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Characterization of epipedons in soils of varying parent materials under cocoa plantation

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Abstract
Epipedons type and thickness affect the properties and productivity of soils. Therefore, the study was carried out at the Obafemi Awolowo University Teaching and Research Farm, Nigeria, to assess the influence of vegetation on epipedon characteristics in soils of varying parent materials with a view to highlighting their salient properties for sustainable utilization of soils in the area. Three mini pits were established within each soil series supporting similar plantation. Morphological description of the soils was undertaken on the field, using the guidelines of FAO. Soil samples were taken from both the top- and sub-surface horizons of the mini pits for analyses, using standard procedures. The epipedons were fairly thick, ranging between 0-20 and 0-30 cm, brightly coloured with good internal drainage, except those of the Jago series, and varied from slightly sticky, slightly-plastic to very sticky, very plastic, suggesting higher clay content at lower depth and the ability of the soils to hold moisture for crop use after cessation of rains. The soils are devoid of gravel within the minipits. The soil's pH was low and ranged between medium acid and slightly acid while the organic matter within the epipedons was relatively moderate. Total nitrogen content varied from medium to high within the soils of Oba and Egbeda series while it varied from low to medium in Iwo and Jago series, available P in the epipedons ranged from low to medium. Exchangeable Ca was lower than the critical value established for soils in southern Nigeria while exchangeable Mg and K values were adequate. Litter production was highest (7.50 t/ha) in Egbeda soil series and least (3.57 t/ha) in Jago series. Soils of Iwo and Oba series had 4.57 t/ha and 5.50 t/ha of litter production, respectively. Tissue phosphorus of litters in Egbeda soils series was high, while that of Iwo and Oba series formed from coarse-grained granite, and hill wash medium to fine material, respectively, was low. Soils of Iwo, Oba and Jago series need supplemental application of nitrogen, phosphorus and calcium fertilizers for optimal cacao production due to their lower values than the minimum required.

Keywords
Pedology, Vegetation, Epipedon, Parent Material, Soil Characteristics

Introduction

Soil properties are influenced by a number of factors and processes. One of such properties is epipedon- a horizon that forms at or near the soil surface and in which most structure of the rock has been obliterated (Soil Survey Staff, 2014). The epipedon is usually dar-. kened by the presence of organic matter and may show evidence of eluviation. Knowledge of soils properties offers insight into their stage of development and dynamics (Rekwar and Ahmed, 2022). Therefore, proper attention should be given to the assessment of epipedons in order to maintain agricultural land at optimum level of productivity.

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Measurement of changes in soil nutrient stocks over time gives an estimate of nutrient mining and aids the maintenance of cropping system for sustainable crop production. The management of vegetation growing on low-fertility tropical soils requires an understand-ding the nutrient cycling process. A fundamental process in phytocycling is litter fall, the major main means through which organic matter and mineral elements are transferred from plantation into the surface of soil (Vitousek and Sanford, 1986). The essence of nutrient self-sustenance mechanism in cacao agroforestory, especially in tropical agroforest regions is nutrient cycling (Hartemink, 2005). Litter assessment is important to determine the level of pro-duction and nutrient cycling in the forest ecosystem (Muoghalu e Odiwe, 2011). Studying nutrient cycling under vege-tation is necessary to evaluate the effect of tree stands to soil development and fertility. Therefore, this work was carried out to assess the impact of cacao on epipedons characteristics and highlight the salient properties of the epipedons for sustainable utilization of soils in the area, with a view to understanding the nutrients' mining pattern, their recycling and hence the fertilizer requirement to ensure sustainable growth and development of crops.

Materials and Methods

Study area

The study was carried out at the Teaching and Research Farm of the Obafemi Awolowo University, Ile-Ife, Nigeria. The area is characterized by a bimodal rainfall pattern with average annual rainfall of about 1400 mm, a relative humidity of about 73.8% and about 6.6 hrd^{-1} of sunshine. Temperature ranged between 27.1 and 34.4°C (Ojetade *et al.*, 2021). Four soil series were used for the study, namely: Egbeda series underlain by fine-grained biotite gneiss and schist (Lat. 7°56´26.9´´–7°56´40.9´´N and Long. 4°55´901´´- 4°55´92.2´´E), Iwo series formed from coarse-grained granite (Lat. 7°54´27.7´´–7°56´07.4´´N and Long. 4°54´15.5´´–4°55´86.1´´E), Oba series formed from hill wash medium to fine material (Lat.7°56´49.0´´-7°.56´50.4´´N and Long. 4°55´71.8´´-4°55´719´´E) and Jago series derived largely from alluvium, with some local colluvium (Lat. 7°56´536´´-7°56´56.8´´N and Long. 4°55´65.8´´–4°55´68.4´´E), all cultivated to cacao (Fig. 1).

Vegetation and land use

The initial vegetation in the study area was rainforest, with trees and shrubs. However, this had given way as a result of human influence. At the time of field investigation, vegetation within the area consisted mainly of cacao (*Theobroma cacao*) with admixture of kola nut (*Cola acuminata*) and oil palm (*Elaeis guineensis*), scattered within the cacao plantation.

Field study, soil and litter sampling, and processing

Three mini pits (50 cm by 50 cm by 50 cm) were established within each soil series under cacao, representing Egbeda, Iwo, Oba and Jago series, respectively. It has been stated that 50 cm is the effective rooting depth from which most nutrient elements are taken up by plant roots, beyond which it is merely for anchorage (Fan *et al.*, 2016). The soils parent materials are fine-grained biotite gneiss and schist (Egbeda series), coarse-grained granite and gneiss (Iwo series), while medium to fine-grained hill wash colluvium and alluvium gave rise to the soils of Oba series. Soils of Jago series are restricted to low-lying portions of the basement complex areas of southwest Nigeria. The mini pits were described using the FAO (2006) guidelines for profile description. The morphological description of the mini pits was

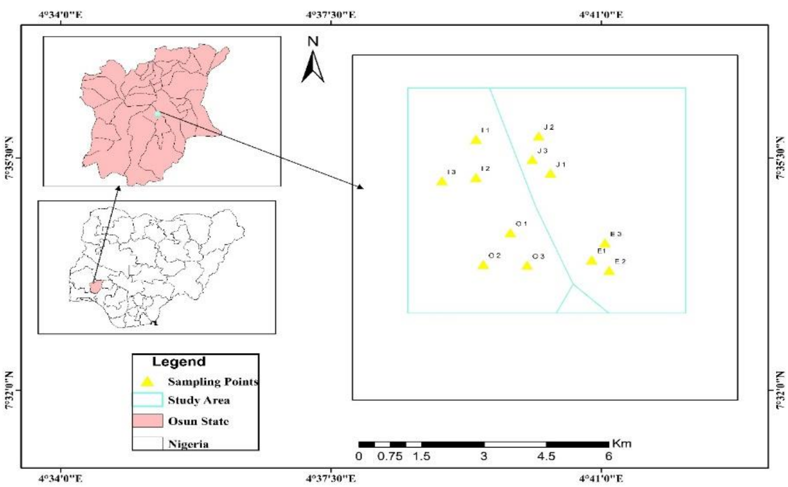

Figure 1.
Map of the study area

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undertaken on the field while two soil samples (the epipedons and sub surface horizons) were taken from each mini pit to assess physical and chemical properties in the laboratory. The air-dried samples were gently crushed in ceramic mortal with pestle. The samples were sieved using a 2 mm sieve, and the fraction less than 2 mm fraction was used for analyses. The proportion of sand, silt and clay was assessed using the hydrometer method (Gee and Or, 2002) while the soil pH was determined in distilled water and 1 M KCl solution (Thomas, 1996). The content of organic carbon was determined by the chromic acid digestion method (Darrell *et al.*, 1994) while total nitrogen was evaluated using the micro-Kjeldahl digestion method (Bremner, 1996). The available phosphorus was determined by the Bray-1 method (Kuo, 1996). The exchangeable cations were extracted using 1 M NH_4OAc solution at pH 7. Calcium and magnesium contents were evaluated with the atomic absorption spectrophotometer while potassium and sodium were determined by the flame photometer (Jones, 1998). Litter samples were taken at three locations (close to where the mini pits were established) within each soil series, using 1 m by 1 m quadrant. The litters were oven-dried at 80°C until constant weights were obtained. The weight of the oven-dried litter per quadrant was taken and averaged to estimate litter production across the soil series. The litter in each quadrant was thoroughly mixed and sub-sampled for the determination of some selected nutrients. The oven-dried litters were ground using a stainless-steel mill. A portion of the ground sample was digested with concentrated H_2SO_4 and 30% H_2O_2. The contents of K and Na in the tissue digest were determined with a flame photometer while that of P was determined by Vanadomolybdate method (Jackson, 1973). Descriptive and inferential statistics (minimum, maximum, mean, standard deviation and correlation) were used to analyse and summarise the data gathered.

Results and Discussion

Morphological and physical properties of the soils

Morphological characteristics of the soils identified on the field and particle size distribution analysis are presented in Tables 1 and 2. The epipedons were fairly thick, ranging between 0-20 and 0-36 cm in Jago and Iwo soil series, respectively. Colours of the soils of Egbeda, Iwo and Oba were bright, ranging from red (2.5YR 4/6) to dark brown (7.5YR 3/2), indicative of good internal drainage.

The soils, other than Jago series, were well drained and situated at higher topographical site. The soils of Jago series are not as bright, the colour ranged from very dark brown (10YR 2/2) to dark reddish brown (5YR 4/2). Soils of Jago Association are situated in low topographical sites, the valley floors with seasonally high-water table (Smyth and Montgomery, 1962). Soil colours are significantly influenced by the position they occupy on the landscape, the prevalent internal drainage and moisture conditions (Gerrard 1981; Fagbami 1981, Ojetade *et al.*, 2014, Ojetade *et al.*, 2021). Structure of the soils varied between medium crumb and sub-angular blocky, to sub-angular blocky and massive within the epipedons and subsurface horizons, respectively. The epipedons were mainly friable, non-sticky and non-plastic as a result of the tree canopy on the soils which prevented direct insolation and raindrop impacts on the soils. The cacao roots also had cohesive effects on soil particles, and as such prevent loss of soil aggregates (Ojetade *et al.*, 2014; 2021). The soils' consistence in the subsurface horizons varied between slightly sticky, slightly plastic and very sticky, very plastic, resulting from the increase in clay content with depth (Ojanuga, 1975; Amusan, 1991, Ojetade *et al.*, 2021). It also indicates that the degree of weathering increased from the lower horizons to the surface horizon (Amusan 1991; Ojetade *et al.*, 2021). Roots, particularly, the very fine roots, were concentrated within the epipedons and decreased with depth, irrespective of the soil series. Sand fraction constituted bulk of the particle size and more on the surface soils than the subsurface. It ranged from 68–76% (mean, 72 ± 4%), 68–74% (mean,71 ± 3%), 68–70% (mean, 69 ± 1%) and 72–80% (mean, 76 ± 4%) in Egbeda, Iwo, Oba and Jago soil series, respectively. Silt fraction was almost constant across the three sampling points within the Egbeda and Iwo soil series (10% and 12%, respectively) while it ranged from 8–12% (mean, 10 ± 2%) and 8–10% (mean, 8 ± 2%) in Oba and Jago soil series, respectively (Table 2). Clay fraction was more in the subsurface soils than that within the epipedons, with the exception of Jago soil series where the reverse was the case. Clay content within the epipedons ranged from 14–22% (mean, 18 ± 4%), 14–20% (mean, 17 ± 3%), 18–24% (mean, 21 ± 3%) and 12–18% (mean, 15 ± 3%) for Egbeda, Iwo, Oba and Jago soil series, respectively while it ranged from 28–46% (mean, 36 ± 9%), 26–44%

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Table 1. *Selected morphological properties*

Soil Series	Mini Pit	Depth (cm)	Colour	Structure	Consistence (moist)
Egbeda	The Epipedons				
	I	0-26	5YR 2.5/2	Sub angular blocky	Non-sticky, non-plastic, friable
	II	0-25	2.5YR 2.5/1	Sub angular blocky	Slightly-sticky, slightly-plastic
	III	0-28	2.5YR 3/3	Sub angular blocky	Slightly-sticky
	Sub surface horizons				
	I	26-50	2.5YR 3/6	Sub angular blocky	Non-sticky, non-plastic, friable
	II	25-50	2.5YR 4/6	Sub angular blocky	Slightly-sticky
	III	28-50	10YR 4/8	Sub angular blocky	Very sticky
Iwo	The Epipedons				
	I	0-30	5YR 3/2	Structureless	Non-sticky, non-plastic
	II	0-36	7.5YR 3/2	Medium crumbs	Slightly-sticky, slightly- plastic
	III	0-31	7.5YR 3/2	Sub angular blocky	Non-sticky, non-plastic
	Sub surface horizons				
	I	30-50	5YR 5/8	Sub angular blocky	Non-sticky, non-plastic
	II	36-50	7.5YR 4/4	Medium crumbs	Slightly-sticky, slightly- plastic
	III	31-50	5YR 5/8	Sub angular blocky	Slightly-sticky, non-plastic
Oba	The Epipedons				
	I	0-28	2.5YR 3/2	Sub angular blocky	Slightly-sticky, slightly- plastic
	II	0-27	5YR 2.5/2	Sub angular blocky	Slightly-sticky, slightly- plastic
	III	0-28	5YR 2.5/2	Sub angular blocky	Non sticky, non-plastic
	Sub surface horizons				
	I	28-30	5YR 4/6	Sub angular blocky	Slightly-sticky, slightly-plastic
	II	27-50	5YR 4/6	Sub angular blocky	Slightly-sticky, slightly-plastic
	III	28-50	5YR 2/2	Sub angular blocky	Slightly-sticky, non-plastic
Jago	The Epipedons				
	I	0-26	10YR 2/2	Sub angular blocky	Non-plastic, non- sticky
	II	0-20	7.5YR 3/2	Medium crumbs	Sticky, plastic
	III	0-26	5YR 4/2	Medium crumbs	Non-sticky, non-plastic
	Sub surface horizons				
	I	26-50	10YR 5/2	Massive soil	Non-plastic
	II	20-50	7.5YR 4/4	Sub angular blocky	Sticky, plastic
	III	26-50	5YR 4/6	Sub angular blocky	Slightly-sticky, slightly- plastic

(mean, 32 ± 10%), 40–46% (mean, 43 ± 3%) and 12–26% (mean, 20 ± 7%) in the sub surface horizons. The soils texture ranged from sandy loam within the epipedons to sandy clay loam in the subsurface horizons. The subsoil texture allows for considerable capacity to hold moisture for crop use long after stoppage of rain without the crops experiencing serious moisture stress.

Chemical properties of the soils

The soils chemical properties are presented in Table 3 The soils acidity was low. It ranged from medium acid through slightly acid to very slightly acid (Adepetu *et al*., 2014). Specifically, the acidity of the epipedons in H_2O ranged between 5.1–6.9 (mean, 6.2 ± 0.9), 4.8–6.4 (mean, 5.8 ± 0.9), 6.1–6.7 (mean, 6.4 ± 0.3) and 5.6–6.3 (mean, 5.9 ± 0.4) while in 1 M KCl, it ranged from 5.1–6.4 (mean, 5.7 ± 0.6), 3.6–5.5 (mean, 4.8 ± 0.9), 5.1–5.6 (mean, 5.3 ± 0.3) and 4.4–5.5 (mean, 4.9 ± 0.6) for Egbeda, Iwo, Oba and Jago soil series, respectively (Table 3).

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Table 2
Particle size distribution
**SL= sandy loam,*
**SCL= sandy clay loam,*
**SC= sandy clay*

Soil Series		Mini Pit	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural Class*
Egbeda	The Epipedons	I	0-26	76	10	14	SL
		II	0-25	68	10	22	SCL
		III	0-28	72	10	18	SL
			Min.	68	10	14	
			Max.	76	10	22	
			Mean	72	10	18	
			Std. Dev.	4	0	4	
	Subsurface horizons	I	26-50	64	8	28	SCL
		II	25-50	56	10	34	CL
		III	28-50	48	6	46	SC
			Min.	48	6	28	
			Max.	64	10	46	
			Mean	56	8	36	
			Std. Dev.	8	2	9	
Iwo	The Epipedons	I	0-30	68	12	20	SCL
		II	0-36	72	12	16	SL
		III	0-31	74	12	14	SL
			Min.	68	12	14	
			Max.	74	12	20	
			Mean	71	12	17	
			Std. Dev.	3	0	3	
	Subsurface horizons	I	30-50	62	12	26	SL
		II	36-50	48	8	44	SC
		III	31-50	66	8	26	SCL
			Min.	48	8	26	
			Max.	66	12	44	
			Mean	59	9	32	
			Std. Dev.	9	2	10	
Oba	The Epipedons	I	0-28	68	10	22	SCL
		II	0-27	68	8	24	SCL
		III	0-28	70	12	18	SC
			Min.	68	8	18	
			Max.	70	12	24	
			Mean	69	10	21	
			Std. Dev.	1	2	3	
	Subsurface horizons	I	27-50	48	10	42	SC
		II	28-30	52	8	40	SC
		III	28-50	48	6	46	SC
			Min.	48	6	40	
			Max.	52	10	46	
			Mean	49	8	43	
			Std. Dev.	2	2	3	
Jago	The Epipedons	I	0-26	76	10	14	SL
		II	0-20	72	10	18	SL
		III	0-26	80	8	12	SL
			Min.	72	8	12	
			Max.	80	10	18	
			Mean	76	9	15	
			Std. Dev.	4	1	3	
	Subsurface horizons	I	26-50	80	8	12	SL
		II	20-50	66	12	22	SCL
		III	26-50	66	8	26	SCL
			Min.	66	8	12	
			Max.	80	12	26	
			Mean	71	9	20	
			Std. Dev.	8	2	7	

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Table 3
Chemical properties

Soil Series	Horizon	Mini Pit	Depth (cm)	pH (H_2O)	pH (KCl)	O.M (%)	N (%)	Avail. P (mg kg^{-1})	Ca^{2+} (c molkg^{-1})	Mg^{2+} (c molkg^{-1})	K^+ (c molkg^{-1})	Na^+ (c molkg^{-1})
Egbeda	The Epipedons	I	0-26	6.6	5.5	2.22	0.11	9.15	4.30	1.90	0.20	0.02
		II	0-25	5.1	5.1	3.63	0.18	11.34	3.00	1.19	0.40	0.03
		III	0-28	6.9	6.4	2.29	0.11	12.15	2.90	1.70	0.30	0.02
			Min.	5.1	5.1	2.22	0.11	9.15	2.90	1.19	0.20	0.02
			Max.	6.9	6.4	3.63	0.18	12.15	4.30	1.90	0.40	0.03
			Mean	6.2	5.7	2.71	0.14	10.88	3.40	1.60	0.30	0.02
			Std. Dev.	0.9	0.6	0.79	0.04	1.55	0.78	0.37	0.10	0.01
	Subsurface horizons	I	26-50	5.5	4.4	0.61	0.03	8.24	2.50	1.80	0.20	0.02
		II	25-50	6.0	4.7	0.87	0.04	11.50	2.30	0.80	0.20	0.03
		III	28-50	5.2	5.7	1.41	0.07	12.61	1.90	0.80	0.30	0.02
			Min.	5.2	4.4	0.61	0.03	8.24	1.90	0.80	0.20	0.02
			Max.	6.0	5.7	1.41	0.07	12.61	2.50	1.80	0.30	0.03
			Mean	5.5	5.0	0.96	0.05	10.78	2.23	1.13	0.23	0.02
			Std. Dev.	0.4	0.7	0.41	0.02	2.27	0.31	0.58	0.06	0.01
Iwo	The Epipedons	I	0-30	4.8	3.6	0.81	0.04	4.91	5.10	1.70	0.90	0.60
		II	0-36	6.2	5.3	0.47	0.02	5.83	5.40	1.90	0.30	0.40
		III	0-31	6.4	5.5	0.81	0.04	7.63	4.70	1.50	0.20	0.40
			Min.	4.8	3.6	0.47	0.02	4.91	4.70	1.50	0.20	0.40
			Max.	6.4	5.5	0.81	0.04	7.63	5.40	1.90	0.90	0.60
			Mean	5.8	4.8	0.70	0.03	6.12	5.07	1.70	0.47	0.47
			Std. Dev.	0.9	0.9	0.20	0.01	1.38	0.35	0.20	0.38	0.12
	Subsurface horizons	I	30-50	6.6	5.9	0.13	0.01	3.80	3.00	1.50	0.10	0.08
		II	36-50	5.8	4.7	0.13	0.01	5.59	5.00	1.30	0.20	0.02
		III	31-50	5.5	4.9	0.07	0.01	7.32	4.70	1.40	0.20	0.03
			Min.	5.5	4.7	0.07	0.01	3.80	3.00	1.30	0.10	0.02
			Max.	6.6	5.9	0.13	0.01	7.32	5.00	1.50	0.20	0.08
			Mean	6.0	5.0	0.11	0.01	5.57	4.23	1.40	0.17	0.04
			Std. Dev.	0.6	0.7	0.03	0.00	1.76	1.08	0.10	0.06	0.03
Oba	The Epipedons	I	0-28	6.5	5.3	2.69	0.13	6.34	6.10	1.80	0.30	0.20
		II	0-27	6.1	5.1	3.23	0.16	8.79	3.90	1.90	0.40	0.02
		III	0-28	6.7	5.6	2.56	0.13	3.70	3.00	2.00	0.50	0.04
			Min.	6.1	5.1	2.56	0.13	3.70	3.00	1.80	0.30	0.02
			Max.	6.7	5.6	3.23	0.16	8.79	6.10	2.00	0.50	0.20
			Mean	6.4	5.3	2.83	0.14	6.28	4.33	1.90	0.40	0.09
			Std. Dev.	0.3	0.3	0.36	0.02	2.55	1.59	0.10	0.10	0.10
	Subsurface horizons	I	28-50	5.7	4.4	0.54	0.03	3.81	2.10	1.70	0.30	0.02
		II	27-50	5.1	5.0	1.34	0.07	3.69	1.90	1.80	0.30	0.05
		III	28-50	5.2	4.1	0.34	0.02	8.79	1.8	1.7	0.32	0.02
			Min.	5.1	4.1	0.34	0.02	3.69	1.80	1.70	0.30	0.02
			Max.	5.7	5.0	1.34	0.07	8.79	2.10	1.80	0.32	0.05
			Mean	5.3	4.5	0.74	0.04	5.43	1.93	1.73	0.31	0.03
			Std. Dev.	0.3	0.5	0.53	0.03	2.91	0.15	0.06	0.01	0.02
Jago	The Epipedons	I	0-26	5.6	4.4	0.61	0.03	4.38	4.30	1.80	0.20	0.03
		II	0-20	6.3	5.5	2.02	0.10	2.85	3.00	1.10	0.1	0.03
		III	0-26	5.8	4.8	0.61	0.03	4.54	3.3	1.3	0.2	0.04
			Min.	5.6	4.4	0.61	0.03	2.85	3.00	1.10	0.10	0.03
			Max.	6.3	5.5	2.02	0.10	4.54	4.30	1.80	0.20	0.04
			Mean	5.9	4.9	1.08	0.05	3.92	3.53	1.40	0.17	0.03
			Std. Dev.	0.4	0.6	0.81	0.04	0.93	0.68	0.36	0.06	0.01
	Subsurface horizons	I	26-50	6.3	3.5	0.07	0.01	2.48	2.50	0.90	0.20	0.03
		II	20-50	4.3	3.2	0.13	0.01	2.08	2.90	0.80	0.10	0.04
		III	26-50	4.8	4.7	0.07	0.01	1.39	1.90	0.80	0.10	0.05
			Min.	4.3	3.2	0.07	0.01	1.39	1.90	0.80	0.10	0.03
			Max.	6.3	4.7	0.13	0.01	2.48	2.90	0.90	0.20	0.05
			Mean	5.1	3.8	0.09	0.00	1.98	2.43	0.83	0.13	0.04
			Std. Dev.	0.9	0.8	0.03	0.00	0.55	0.50	0.06	0.06	0.01

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(For the subsurface soils, pH values in H_2O ranged from 5.2–6.0 (mean, 5.5 ± 0.4), 5.5–6.6 (mean, 6.0 ± 0.6), 5.1–5.7 (mean, 5.3 ± 0.3) and 4.3–6.3 (mean, 5.1 ± 0.9) and in 1 M KCl solution, however, the values ranged from 4.7–5.9 (mean, 5.0 ± 0.7), 4.1–5.0 (mean, 4.5 ± 0.5) and 3.2–4.7 (mean, 3.8 ± 0.8) for Egbeda, Iwo, Oba and Jago soil series, respectively. The pH was less variable within the soil series, irrespective of the depth of sampling, as the standard deviations were less than a unit within each soil series for both the epipedons and subsurface soils. This is in agreement with Akinbola *et al* (2006) and Ojetade *et al* (2016) who reported similar observation. Within the epipedons, there were positive significant correlations of organic matter (0.969) and total nitrogen (0.955), with pH (Table 4). Organic matter (OM) content within the soils was relatively high, especially within the epipedons across the various soil series investigated. Phytocycling and improved activities of soil microbes as a result of optimum aeration and moisture regimes within the epipedons could be accountable (Olayinka 2009; Ojetade *et al.*, 2021). However, the content of OM in the soils of Iwo and Jago series was relatively low within the epipedons and subsurface horizons. The coarse/porous nature of the soils and sparse vegetal cover may be responsible. Within the epipedons, OM ranged from 2.22–3.63% (mean, 2.71 ± 0.79), 0.47–0.81% (mean, 0.70 ± 0.20%), 2.56–3.23% (mean, 2.83 ± 0.36%) and 0.61–2.02% (mean, 1.08 ± 0.81%) for Egbeda, Iwo, Oba and soil Jago soil series, respectively (Table 3). Correlation (0.986) between the OM and total nitrogen was positively highly significant (Table 4). Iwo, Oba and Jago soil series, respectively. The soils' total nitrogen (T-N) content varied from medium to high within the soils series of Oba and Egbeda while it varied from low to medium in Iwo and Jago soil, according to Sobulo and Adepetu (1987) who classified total nitrogen into < 0.1%, (low), 0.1–0.2% (medium) and > 0.2% (high). Specifically, within the epipedons, T-N ranged from 0.11–0.18% (mean, 0.14 ± 0.04%), 0.02–0.04% (mean, 0.03 ± 0.01%), 0.13–0.16% (mean, 0.14 ± 0.02%) and 0.03–0.10 (mean, 0.05 ± 0.04%) for Egbeda, Iwo, Oba and Jago soil series, respectively. For the subsurface horizons, it ranged from 0.03–0.07% (mean, 0.05 ± 0.02%) and 0.02–0.07% (mean, 0.04 ± 0.03%) for Egbeda and Oba while it remained constant for Iwo and Jago soil series, respectively. Therefore, the T-N content of the Egbeda and Oba soil series would suffice for optimum cacao production. The values were higher than the minimum value of 0.09% reported as ideal for cacao production (Egbe *et al.*, 1989). However, Iwo and Jago soil series would need additional inputs of nitrogenous fertilizer for optimum cacao production. For the subsurface horizons, OM ranged from 0.61–1.41% (mean, 0.96 ± 0.41%), 0.07–0.13% (mean, 0.11 ± 0.03%), 0.34–1.34% (mean, 0.74 ± 0.53%) and 0.07–0.13% (mean, 0.09 ± 0.03%) for Egbeda, Iwo, Oba and Jago soil series, respectively. The available phosphorus (avail-P) within the epipedons ranged from 9.15–12.15 mg kg^{-1} (mean, 10.88 ± 1.55 mg/kg),

Table 4. *Correlation Matrix of selected soil properties with litters*

	Sand	Silt	Clay	pH	O.M.	N	Avail P	Ca^{2+}	Mg^{2+}	K^+	Na^+	Litter Qty.	Tissue		
													P	K^+	Na^+
							Correlation value (r)								
Sand															
Silt	-.381														
Clay	-.925	.000													
pH	-.614	-.481	.863												
O.M	-.557	-.464	.794	**.969***											
N	-.557	-.464	.794	**.955***	**0.986****										
Avail P	-.421	-.115	.503	.622	.789	.789									
Ca^{2+}	-.518	.876	.199	-.318	-.421	-.421	-.377								
Mg^{2+}	.670	-.596	-.479	-.226	-.357	-.357	-.725	-.333							
K^+	.797	-.350	-.718	-.544	-.644	-.644	-.836	-.185	.940						
Na^+	-.254	**.967***	-.124	-.607	-.634	-.634	-.363	.920	-.373	-.116					
Litter Qty.	-.467	-.050	.525	.609	.774	.774	**.998****	-.313	-.770	-.871	-.302				
Tissue P	-.319	-.271	.456	.655	.821	.821	**.987***	-.519	-.604	-.743	-.506	**.973***			
Tissue K^+	-.867	-.125	**.990***	.925	.871	.871	.571	.057	-.444	-.708	-.259	.585	.544		
Tissue Na^+	-.022	-.200	.106	.338	.560	.560	.911	-.583	-.560	-.592	-.423	.893	.928	.197	

* Significant correlation at the 0.05 level (2-tailed). ** Significant correlation at the 0.01 level (2-tailed).

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4.91–7.63 mg kg^{-1} (mean, 6.12 ± 1.38 mg kg^{-1}), 3.70–8.79 mg kg^{-1} (mean, 6.28 ± 2.55 mg kg^{-1}) and 2.85–4.54 mg kg^{-1} (mean, 3.92 ± 0.93 mg kg^{-1}) for Egbeda, Iwo, Oba and Jago soil series, respectively. Within the epipedons, a highly positive significant correlation (0.998) existed between the available P and leave litter quantity (Table 5). For the subsurface soils, available P values ranged from 8.24–12.61 mg kg^{-1} (mean, 10.78 ± 2.27), 3.80–7.32 mg kg^{-1} (mean, 5.57 ± 1.76), 3.69–8.79 mg kg^{-1} (mean, 5.43 ± 2.91 mg kg^{-1}) and 1.39–2.48 mg kg^{-1} (mean, 1.98 ± 0.55 mg kg^{-1}) for Egbeda, Iwo, Oba and Jago soil series, respectively. The values were within the low to medium range reported by Adepetu (1990) who ranked the available P content of Nigeria soils into < 8 mg kg^{-1} (low), 8-20 mg kg^{-1} (medium) and >20 mg kg^{-1} (high). It was only the soils of Egbeda series that had adequate available P content. The soils of Iwo, Oba and Jago series would need supplemental application of phosphorus fertilizers for optimal cacao production since the values obtained were below the critical value. Ibiremo *et al* (2011) reported that 10 ppm of available P would be required for optimal cacao production. The contents of exchangeable bases across the four soil series studied were relatively low. It was reported that upland soils of central western Nigeria contained low exchange capacity due to the kaolinitic nature of their clay type (Smyth and Montgomery, 1962). The concentrations of the basic cations were generally low across the soil series. These values, still, decreased further with soil depth (Table 3). This was in accordance with Sehgal *et al* (1972) who reported that the relative abundance of exchangeable bases on the surface soils was due to continuous recharge by mobile constituents released by the decomposition of organic materials deposits on soil surface. Exchangeable calcium contributed the most, while exchangeable sodium contributed the least, to the total exchangeable bases. Specifically, for the epipedons, the values of exchangeable calcium ranged from 2.90–4.30 cmol kg^{-1} (mean, 3.40 ± 0.78 cmol kg^{-1}), 4.70–5.40 cmol kg^{-1} (mean, 5.07 ± 0.35 cmol kg^{-1}), 3.00–6.10 cmol kg^{-1} (mean, 4.33 ± 1.59 cmol kg^{-1}) and 3.00–4.30 cmol kg^{-1} (mean, 3.53 ± 0.68 cmol kg^{-1}), that of magnesium ranged from 1.19–1.90 cmol kg^{-1} (mean, 1.60 ± 0.37 cmol kg^{-1}), 1.50–1.90 cmol kg^{-1} (mean, 1.70 ± 0.2 cmol kg^{-1}), 1.80–2.00 cmol kg^{-1} (mean, 1.90 ± 0.10 cmol kg^{-1}) and 1.10–1.80 cmol kg^{-1} (mean, 1.4 ± 0.36 cmol kg^{-1}) while that of potassium ranged from 0.20–0.40 cmol kg^{-1} (mean, 0.30 ± 0.10 cmol kg^{-1}), 0.20–0.90 (mean, 0.47 ± 0.38 cmol kg^{-1}), 0.30–0.50 cmol kg^{-1} (mean, 0.40 ± 0.10 cmol kg^{-1}) and 1.10–1.80 cmol kg^{-1} (mean, 1.4 ± 0.36 cmol kg^{-1}) for Egbeda, Iwo, Oba and Jago soil series, respectively. For the subsurface horizons, the values of exchangeable calcium ranged from 1.90–2.50 cmol kg^{-1} (mean, 2.23 ± 0.31 cmol kg^{-1}), 3.00–5.00 cmol kg^{-1} (mean, 4.23 ± 1.08 cmol kg^{-1}), 1.80–2.10 cmol kg^{-1} (mean, 1.93 ± 0.15 cmol kg^{-1}) and 1.90–2.90 cmol kg^{-1} (mean, 2.43 ± 0.50 cmol kg^{-1}), that of magnesium ranged from 0.80–1.80 cmol kg^{-1} (mean, 1.13 ± 0.58 cmol kg^{-1}), 1.30–1.50 cmol kg^{-1} (mean, 1.40 ± 0.10 cmol kg^{-1}), 1.70–1.80 cmol kg^{-1} (mean, 1.73 ± 0.06 cmol kg^{-1}) and 0.80–0.90 cmol kg^{-1} (mean, 0.83 ± 0.06 cmol kg^{-1}) while that of potassium ranged from 0.20–0.30 cmol kg^{-1} (mean, 0.23 ± 0.06 cmol kg^{-1}), 0.20–0.17 cmol kg^{-1} (mean, 0.17 ± 0.06 cmol kg^{-1}), 0.30–0.32 cmol kg^{-1} (mean, 0.31 ± 0.01 cmol kg^{-1}) and 0.10–0.20 cmol kg^{-1} (mean, 0.13 ± 0.06 cmol kg^{-1}) for Egbeda, Iwo, Oba and Jago soil series, respectively. The values for exchangeable calcium were below the critical value of 5.0 cmolkg^{-1} soil for optimal cacao production (Ipinmoroti *et al.,* 2014). Therefore, application of calcium-containing fertilizer would be required for optimal cacao yields. The exchangeable Mg content was higher than 0.8 cmol kg^{-1} soil which is the minimum required for optimal cacao production (Ipinmoroti *et al.,* 2009). Potassium content of the soils was above the critical level of 0.03 cmolkg^{-1} for optimal cacao production (Aikpokpodion, 2010). Therefore, potassium fertilizer supplement would not be necessary for the soils for optimal cacao yields. The values of exchangeable sodium were generally low across the plantations, less than 1 cmolkg^{-1}, the threshold above which it may become harmful to plants (Uwitonze *et al.*, 2016). However, the essentiality of sodium in plant nutrition has not been established.

Litter production and nutrient uptake within the plantation

Table 5 shows the quantity of litters produced and nutrient content of the litters across the soil series. Litter production on Egbeda soil series was highest while that on Jago series was least. This could have resulted from higher clay content in Egbeda soil series which allowed for moisture retention longer after the stoppage of rains, and favourable moisture/aeration regime while the sandy soils of Jago series, located at lower topographic position with the attendant higher water table which might have prevented ade-

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quate aeration by the plant roots. Litter production across the sites fallows the sequence: Egbeda> Oba> Iwo >Jago with 6.00–8.50 t ha^{-1} (mean, 7.50 ± 1.32 t ha^{-1}), 4.00–7.00 t ha^{-1} (mean, 5.50 ± 3.51 t ha^{-1}), 4.00–5.50 t ha^{-1} (mean, 4.57 ± 0.81 t ha^{-1}) and 2.00–4.50 t ha^{-1} (mean, 3.57 ± 1.37 t ha^{-1}) (Table 5). The variation among the three sample locations within each soil series was least in the soils of Iwo series with standard deviation of 0.81. Variation was highest in Oba series with standard deviations of 3.51, followed by Egbeda and Jago series with deviations from the means of 1.32 and 1.37, respectively. The highest standard deviation was observed in Oba soil series. They occupied lower slope portion which encouraged movement of litter materials into and out of the location. Positive significant correlation (0.990) existed between clay and tissue K. Tissue phosphorus of cacao litter across the soil series was substantially high (Table 5). It ranged between 150.50 and 236.18 mg kg^{-1}, the soils of Egbeda series having the highest. Incidentally, the soils of Egbeda series also had the highest soil available P for both the surface horizons {9.15–12.15 mg kg^{-1} (mean, 10.88 ± 1.55 mg kg^{-1})} and sub surface horizons {8.24–12.61 mg kg^{-1} (mean, 10.78 ± 2.27 mg kg^{-1})} (Table 3). This was followed by those of Oba, Iwo and Jago series with 168.50–215.60 mg kg^{-1} (mean, 189.10 ± 24.10 mg kg^{-1}), 153.82–171.49 mg kg^{-1} (mean, 163.64 ± 9.00 mg kg^{-1}) and 150.50–174.40 mg kg^{-1} (mean, 162.50 ± 11.95 mg kg^{-1}). Positive significant correlation (0.973) existed

Table 5
Litter production and nutrient content by cacao on different soil series

Soil Series	Sample Number	Litter Quantity	Tissue		
			P	K^+	Na^+
		(mg kg^{-1})			
Egbeda	I	8.50	221.47	7.60	1.00
	II	6.00	236.18	5.69	1.67
	III	8.00	227.35	7.60	1.00
	Min.	6.00	221.47	5.69	1.00
	Max.	8.50	236.18	7.60	1.67
	Mean	7.50	228.33	6.96	1.22
	Std. Dev.	1.32	7.40	1.10	0.39
Iwo	I	4.20	153.82	6.64	0.66
	II	5.50	165.60	4.25	0.33
	III	4.00	171.49	5.68	0.70
	Min.	4.00	153.82	4.25	0.33
	Max.	5.50	171.49	6.64	0.70
	Mean	4.57	163.64	5.52	0.56
	Std. Dev.	0.81	9.00	1.20	0.20
Oba	I	7.00	183.20	7.12	0.67
	II	4.00	215.60	6,64	0.67
	III	4.50	168.50	10.5	0.67
	Min.	4.00	168.50	7.12	0.67
	Max.	7.00	215.60	10.50	0.67
	Mean	5.50	189.10	8.81	0.67
	Std. Dev.	3.51	24.10	5.36	0.00
Jago	I	2.00	174.4	4.73	0.66
	II	4.20	162.6	4.25	0.66
	III	4.50	150.9	5.20	0.33
	Min.	2.00	150.50	4.25	0.33
	Max.	4.50	174.40	5.20	0.66
	Mean	3.57	162.50	4.73	0.55
	Std. Dev.	1.37	11.95	0.48	0.19

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between tissue P and litter quantity within the epipedons (Table 4). The soils of Oba series had the plant with the highest tissue K (7.12–10.50 mg kg^{-1} (mean, 8.8 ± 5.36 mg kg^{-1}). This was followed by the soils of Egbeda, Iwo and Jago series with 5.69–7.60 mg kg^{-1} (mean, 6.96 ± 1.10 mg kg^{-1}), 4.25–6.64 mg kg^{-1} (mean, 5.52±1.20 mg kg^{-1}) and 4.25–5.20 mg kg^{-1} (mean, 4.73 ± 0.48 mg kg^{-1}). However, the lowest standard deviation was observed in the tissue K for the soils of the Jago series (0.48) followed by Egbeda, Iwo and Oba series with standard deviations of 1.10, 1.20 and 5.36, respectively. The tissue sodium was generally low across the soil series. The epipedons are too thin, too light and contained lower organic matter content to qualify as histic, mollic or melanic epipedon. They would, therefore, classify as ochric epipedons based on these features (USDA Soil Survey Staff, 1999).

Conclusions

The study examined the influence of cacao plantation on the epipedons' characteristics and highlighted their salient properties. The epipedons were fairly thick, brightly coloured and well drained, with good internal drainage. The subsurface horizons varied from slightly sticky, slightly-plastic to very sticky and very plastic. Clay content was more in the subsoils, indicating the soils' capacity to hold moisture for crop use after stoppage of rain without experiencing moisture stress. The soils are devoid of gravel within 50-cm of the surface. The soils acidity was low. It ranged between medium acid and slightly acid. Organic matter content was relatively high. The soils' total nitrogen content varied from medium to high within Egbeda and Oba soil series while it varied from low to medium in Iwo and Jago series, available phosphorus for the surface soils ranged low to medium. exchangeable Ca was low, while Mg and K values were adequate for optimal cacao production. Litter production within the plantations was fairly high. Tissue phosphorus of cacao across the plantations was substantially high. The soils of Iwo, Oba and Jago series would need supplemental application of nitrogen and phosphorus fertilizers for optimal cacao production.

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