	Area Coverage (ha)	Percentage (%)
1	Rhodic Kandiudalf,	3,795.40	11.09
2	Ruptic-Alfic Eutrudepts	1,928.96	5.64
3	Typic kandiudalfs	10,170.91	29.72
4	Plinthic Kandiudalfs	4,590.31	13.41
5	Plinthaquic Kandiudalf	2,574.02	7.52
6	Grossarenic Kandiudalfs	3, 695.07	10.80
7	Typic Eutrudept	5,919	17.29
8	Arenic Kandiudalfs	1,547.12	4.52

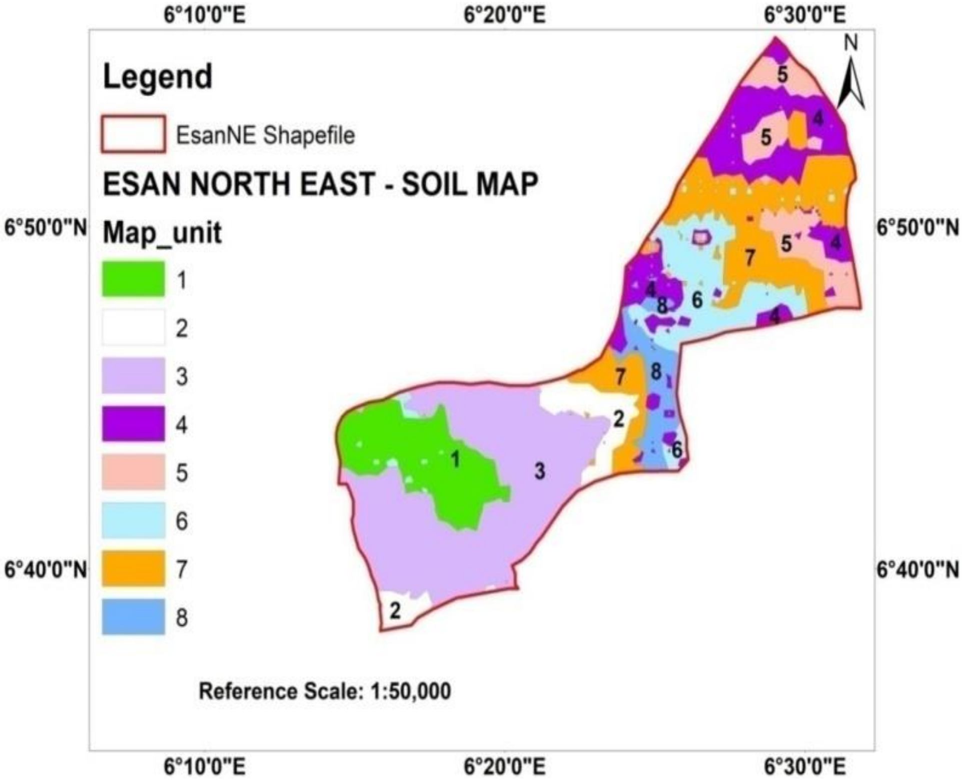

Fig. 2: Soil map of study area

Table 10: Summary of aggregate land suitability for oil palm and rubber

Pedon	USDA taxonomy	Limitation		Parametric		Size	Area coverage
		Oil palm	Rubber	Oil palm	Rubber	(ha)	(%)
1	Rhodic Kandiudalf	S3(c)	S3(c,f)	44.17 (S3)	51.96(S2)	3,795.40	11.09
2	Ruptic-Alfic Eutrudept	S3(c,w)	N(w)	47.91(S3)	13.00(N)	1,928.96	5.64
3	Typic Kandiudalf	S3(c)	S3(c,f)	41.49.(S3)	51.96(S2)	10,170.91	29.72
4	Plinthic Kandiudalf	S3(c)	S3(c,f)	44.17(S3)	51.96(S2)	4,590.31	13.41
5	Plinthaquic Kandiudalf	N2(w)	S3(c,w,f)	11.25(N)	51.96(S2)	2,574.02	7.52
6	Grossarenic Kandiudalf	S3(c)	S3(c,f)	40.72(S3)	51.96(S2)	3,695.07	10.80
7	Typic Dytrudept	S3(c)	S3(c,w,f)	40.72(S3)	51.96(S2)	5,915.00	17.29
8	Arenic Kandiudalf	S3(c)	S3(c,f)	44.17(S3)	45.00(S3)	1,547.12	4.52

Discussion

Soil types in the study area are largely influenced by the activities of soil forming factors; among which the dominant ones are topography as expressed in slope, parent material and climate (rainfall and temperature). Variations in soil colour could be associated with drainage, parent material and environmental factors (rainfall, humidity and temperature) (*Osujike et al*., 2018), though organic matter content may be responsible for the brownish colour of surface horizons in all the pedons (Okunsebor and Umweni, 2021). Textural class for pedons 1, 7 and 8 was light in surface horizons but medium in pedons 2,3,4,5 and 6; while that of sub-surface horizons varied from medium to heavy (except for pedons 7and 8), which suggests a moderate rate of leaching in the study area.

Structure of pedons for most of the pedons was sub-angular blocky (except for pedon 8 – surface horizon); sub-angular blocky structured soils are prone to erosion. Root abundance varied in all the pedons; variations in root abundance may be associated with soil type and plant species present in the mapping units.

Table 4: Land suitability evaluation of all the pedons for oil palm cultivation (limitation)

Pedons Land qualities	1	2	3	4	5	6	7	8
Climate (c)								
Mean Annual Rainfall (mm)	S2(1,540)	S2(1,540)	S2(1,540)	S2(1,540)	S2(1,540)	S2(1,540)	S2(1,540)	S2(1,540)
Length of Dry season (months)	S3(3-4)	S3(3-4)	S3(3-4)	S3(3-4)	S3(3-4)	S3(3-4)	S3(3-4)	S3(3-4)
Mean Annual Temperature (˚C)	$S1_1$(31)	$S1_1$(31)	$S1_1$(31)	$S1_1$(31)	$S1_1$(31)	$S1_1$(31)	$S1_1$(31)	$S1_1$(31)
Topography (t)								
Slope (%)	$S1_2$(2.9-4.4)	$S1_1$(0-1.6)	$S1_1$ (1.6-2.9)	$S1_2$(2.9-4.4)	S2(6.1-8.2)	$S1_2$(2.9-4.4)	$S1_2$(2.9-4.4)	$S1_1$ (1.6-2.9)
Wetness (w)								
Flooding	$S1_1$(F0)	$S1_2$ (Fo)	$S1_1$ (F0)	S3(F2)	N2(F3)	$S1_2$(Fo)	$S1_2$(Fo)	$S1_2$(Fo)
Drainage	$S1_1$(excessive-well)	S3 (seasonally poor)	S2(Fairly well)	$S1_2$(Well)	S2(Imperfect)	$S1_2$(Fairly -well)	$S1_2$(fairly well imperfect)	$S1_2$(Fairly well)
Soil physical characteristics (s)								
Texture	$S1_1$ (LS-SC)	$S1_2$(SL-SCL)	$S1_1$(SL-C)	$S1_1$(SL-C)	$S1_1$ (SL-C)	$S1_1$ (SL-SC)	$S1_2$ (LS-SCL)	$S1_1$ (S-SCL)
Structure	$S1_2$ (SAB)	$S1_2$ (SAB)	$S1_2$ (SAB)	$S1_2$ (SAB)	$S1_2$ (SAB)	$S1_2$ (SAB)	$S1_2$ (SAB)	$S1_2$ (SAB)
Coarse fragment (vol.) within 100 cm	-	-	-		S3(55)	-	-	-
Soil depth (cm)	$S1_1$(>180)	$S1_1$(>176)	$S1_1$(>190)	$S1_1$(>145)	$S1_1$ (140)	$S1_1$ (>190)	$S1_1$(>192)	$S1_1$(>182)
Fertility (f)								
ECEC (meq/100)	S2(5.10-6.74)	S2(5.25-10.39)	S2(6.79-7.90)	S2(6.01-9.86)	S2(6.37-11.58)	S2(5.51-9.85)	S2(6.61-10.08)	S2(5.84-7.68
Base saturation (%)	$S1_1$(79.52-89.76)	$S1_1$(88.59-92.30)	$S1_1$ (53.81-86.13)	$S1_1$ (82.37-94.12)	$S1_1$(60.38-94.78)	$S1_1$(89.97-93.88)	$S1_1$ (90.97-97.06)	$S1_1$ (60.85-94.28)
pH	$S1_2$ (4.38-6.60)	$S1_2$ (4.15-4.76)	$S1_2$(4.04-4.85)	$S1_2$(4.16-5.24)	$S1_2$(4.83-5.53)	$S1_2$(5.07-6.08)	$S1_2$(5.99-6.18)	$S1_2$(5.15-5.95)
Organic matter (%)	$S1_2$(0.86)	S2(0.32)	$S1_2$(0.87)	S2(0.55)	$S1_1$(1.62)	S2(0.41)	S2(0.64)	$S1_1$ (1.53)
Aggregate suitability class	S3(c)	S3(c,w)	S3(c)	S3(c)	N2(w)	S3(c)	S3(c)	S3(c)
Land area (Ha)	3,795.40	1,928.96	10,170.91	4,590.31	2,574.02	3,695.07	5,915.00	1,547.12
% coverage	11.09	5.64	29.72	13.41	7.52	10.80	17.29	4.52

Table 5: Land suitability evaluation of all the pedons for oil palm cultivation (parametric

Pedons Land qualities	1	2	3	4	5	6	7	8
Climate (c)								
Mean Annual Rainfall (mm)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)
Length of Dry season (months)	60(S3)	60(S3)	60(S3)	60(S3)	60(S3)	60(S3)	60(S3)	60(S3)
Mean Annual Temperature (˚C)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)
Topography (t)								
Slope (%)	85($S1_2$)	100($S1_1$)	100($S1_1$)	85($S1_2$)	75(S2)	85($S1_2$)	85($S1_2$)	100($S1_1$)
Wetness (w)								
Flooding	100($S1_1$)	85($S1_2$)	100($S1_1$)	60(S3)	25(N2)	85($S1_2$)	85($S1_2$)	85($S1_2$)
Drainage	100($S1_1$)	60(S2)	75(S2)	85($S1_2$)	75(S2)	85($S1_2$)	85($S1_2$)	85($S1_2$)
Soil physical characteristics (s)								
Texture	100($S1_1$)	85($S1_2$)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)	85($S1_2$)	100($S1_1$)
Structure	85($S1_2$)	85($S1_2$)	85($S1_2$)	85($S1_2$)	85($S1_2$)	85($S1_2$)	85($S1_2$)	85($S1_2$)
Coarse fragment (vol.) within 100 cm	-	-	-		60(S3)	-	-	-
Soil depth (cm)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)
Fertility (f)								
ECEC (meq/100)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)
Base saturation (%)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)	100($S1_1$)
pH	85($S1_2$)	85($S1_2$)	85($S1_2$)	85($S1_2$)	85($S1_2$)	85($S1_2$)	85($S1_2$)	85($S1_2$)
Organic matter (%)	85($S1_2$)	75(S2)	85($S1_2$)	75(S2)	100($S1_1$)	75(S2)	75(S2)	100($S1_1$)
Aggregate suitability class	44.17 (S3)	47.91(S3)	41.49(S3)	44.17(S3)	11.25(N)	40.72(S3)	40.72(S3)	44.17(S3)
Land area (Ha)	3,795.40	1,928.96	10,170.91	4,590.31	2,574.02	3,695.07	5,915.00	1,547.12
% coverage	11.09	5.64	29.72	13.41	7.52	10.80	17.29	4.52

Table 6: Land suitability evaluation of all the pedons for rubber cultivation (limitation)

Pedons **Land characteristics**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Climate (c)								
Average temperature (°C)	S2 (31°C)	S2 (31°C)	S2 (31°C)	S2 (31°C)	S2 (31°C)	S2 (31°C)	S2 (31°C)	S2 (31°C)
Rainfall (mm/year)	S2(1,540)	S2(1,540)	S2(1,540)	S2(1,540)	S2(1,540)	S2(1,540)	S2(1,540)	S2(1,540)
Length of dry season (months)	S3(3-4)	S3(3-4)	S3(3-4)	S3(3-4)	S3(3-4)	S3(3-4)	S3(3-4)	S3(3-4)
Wetness (w)								
Drainage	S1(Excessive-Well)	N(Seasonally poor)	S2(Fairly well)	S1(Well)	S3(Imperfect)	S2(Fairly well)	S3(Fairly well-Imperfect)	S2(Fairly well)
Erosion hazard	S1(Very low)	S2(Moderate)	S1(Very low)	S(Very low)	S1(Very low)	S1(Very low)	S1(Very low)	S1(Very low)
Flooding hazard	S1(No)	S1(No)	S1(No)	S2(Medium)	S3(seasonally flooded)	S1(No)	S1(No)	S1(No)
Soil physical characteristics (s)								
Texture	S2(LS-SC)	S2(SL-SCL)	S1(SL-C)	S1(SL-C)	S1(SL-C)	S1(LS-SC)	S2(SL-SCL)	S2(S-SCL)
Soil effective depth (cm)	S1(>180)	S1(>176)	S1(>177)	S1(>145)	S2(140)	S1(>190)	S1(>192)	S1(>182)
Rock outcrop (%)	-	-	-	-	-	-	-	
Fertility (f)								
Base Saturation (%)	S3(79.52-89.76)	S3(88.59-92.30)	S3(53.81-86.13)	S3(82.37-94.12)	S3(60.38-94.78)	S3(89.97-93.88)	S3(90.97-97.06)	S3(60.85-94.28)
C - Organic (%)	S1(0.16-1.23)	S1(0.30-0.59)	S1(0.09-0.92)	S1(0.24-1.73)	S1(0.54-0.86)	S1(0.11-0.24)	S1(0.02-0.89)	S1(0.07-1.59)
Soil Acidity	S2(4.34-4.75)	S2(4.44-4.76)	S2(4.04-4.90)	S2(4.16-5.24)	S2(4.83-5.53)	S1(5.07-6.08)	S1(5.99-6.18)	S1(5.15-5.95)
CEC (cmolkg^{-1})	S1(10.72-26.42)	S1(9.60-27.10)	S1(9.80-29.60)	S17.66-26.96)	S1(9.66-28.96)	S1(4.98-26.32)	S1(7.12-19.56)	S1(8.06-18.96)
Topography (t)								
Slope class (%)	S1(2.9-4.4)	S1(0-1.6)	S1(1.6-2.9)	S1(2.9-4.4)	S2(6.1-8.2)	S1 (2.9-4.4)	S1(2.9-4.4)	S1(1.6-2.9)
Aggregate suitability class	S3(c,f)	N(w)	S3(c,f)	S3(c,f)	S3(c,w,f)	S3(c,f)	S3(c,w,f)	S3(c,f)
Land area (Ha)	3,795.40	1,928.96	10,170.91	4,590.31	2,574.02	3,695.07	5,915.00	1,547.12
% coverage	11.09	5.64	29.72	13.41	7.52	10.80	17.29	4.52

Table 7: Land Suitability Evaluation of all the pedons for Rubber Cultivation (Parametric)

Pedons **Land characteristics**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Climate (c)								
Average temperature (°C)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)
Rainfall (mm/year)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)
Length of dry season (months)	60(S3)	60(S3)	60(S3)	60(S3)	60(S3)	60(S3)	60(S3)	60(S3)
Wetness (w)								
Drainage	100(S1)	25(N)	75(S2)	100(S1)	60(S3)	75(S2)	60(S3)	75(S2)
Erosion hazard	100(S1)	75(S2)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Flooding hazard	100(S1)	100(S1)	100(S1)	75(S2)	60(S3)	100(S1)	100(S1)	100(S1)
Soil physical characteristics (s)								
Texture	75(S2)	75(S2)	100(S1)	100(S1)	100(S1)	100(S1)	75(S2)	75(S2)
Soil effective depth (cm)	100(S1)	100(S1)	100(S1)	100(S1)	75(S2)	100(S1)	100(S1)	100(S1)
Rock outcrop (%)	-	-	-	-	-	-	-	
Fertility (f)								
Base Saturation (%)	60(S3)	60(S3)	60(S3)	60(S3)	60(S3)	60(S3)	60(S3)	60(S3)
C - Organic (%)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Soil Acidity	75(S2)	75(S2)	75(S2)	75(S2)	75(S2)	100(S1)	100(S1)	100(S1)
CEC (cmolkg^{-1})	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Topography (t)								
Slope class (%)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Aggregate suitability class	51.96(S2)	13.00(N)	51.96(S2)	51.96(S2)	51.96(S2)	51.96(S2)	51.96(S2)	45.00(S3)
Land area (Ha)	3,795.40	1,928.96	10,170.91	4,590.31	2,574.02	3,695.07	5,915.00	1,547.12
% coverage	11.09	5.64	29.72	13.41	7.52	10.80	17.29	4.52

Table 8: Land suitability guideline for oil palm cultivation

Land Characteristics	Suitability Classes					
	$S1_1$	$S1_2$	S_2	S_3	N_1	N_2
Score %	95-100	85-95	85	60	40	25
Climate (c)						
Mean ann. Rainfall (mm)	>2000	1,700-2000	>1450-1700	>1250-1450	-	<1250
Length of dry season (months)	≥1	1-2	2-3	3-4	-	>4
Mean ann. Temperature (^{0}C)	>29	27-29	24-27	22-24	-	<22
Topography (t)						
Slope (S) (%)	0-4	4-8	8-16	16-30	-	>30
Wetness (w)	F0	Fo	F1	F2	-	F3
Flooding						
Drainage	Perfect	Mod-Well	-	Poor, aeric	Poor drainable	Very poor, not drainable
Soil physical characteristic (s)						
Texture	Cl, SCL,L	CL,SCL,L	SCL-L	SCL-LFS	ANY	S,CS
Structure	Blocky	Blocky	-	-	-	Massive single grain
Coarse fragmentation (vol.) within 100 cm (z)	>3-10	10-15	15-35	35-55	-	>55
Depth (cm)	>100	10-100	50-90	25-50	-	<25
Fertility characteristics(f)						
ECEC (meq/100 g)	>16	15-16	<15	-	-	-
Base saturation (BS%)	>35	20-35	<20	-	-	-
pH	5.5-6.0	5.5-6.0	6.0-6.5	6.5-7.0	<4,>7.0	<4,>7.0
Organic matter (gkg^{-1} OC, 0-15)	>15	1.2-0.8	<8	-	-	-
Salinity % Alkalinity (N) EC mmhos	<1	<1-2	>2-3	>3-4	>4-8	>38

Legend: Fo=No flooding, F1= 1-2 flooding months in ≥ ten years, F2=not more than 2-3 flooding months in 5years out of 10, F3= 2-4 months every year, F4 ≥ 4 months in almost every year. *Source:* Oko-oboh *et al*. (2018)

Table 9: Land requirements for rubber (*Hevea brasilensis*) cultivation

Land Characteristics	Suitability classes			
	S1	S2	S3	N
Average temperature ℃	26-30	30-34	22-24	>34
Rainfall (mm/year)	2500-3000	3000-3500	3500-4000	>4000
Length of dry season	1-2	2-3	3-4	>4
Drainage	Well	Moderately	Imperfectly	poorly
Texture	Fine	Medium	Moderate coarse	Coarse
Soil effective depth(cm)	>100	75-100	50-75	<50
Peat depth(cm)	<60	60-140	140-200	>200
Peat ripeness	Saprists	Saprists /Hernists	Hernists /Fibrists	Fibrists
CEC (cmolkg^{-1})	-	-	-	-
Base Saturation (%)	<35	35-40	>50	-
Soil acidity (H_2O)	5.0-6.0	4.5-5.0	<15	-
C – Organic (%)	>0,8	50,8	-	-
Slope class (%)	<8	8-16	16-30	>30
Erosion hazard	Very low	Low	Medium	High
Flooding hazard	Slight	Moderate		
Rock outcrop (%)	<5	5-15	15-20	>40
Limitation level	Score number	Land suitability class		
No limitation	0	No limitation		
	1	Slight		
	2	Moderate		
	3	severe/very severe		

Source: Bhermana *et al*, (2013)

Sand fraction was highest among particle size fractions with variation ranging from low (pedons 7 and 8) to medium (pedons 1, 2, 3, 4, 5 and 6), which confirms the heterogeneity of parent material in the study area. Silt fraction had the least values with variation ranging from low (pedon 8) – medium (pedons 2, 4 5) – high (pedons 1,3,6 and 7). Ahukaemere *et al*. (2017) opined that low silt fraction could be attributed to high degree of weathering in soils. Clay fraction had high variation throughout the study area, which could be attributed to argilluviation and soil texture (Udoh *et al*., 2008; Ahukaemere *et al*., 2017). Soil pH varied from extremely acidic to slightly; a condition that is typical for udic moisture regime. Coefficient of variation for soil pH ranged from medium in pedon 1 to low in all other pedons; indicating the homogeneity of all the horizons in terms of pH. Organic carbon content was highest in surface horizons and decreased with increase in depth; coefficient of variation ranged from high to medium. Generally, organic carbon was low (< 4%) in all the pedons according to the ratings of FDALR, (1985). Nitrogen values were below the critical limit of 0.15% (FMANR, 1999; Chude, 2011), which indicates nitrogen deficiency.

Soil classification: The pedons were designated as 1,2,3,4,5,6,7 and 8 (Table 3, Figure 2). Generally, all the pedons had an ochric epipedon, as suggested by the light colour and thickness of their surface horizon. Clay eluviation and illuviation was clearly demonstrated by particle size data of pedons 1, 3, 4, 5, 6 and 8, suggesting the presence of clay coatings in their horizons, and the presence of an argillic or a kandic horizon. Argillic and kandic horizons were established in the pedons (pedons 1,3,4,5,6 and 8) because they had coarser surface textured horizons over vertically continuous subsurface horizons; ECEC(CLAY) value of 12 $cmol^{-1}$ clay or more in surface horizons and ECEC(CLAY) value less than 12 $cmol^{-1}$ clay in subsurface horizons, organic matter content that decreased regularly down the profile and clay content increase with depth (Soil Survey Staff, 2014); these in addition to the requirement of a base saturation (by sum of cations) greater than 35% at the appropriate depth placed the pedons in the order Alfisols. They qualified as Udalf at suborder level because of the presence of a deep soil moisture control depth that is not dry for 90 consecutive days (Udic moisture regime). The pedons qualified as Kandiudalfs at Great Group level because they satisfied the conditions of no lithic, paralithic or petroferric contact within 150 cm of the mineral soil surface and had an ECEC (CLAY) value less than12 $cmol^{-1}$ clay in their kandic horizons. This confirms the findings of Imadojemu *et al.* (2018) who established the presence of an udic moisture regime and a Kandic endopedon in the soils of Edo state. At subgroup level, pedon 1 was classified as Rhodic Kandiudalf, because it has, throughout the profile a hue of 2.5YR and a colour value of 3; which is in agreement with findings of Okusami *et al*. (1997). Pedon 3 qualified as Typic kandiudalfs because it had properties that were central to the Great group (Kandiudalfs). Pedon 4 was classified as Plinthic Kandiudalfs because of the presence of 5 percent or more (by volume) plinthite in one horizon within 150 cm of the mineral soil surface. Pedon 5 was classified as Plinthaquic Kandiudalf due to the presence of redox depletion within 75 cm; and more than 5% by volume of plinthite in two horizons within 150cm of the mineral soil. Pedon 6 qualified as Grossarenic Kandiudalfs because it had a textural class of loamy fine sand and sandy loam throughout a layer extending from the mineral soil surface to the top of a kandic horizon at a depth of 100 cm or more. Pedon 8 was classified as Arenic Kandiudalfs because of the presence of a textural class of sand and loamy sand throughout a layer extending from the mineral soil surface to the top of a kandic horizon at a depth of 50 to 100 cm.

Pedons 2 and 7 were classified as the order Inceptisols because of the presence of a Cambic B horizon (Soil Survey Staff, 2014). This is in line with the findings of Okunsebor and Umweni (2021), which placed soils of Edo state in similar soil order. The presence of an Udic moisture regime qualified the soils as Udept at sub order level. They qualified as Eutrudepts at the great group level because they have a base saturation (by NH_4OAc) of 60% or more in one or more horizons at a depth between 25 and 75 cm from the mineral soil surface. At sub group level, pedon 2 qualified as Ruptic-Alfic Eutrudepts because it had a Cambic B horizon that include 10 – 50% (by volume) illuvial part that otherwise meet the requirements for an argillic or Kandic horizon; pedon 7 qualified as Typic Eutrudept because it had properties central to the great group (Eutrudepts). This agrees with the findings of Agbogun (2021), who classified similar soils in Edo state.

Land suitability evaluation: Suitability assessment for oil palm and rubber cultivation (Table 4,5,6 and 7) was based on the guidelines (Table 8 and 9) provided by Sys (1985) as modified by Oko-Oboh *et al*. (2018) and Bhermana *et al*. (2013). The land qualities evaluated were climate, wetness, topography, soil physical characteristics and fertility characteristics.

Climate (c): all the pedons were rated S2 (moderately suitable) with reference to annual rainfall of the study area (1, 540 mm), S3 (marginally suitable) with reference to length of dry months (3-4 months) and $S1_1$ (highly suitable) for oil palm but S2 (moderately suitable) for rubber in terms of mean annual temperatures (31°C). Length of dry season ≤ 1 month is optimal for oil palm cultivation (Sys, 1985; Oko-Oboh *et al.*, 2018); 1 – 2 months is optimal for rubber.

Topography (t) as expressed in slope was optimum ($S1_1$ and $S1_2$) in pedons 1, 2, 3, 4, 6 7 and 8 but sub optimum (S2) in pedon 5 for oil palm and rubber.

Wetness (w): Pedons 1, 6, 7 and 8 were well drained with no flooding problems, thus were rated highly suitable ($S1_1$, $S1_2$) for both crops. Pedon 3 was rated moderately suitable (S2) due to limitation in drainage condition, pedon 2 was not suitable (N) for rubber due to limitation in drainage but marginally suitable (S3) for oil palm due to limitation in drainage condition. Pedon 4 had no limitation in drainage condition ($S1_2$) but had limitation in flooding condition (S3) for both crops. Pedon 5 had an imperfect drainage condition (N1) and flooding problem (N2) for oil palm but was marginally suitable (S3) due to limition in flooding and erosion hazard

*Soil physical characteristics (s)***:** All the pedons were highly suitable for oil palm cultivation on the basis of texture **(**$S1_1$) and structure ($S1_2$). However, in terms of texture, pedons 3, 4, 5 and 6 were highly suitable (S1), while pedons 1, 2, 7 and 8 were moderately suitable (S3) for rubber cultivation. All the pedons were S1 (highly suitable) in terms of depth for rubber and oil palm; except for pedon 5 that had stones within 100 cm, thus, was rated S3 (marginally suitable) for oil palm cultivation.

Fertility characteristics (f): This refers to chemical fertility that takes into consideration the properties that are easily altered as well as the requirements for potential fertility as it affects oil palm production. Effective Cation Exchange Capacity (ECEC) was less than 15 in all the pedons, thus, all the pedons qualified as S2 (moderately suitable). Base Saturation (BS) was greater (>) than 35% in all the pedons, rating all the pedons highly suitable ($S1_1$) for oil palm cultivation; but all the pedons were rated S3 (Marginally Suitable) for rubber cultivation. On the basis of pH, all the pedons were rated highly suitable ($S1_1$) for oil palm cultivation; for rubber, pedons 6, 7 and 8 were highly suitable (S1) while pedons 1, 2, 3, 4 and 5 were moderately suitable. Based on organic matter content, pedons 1, 3, 5and 8 were rated highly suitable ($S1_1$- pedons 5 and 8; $S1_2$- pedons 1 and 3); while pedons 2, 4 and 7 were moderately suitable (S2) for oil palm cultivation. However, all the pedons were highly suitable (S1) for rubber cultivation. In terms of CEC, all the pedons were highly suitable (S1) for rubber cultivation.

Aggregate suitability rating showed that pedons 1, 3, 4, 6, 7 and 8 (29,713.81 ha and 86.83% of the study area) were marginally suitable (S3) for oil palm and rubber cultivation due to limitations in climatic condition (length of dry season) and wetness (and fertility – rubber). Pedon 2 (1, 928.96 hectares and 5.64% of the study area) was marginally suitable (S3) for oil palm due to limitations in climatic condition (length of dry season) and wetness, but currently not suitable (N1) for rubber due to limitation in wetness (drainage). Pedon 5 (2, 574.02 ha and 7.52% of the study area) was marginally suitable for rubber due to limitations in climatic condition (length of dry season) and wetness but permanently not suitable (N2) for oil palm cultivation because of limitation in wetness (flooding). Major limitations to oil palm and rubber cultivation in the study area was climate (rainfall and length of dry season). Moisture availability is crucial for the growth and productivity of both oil palm and rubber. Oil palm requires consistent and adequate moisture to sustain its high water demand due to large canopy and extensive root system (De la Peña *et al*., 2024). Similarly, rubber depends on consistent moisture to maintain its latex production (Uttran *et al*., 2023). Rainfall amount greater than 1700 mm (>1700 mm) and dry season period of less than one month (< 1 month) is the optimal requirement for oil palm (Oko-Oboh *et al*., 2018).

Parametric method showed that pedons 1,3,4,6 and 7 (28,526.69 ha and 82.31% of the study area) were moderately suitable (S2) for rubber but marginally suitable (S3) for oil palm pedon 2 (1,928.96 hectares and 5.64%) was marginally suitable (S3) for oil palm but not suitable (N) for rubber cultivation. Pedon 5 (2,574.02ha and 7.52% of the study area) was moderately suitable (S2) for rubber but not suitable (N) for oil palm cultivation; pedon 8 (1,547.12 and 4.52%) was marginally suitable (S3) for both crops.

Results from the two evaluation methods (Table 10) showed that there was no difference in aggregate suitability assessment for oil palm, while that of rubber improved from S3 to S2 (except for pedons 2 and 8). Therefore, the choice of evaluation method for a study of this nature for oil palm and rubber is based on the evaluator's discretion; however, the limitation method may be preferred because it gives actual information on land characteristics.

Conclusion

The study area had 8 mapping units. Mapping units 1, 3, 4, 6 and 7 (82.31%) were marginally suitable (S3) for oil palm and rubber by limitation method; marginally suitable for oil palm (S3) but moderately suitable (S2) for rubber by parametric method. Mapping unit 2 (5.64%) was marginally suitable (S3) for oil palm but not suitable (N) for rubber by both methods; mapping unit 8 (4.52%) was marginally suitable (S3) by both methods; mapping unit 5 (7.52%) was not suitable (N) for oil palm by both methods but marginally suitable (S3) for rubber by limitation method, and moderately suitable (S2) by parametric method. Mapping units 1,3,4,6,7 and 8 may be used for cultivation for both crops when there is sufficient economic justification for investment; mapping unit 2 may also be used for cultivation of oil palm, and mapping unit 5 for rubber cultivation. Since the major limitation to cultivation of oil palm and rubber in the study area is climate, management practices such as supplementary irrigation; even though it is expensive would solve the challenge of moisture stress.

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