

Developing an Interactive Three Dimensional (3D) Digital Soil Map for Some Part of Ondo State, Tropical Soil, Nigeria

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ABSTRACT

Reliable soil information is fundamental to sustainable land management, agricultural productivity, and environmental planning. Digital Soil Map (DSM) enable better understanding of soil variability especially in tropical regions where soil properties vary considerably across space and depth. This study aimed to develop an interactive three-dimensional (3D) DSM for Ondo North tropical soil, Southwestern Nigeria using soil pedological/morphological characteristics, physico-chemical properties, macro- and micro-nutrients properties of the study area. Soil pedon (profile pit; 1.0×1.5×2.0m) were dug, and 0-5, 5-15, 15-30, 30-60, 60-100, and 100-200 cm depthwise samples were taken. Field observations were collected by inspection for color, texture, structure, drainage slope, land use/crops, mottle, consistence, inclusion using field data form. Physico-chemical properties, macro- and micro-nutrients contents of soil samples were obtained using standard procedure. Soil organic carbon (SOC) and organic matter (SOM) were typically found highest in surface layers (0-5 cm) and ranged respectively from 0.03 to 4.28 % and 0.10 to 5.98 % across the study sites. Soil pH values were slightly acidic to neutral conditions, ranging from 5.01 to 6.97 with sub soil more acidic than the surface soil layers. Electrical conductivity (EC) values varied significantly from 3.00 to 657.00 $\mu\text{S}/\text{cm}$, with peak values mostly in surface layers (103 to 657.00 $\mu\text{S}/\text{cm}$). The redox potential (mV) ranged from 21.00 mV (more reduced conditions) to 186.00 mV (more oxidized conditions) for surface soil and 36.00 to 186.00 mV for subsoil layer. Organic nitrogen (ON) values vary from 0.01 to 3.74%, highest in surface layers (0.04 to 3.74%) and lower in the subsoil (0.01 to 0.89%). Phosphorus (P) content varied widely, from 0.01 to 0.59 mg/kg, with the highest concentrations in surface layers (0.01 to 0.45 mg/kg) and lowest concentrations in subsoil (0.03 to 0.59mg/kg). Most sites exhibited decreasing organic matter, nitrogen, and phosphorus with depth, exchangeable bases were dominated by calcium followed by magnesium, potassium and sodium which is low indicating the absence of sodicity risk. Moderate Iron and Manganese concentration respectively indicate advanced tropical weathering, Copper and Zinc exhibited surface enrichment linked to surface enrichment linked to organic matter while Chromium were generally low reflecting lithogenic origin and minimal contamination. The morphological analysis indicated that the Akoko South East and some part in Akoko North West of the study area consists of well-drained soils with textures ranging from loamy sand to clay and moderate prismatic structures. In contrast, other areas feature moderately drained soils with textures varying from loamy to clay, this brings a better view without pervasiveness for sustainable agricultural productivity in the study area.

Keywords: pedological/morphological characteristics, physicochemical properties, macro and micro nutrients, DSM, SOC

INTRODUCTION

Soil is a dynamic natural resource consisting of mineral particles, organic matter, water, air and living organisms. It supports plant growth, nutrient cycling, biodiversity, water regulation and several human activities. Soil properties vary considerably across landscapes because of differences in parent material, climate, organisms, relief, land use and time. Understanding these variations is essential for sustainable agriculture, environmental conservation and effective land-use planning (Adewara et al 2024).

The physical and chemical characteristics of soil, including texture, pH, organic carbon, bulk density, electrical conductivity, cation exchange capacity and nutrient concentrations, influence soil fertility and agricultural productivity. Soil fertility refers to the ability of soil to supply essential nutrients to plants in adequate quantities and appropriate proportions. Important macronutrients include nitrogen, phosphorus, potassium, calcium, magnesium and sulfur, while micronutrients include iron, manganese, zinc, copper, boron and molybdenum. Their availability is influenced by soil pH, organic matter, texture, moisture, clay content, cation exchange capacity and other soil properties (Dada et al.,2020)

Soil formation, known as pedogenesis, is controlled principally by five interacting factors: climate, organisms, relief, parent material and time. Parent material influences the mineral composition and initial characteristics of soil, while climate affects weathering, leaching and biological processes. Relief controls drainage, erosion, deposition and moisture distribution. Organisms contribute organic residues and nutrient cycling, while time determines the duration of soil-forming processes. Recent developments in pedology have expanded the discipline to include pedometrics, spectral pedology and other quantitative approaches for understanding soil variation (Srivata and Yetgin,2024).

Pedology is concerned with the genesis, morphology, classification and distribution of soils. Pedological investigation provides information about soil horizons, colour, texture, structure, drainage, parent material and landscape position. Such information is important for evaluating soil behaviour, agricultural suitability and environmental functions. Contemporary pedology increasingly combines traditional field observations with quantitative and digital techniques, thereby improving the understanding and mapping of spatial soil variability (Bourma et al., 2022, Corti et al., 2024).

Soil fertility is influenced by several physical and chemical properties. Soil pH is particularly important because it regulates nutrient availability, microbial activity, and the solubility of potentially toxic elements. Cation exchange capacity indicates the ability of soil colloids to retain and exchange nutrient cations. Organic matter contributes to nutrient supply, aggregation, water retention, microbial activity, and cation exchange capacity. Soil texture affects water retention, drainage, aeration, and nutrient retention, while bulk density provides an indication of soil compaction and pore space. Electrical conductivity is commonly used to assess soluble salt concentration and potential salinity problems.(Hassan et al.,2024, Liu et al., 2024, Mesele et al., 2024, Wan et al, 2025, Vakeri et al., 2025,).

The assessment of soil fertility therefore requires laboratory determination of important soil properties and nutrients. Soil pH may be determined using soil-water, calcium chloride or potassium chloride suspensions. Electrical conductivity can be determined from soil-water extracts. Organic carbon can be estimated using wet oxidation or dry combustion techniques, while exchangeable bases such as calcium, magnesium, potassium and sodium can be extracted and quantified using appropriate analytical procedures. Available phosphorus may be determined using extractants such as Bray, Olsen or Mehlich methods depending on soil characteristics. Micronutrients such as iron, manganese, zinc and copper can also be determined using appropriate extraction and instrumental methods.(Al-Obaidi et al.,2023, Choudhary et al.,2023, Hicks-Pries et al., 2024Saleem et al., 2023,

The study area is located in the northern part of Ondo State, Nigeria, and covers selected areas within Owo, Ose and the Akoko axis. The area contains six Local Government Areas: Akoko North-East, Akoko North-West, Akoko South-East, Akoko South-West, Ose and Owo. It experiences distinct wet and dry seasons and supports forest and savanna-influenced vegetation. Agriculture is an important economic activity, with crops such as cocoa, cassava and maize cultivated in the area. The geological environment includes crystalline rocks such as granite, gneiss, migmatite and charnockite. Variations in geology, relief, climate, vegetation and land use contribute to differences in soil characteristics across the landscape.

Despite the agricultural importance of Ondo North, detailed and easily accessible spatial information on its soil properties and fertility status remains limited. Conventional soil surveys are often expensive, labour-intensive and time-consuming, and their resulting maps may not adequately represent fine-scale spatial variability. The absence of detailed soil information can result in inappropriate crop selection, inefficient fertilizer application, poor irrigation decisions, ineffective land-use planning and increased risk of soil degradation.

Digital Soil Mapping (DSM) provides an important approach for addressing these limitations. DSM involves the prediction and mapping of soil classes or properties using field and laboratory observations together with geographically referenced environmental covariates. These covariates may include elevation, slope, climate, vegetation indices, remote-sensing information, geology and other landscape characteristics. Statistical and machine-learning models are then used to establish relationships between measured soil properties and environmental variables and to predict soil properties at unsampled locations (Dutta et al., 2024)

Digital soil mapping has become particularly important because it can produce detailed, continuous and potentially updatable soil information more efficiently than conventional mapping. A broad-scale review found that DSM is increasingly used to map properties such as soil organic carbon, texture and other important soil characteristics, although prediction accuracy can decline with increasing soil depth (Chen et al., 2022). This is particularly relevant to the present study because the proposed three-dimensional digital soil mapping approach requires information on soil properties at different depths rather than only at the surface.

The need for digital soil information is especially important in Africa. Recent reviews have identified challenges including inadequate sampling density, limited availability of suitable environmental covariates, positional errors in legacy soil data and insufficient reporting of prediction uncertainty. Many African DSM studies have focused primarily on the topsoil, while deeper soil layers remain comparatively underrepresented (Applications and Challenges of Digital Soil Mapping in Africa, 2024). These limitations demonstrate the need for detailed local studies that combine field sampling, laboratory analysis and spatial modelling.

Nigeria has developed digital soil information from existing soil-survey data, but national-scale datasets may not adequately capture the detailed variability needed for local agricultural management. Local digital soil mapping can therefore complement existing national information by providing more detailed information about soil properties within specific landscapes.

For Ondo North, integrating pedological observations with soil fertility analyses and digital spatial modelling can provide a better understanding of the distribution and variability of soil properties. A three-dimensional digital soil map can represent variations in soil characteristics across both geographic location and depth, thereby providing more useful information for agricultural planning and soil management.

Therefore, this study aims to develop an interactive three-dimensional (3D) digital soil map of the tropical soils of Ondo North. Specifically, the study will evaluate the pedological characteristics of the soils, determine their physical and chemical properties and macro- and micronutrient status, and construct 3D digital maps showing the spatial distribution of selected soil properties.

The study is expected to provide useful information for farmers, researchers, agricultural extension personnel, environmental managers and policy makers. The resulting information can support appropriate crop selection, fertilizer management, irrigation planning, soil conservation, land-use planning and sustainable agricultural development. It can also provide baseline information for future monitoring and refinement of digital soil information in Ondo State.

MATERIALS AND METHOD

Materials

GPS land area meter, sample bags, weighing balance, mortar and pestle, filter paper, funnel, beakers, burette, pipette, volumetric flasks, conical flask, retort stand, sieve, sample bottle, soil samples.

Reagents

Potassium dichromate (BDX, England), concentrated sulphuric acid (BDX, England), phosphoric acid (BDX, England), ferrous ammonium sulphate (Sigma-Aldrich, Germany), diphenylamine (BDX, England), ammonium molybdate (Sigma-Aldrich, Germany), hydrochloric acid (BDX, England), ammonium fluoride (Sigma-Aldrich, Germany), ammonium hydroxide (Sigma-Aldrich, Germany), acetic acid (BDX, England).

Equipment

UV Spectrophotometer, Atomic Absorption Spectrometry (AAS), Mechanical Shaker, pH meter, Conductivity meter.

Description of the Study Area

Ondo north is located in the northern part of Ondo State, Nigeria. It is bordered by Ondo central to the east, Edo state to the south, Ekiti state to the north and Kogi state to the west. The state encompasses several local government areas, including; akoko north-west, akoko north –west, akoko south- east, akoko south-west, ose and owo. (Ige *et al.*, 2020). Ondo north is predominantly agrarian, with agriculture serving as the primary occupation of a significant portion of the population. Major crops grown in the district include cocoa, palm oil, cassava, yam, maize, and vegetables (Adeleye *et al.*, 2020). The state also has significant mineral resources such as limestone, sandstone, kaolin, and clay, which contribute to its economic development (Olade 2019). Ondo State lies between latitude 5°45'N and 7°52'N and longitude 4°20'E and 6°E. The state covers an area of approximately 15,500 square kilometers, with population of about 5.6 million people (Jeje *et al.*, 2023) (Fig. 1).

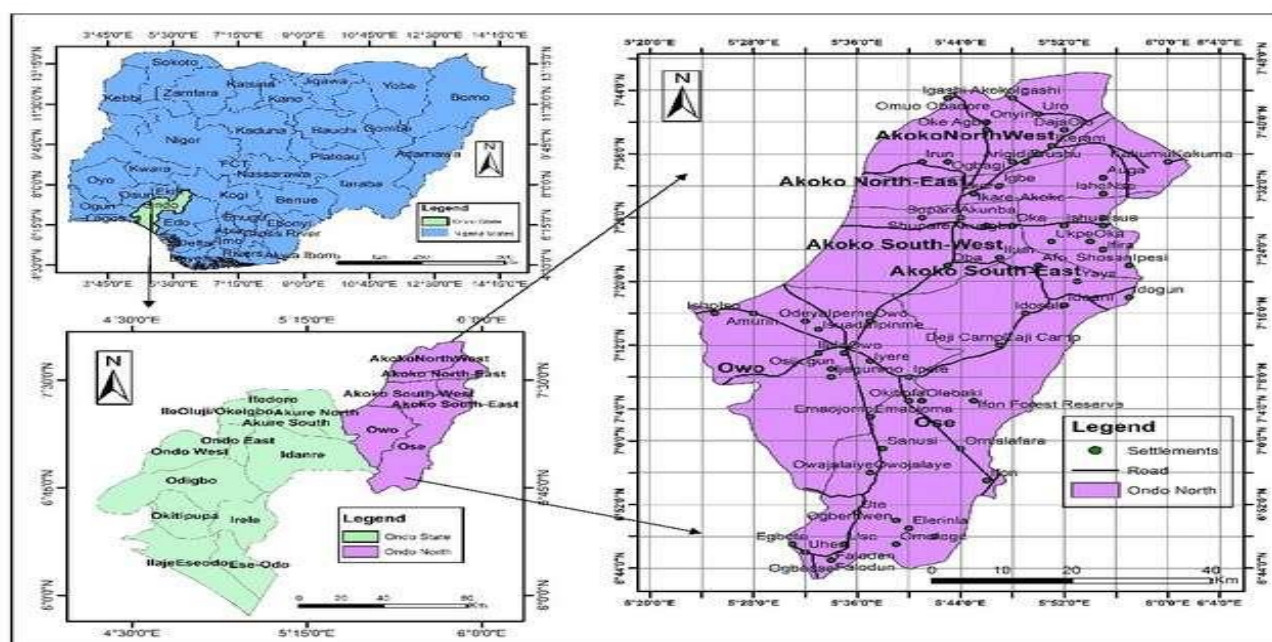


Fig 1: Map of the study area

Field Studies and Sampling Methodology

The study area was sampled on a regular 20 × 20 km grid; within selected grid cells, soil pits (1.0 × 1.5 × 2.0 m) were excavated and soil samples were taken from standard depth intervals (0 – 5, 5 – 15, 15 – 30, 30 – 60, 60 – 100 and 100 – 200 cm) in accordance with Global Soil Map/WoSIS depth-slicing conventions for profile-based datasets (Pondthai *et al.*, 2025) (Plate 3.1). Field morphological characteristics were recorded by examining the profile physically and Muncell Colour Chart. These observations were recorded in pre-data sheet (Figure 3.2) and georeferenced using Garmin GPS units (Garmin Etrex 10). Samples were placed in airtight polyethylene bags, appropriately labeled on the field and transported to the laboratory for drying, preparation and analysis (Dada *et al.*, 2020).

Sample Preparation

The soil samples were air-dried in an open dust free laboratory with constant turning. Stones, root debris in the soil were removed during the period of drying. The soil samples were disaggregate using a mortar and pestle and then sieved using a 2mm sieve. The sieved soil samples were then kept in polyethylene bags labeled

accordingly and kept in cool dry place pending the analysis. Precautions were taken to avoid contamination during sampling, drying and storage (Grahmann *et al.*, 2022).

Determination of soil morphological properties

Field observations, including altitude, slope, vegetation cover, surface drainage, and other site characteristics, were done by physical inspection following expert guidance and recorded in the pre-data sheet following standard procedures outlined in the *Field Book for Describing and Sampling Soils* (USDA-NRCS, 2023) and the *FAO Guidelines for Soil Description* (FAO, 2022).

Physico-chemical, micro and macronutrient properties of the soil samples

Determination of pH

pH meter was calibrated with pH 7.0 and pH 4.0 buffer before use. Ten grams (10g) of the prepared soil sample was mixed with 20ml of distilled water in a 50ml beaker, and stirred with a glass rod and allowed to stay for 30mins. The pH was measured by introducing a glass probe of the pH meter into the soil solution. The reading was recorded immediately as the meter got stabilized (Sparks *et al.*, 2020).

Determination of Electrical Conductivity (EC)

The conductivity meter was calibrated with Potassium Chloride Solution (KCl) 0.01 N. Ten grams (10g) of the prepared soil sample was mixed with 20ml of distilled water in a 50ml beaker, and stirred with a glass rod and allowed to stay for 30mins. The electrode was immersed into the solution and the reading was recorded immediately as the meter got stabilized. The reading was multiplied by 1000 and was recorded in $\mu\text{S}/\text{cm}$ (Lu *et al.*, 2022).

Determination of Redox Potential (mV)

Ten grams (10 g) of the 2 mm sieved soil sample was mixed with 20 mL of distilled water in a 50 mL beaker, and stirred with a glass rod and allowed to stay for 30 mins. The redox potential was measured by introducing a glass probe of the ORP meter (Oxidation–Reduction Potential meter) into the soil solution. The reading was recorded immediately as the meter got stabilized (Boie *et al.*, 2024).

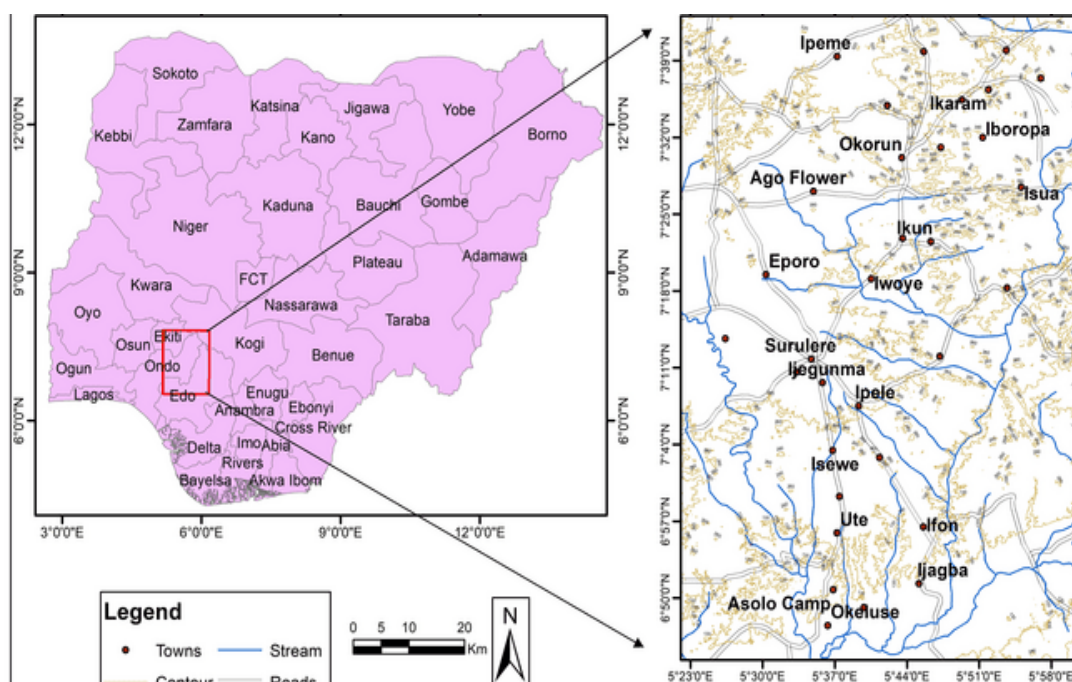


Fig. 2: map showing the sampling point



Plate1: Profile pit of the study area



Plate 2: samples exposed to sunlight for drying

Determination of Total Organic Carbon

Walkey-Black method was used to estimate the amount of organic carbon in the soil samples. One gram (1g) of the prepared soil sample was weighed into a 500 mL conical flask, 10 mL 1 N potassium dichromate solution was added using a pipette, 20 mL concentrated H_2SO_4 was added using a pipette, the conical flask was swirl to mix the suspension, and allowed to stand for 30 minutes. 200 mL distilled water was added, then 10 mL concentrated H_3PO_4 using a pipette, 10 – 15 drops diphenylamine indicator was added, and it was titrated with 0.5 M ferrous ammonium sulfate solution, until the color changes from violet-blue to green. Blank determination was similarly done and the percentage organic carbon was calculated using the titration readings percent organic carbon was calculated using the titre values. These values were used to estimate percent organic matter (Noreen *et al.*, 2023).

$$\text{oxidisable organic carbon (\%)} = \frac{(V_b - V_s) \times 0.3 \times M}{W_t} \quad 1$$

$$\text{Total organic carbon (\%)} = 1.334 \times \text{oxidisable organic carbon (\%)} \quad 2$$

$$M = \frac{10}{V_b} \quad 3$$

where:

M = Molarity of ferrous ammonium sulfate (about 0.5 M)

V_b = Volume of ferrous ammonium sulfate solution required to titrate the blank (mL)

V_s = Volume of ferrous ammonium sulfate solution required to titrate the sample (mL)

W_t = Weight of air-dry soil (g)

$0.3 = 3 \times 10^{-3} \times 100$, where 3 is the equivalent weight of C.

$Total\ organic\ matter\ (\%) = 1.724 \times total\ organic\ matter\ (\%)$ 4

Determination of Exchangeable Bases and Micro and macronutrients (Ammonium Acetate Method)

The exchangeable bases (Ca^{2+} , Mg^{2+} , K^+ , and Na^+) with the micro and macro nutrients in the soil samples were determined using the ammonium acetate extraction method (Gavlak *et al* 2005). Ten grams (10 g) of the prepared soil sample was weighed into a 100 mL beaker, and 50 mL of 1 N ammonium acetate (NH_4OAc) solution was added. The mixture was shaken on a reciprocating shaker at 200 rpm for 30 minutes to ensure complete extraction of the exchangeable cations. The suspension was then filtered through a Whatman No. 1 filter paper into a 60 mL sample bottle for analysis. The filtrate was analyzed for potassium (K^+), sodium (Na^+), (Ca^{2+}) and magnesium (Mg^{2+}), micronutrients and macronutrients concentrations were determined using an atomic absorption spectrophotometer (AAS).

Determination of soil texture

Soil texture was determined using the Bouyoucos hydrometer method (Gavlak *et al* 2005). Fifty grams (50 g) of the air-dried, ground, and sieved soil sample was weighed into a 250 mL Erlenmeyer flask. To this, 100 mL of 5% Calgon (sodium hexametaphosphate) solution was added as a dispersing agent. The mixture was swirled for several minutes to ensure complete dispersion of soil separates (sand, silt, and clay). The dispersed sample was transferred into a 1000 mL graduated cylinder, and the flask was rinsed thoroughly with distilled water to ensure all residues were included. The cylinder was then filled up to the 1,000 mL mark with distilled water. A plunger was placed in it and gently stirred the suspension over a period of about 30 seconds in order to have a homogenous mixture. The plunger was removed immediately after the mixing and the time noted. The hydrometer was then gently inserted in the suspension and the initial reading of the hydrometer (R_1) was recorded 40 seconds after the mixture. The second measurement of hydrometer (R_2) was 2 hours later after the suspension was left to settle. Both readings were noted and the hydrometer was washed off.

Calculation:

$$Clay + silt = \frac{(1st\ reading - blank)}{weight} \times 100 \quad 5$$

$$clay (\%) = \frac{(2nd\ reading - blank\ 2)}{weight} \times 100 \quad 6$$

$$silt (\%) = (clay + silt) - clay \quad 7$$

$$sand (\%) = 100 - \left[\left(\frac{R_{1st} - RC_1}{weight} \right) \right] \times 100 \quad 8$$

$$clay (\%) = \left(\frac{R_{2nd} - RC_2}{weight} \right) \times 100 \quad 9$$

$$silt (\%) = 100 - sand - clay \quad 10$$

Where:

R_1 = First hydrometer reading (40 seconds), R_2 = Second hydrometer reading (2 hours), RC_1 , RC_2 = Control hydrometer readings (blank, without soil), w = Weight of soil sample (g).

Temperature Correction: Each degree Celsius ($^{\circ}\text{C}$) above or below 20°C should be added or subtracted 0.36 g/L respectively, to calibrate the hydrometer.

Determination of Phosphorus (Bray P1 Method)

Bray-1 technique is the most common technique used in determining the amount of phosphorus available in acid soils, which is done by means of extraction with a $0.03\text{ M NH}_4\text{F}$ and 0.025 M solution of HCl . This acidic medium liberates loosely bound phosphorus, facilitating plant accessibility. A Soil-Bray solution mixture is prepared in a 1:7 ratios, shaken for 5 minutes, filtered, and phosphorus concentration is analyzed colorimetrically via spectrophotometry (Mustapha *et al.*, 2022; Dermawan *et al.*, 2024; Biassoni *et al.*, 2023; Saha and Pal 2024).

Determination of Nitrogen

The organic nitrogen content was estimated indirectly by dividing the organic carbon content by a factor of 20. This method is based on the assumption that organic matter in soil contains carbon to nitrogen in an approximate ratio 20:1 (Wang *et al.*, 2023).

Constructing 3D digital soil maps for the study area.

3D map was generated using the ArcGIS for detailed spatial and depth representation (Abdulmanov *et al.*, 2021).

RESULTS AND DISCUSSION

Morphological characteristics of soil samples from the study area

The result of the morphological characteristics of pedons from the study area are presented in Table 2.

Pedon 1(Ikaram)

The soil at Ikaram displays a notable depth-related variation, 0–5 cm, Grayish brown (10YR 5/2), 5–15 cm is Dark grayish brown (10YR 4/2) The darker colour at the surface is attributed to relatively higher organic matter accumulation from plant residues and microbial decomposition, weak to fine granular reflects active biological processes (roots, microorganisms, soil fauna) that promote aggregation. Silt loam implies mediocre parent matter weathering and excellent interrelationships among sand, silt, and clay fraction, which clarifies why mottling is scant and insignificant, Loose consistence implies good aeration and penetration of roots. This horizon is a common A horizon with moderate fertility capacity and favourable tilth to cultivation with 15–30 cm dark brown (7.5YR 3/3) indicating that this change of silt loam to silty clay is by downward movement and clay particle accumulation. Slightly sticky Fine Granular Moderate with high clay content. This is probably a transitional AB or Bt horizon with initial sign of an argillic horizon formation and also very weakly red (10R 5/4) with strong brown (7.5YR 5/6) 30–60 cm, Weak red (10R 5/4), 60–100 cm and the progressive reddening of the soils is due to the very intense weathering of the tropical areas, Clay texture predominance indicates high level of pedogenic process and Very sticky consistence reflects the very high level of clay mineral formation. These characteristics suggest formation under humid tropical conditions with strong laterization tendencies. 100+scm reddish yellow (5YR 6/8) The reddish-yellow colour reflects dominance of oxidized iron compounds (hematite and goethite) Increased mottling at depth may indicate slight periodic moisture fluctuation. Clayey nature suggests proximity to highly weathered parent material, this horizon likely represents the C horizon or highly weathered saprolite.

Pedon 2(Ago Flower)

Ago Flower lies on a gentle mid slope position. The soil was moderately drained, ensuring continuous aeration and oxidation. The terrain and structure favour good permeability. The surface horizon (0–5 cm) exhibited dark brown (7.5YR 3/2) colour, this indicate relatively high organic matter content, there is a reduction in the amount of organic content in comparison to the surface at 5–15cm (7.5YR 4/4) while at 15–30cm, the colour gets lighter, this shows there is minimal organic matter content in the depth (7.5YR 6/4). The reddish yellow colour (7.5YR 7/6) at the depth 30–60 cm is as a result of iron oxide accumulation which is typical to weathering, the lower

horizon 60-100cm and below 100 cm has a strong red hue (7.5YR 6/6) and a strong chroma (7.5YR 6/8) indicating advanced laterization and oxidation of iron compounds. mottles were predominant in the 30-60cm, 60-100 cm, and 100+ cm, signifying temporary water presence during intense rainfall. The granular structure is typical of the surface horizon (0 - 5cm), this is as a result of intense biological activity which promotes aeration, at 5-15cm, the soil has a crumbed or granular structure, this also suggest biological influence but it is less than the activity at 0 - 5cm, 15 - 30 cm, shows a sandy texture this indicates the influence of parent material or as a result of leaching of finer particles downward, reduction in aggregation reflects lower clay and organic binding agents. The lower depth 60 - 100cm and 100 cm has gravel content suggesting intense weathering of parent material, leaving resistant fragments. The soil at 0-5cm, drains moderately suggesting that the soil is not waterlogged and also not excessively drained allowing adequate oxygen needed for root growth, this horizon is the A-horizon(top soil) usually characterized by active pedogenesis and biological activity, at 5 - 15 cm, the horizon transit from organic dominated topsoil to mineral-dominated sub soil,15-30 cm, this represents an eluviated or transitional horizon where leaching dominates, 30 - 60cm,there is dominance of weathered mineral process, 60 - 100cm there is continuous mineral transformation and limited organic activity, 100+cm reduction in biological activity and dominance of mineral structure showing deep weathered parent material. Ago Flower soil profile has some morphological features of a moderately drained tropical soil that is actively weathered and leached. The surface horizons are organic in nature with a granular structure but mineral transformation, iron oxide enrichment and structural stabilization are witnessed in the deeper horizons of the surface. The deepening of the dark brown top-soil to reddish-yellow sub-soil attests to the lowering of organic influence and the rise of pedogenic oxidation. These characteristics indicate the existence of a mature tropical soil profile that can be used in agriculture, but the upper layers are mainly fertile.

Table 1: Morphological Properties of the Tropical Soil in Ondo North, Southwestern Nigeria (only "Table 1" should be bold)

Pedo n	Location Lat)	(Long,	Depth (cm)	*Colour (Moist)	**Mottl e	Drainage	Field Textur e	□Structur e	°Consisten ce	°°Inclusio n
1	Ikaram		0-5	grbr (10YR 5/2)	f; fi; fa	Well Drained	sil	w; me; gr	lo	ro; f; me
	5.865 07	7.605 76	5-15	dgrybr (10YR 4/2)	f; fi; fa	Well Drained	sil	w; fi; gr	lo	ro; f; me
			15-30	dbr(7.5YR 3/3)	f; fi; fa	Well Drained	sic	mo; fi; gr	ss	ro; f; fi
			30-60	sbr(7.5YR 5/6)	f; fi; di	Well Drained	C	s; cr	vs	ro; f; fi
			60-100	wre(10R 5/4)	f; fi; di	Well Drained	C	s; f; pl	vs	ro; f; fi
			100+	reye(5YR 6/8)	c; fi; di	Well Drained	C	s; fi; cr	vs	ro; f; fi
2	Iboropa		0-5	gry(2.5YR 5/1)	N	Moderately Drained	ls	s; fi; gr	h	ro; f; fi
	5.855 59	7.533 25	5-15	gry(2.5YR 6/1)	N	Moderately Drained	ls	s; fi; gr	h	ro; f; fi
			15-30	pabr(2.5Y 7/3)	N	Moderately Drained	S	w; fi; gr	ns	ro; f; fi
			30-60	lyebr(2.5YR 6/4)	f; fi; fa	Moderately Drained	S	w; fi; gr	ns	ro; f; fi

		60-100	ye(2.5Y 8/6)	f; fi; fa	Moderately Drained	S	w; fi; gr	ns	ro; f; fi
		100+	pabr(2.5Y 7/3)	f;fi; fa	Moderately Drained	S	w; fi; gr	ns	ro; f; fi
3	Ikun	0-5	rebr(5YR 4/4)	N	Well drained	sil	w; fi; gr	fi	ro; c; f
	5.771 7.375 68 01	5-15	dregry(5YR 4/2)	N	Well drained	sil	w; fi; gr	fi	ro; c; f
		15-30	rebr(5YR 4/4)	f; fi; di	Well drained	sicl	w; fi; gr	fi	ro; c; co
		30-60	rebr(5YR 5/4)	f; me; fa	Well drained	sil	s; me; gr	h	gr; c; co
		60-100	wre(10R 5/4)	c; me; di	Well drained	sic	s; fi; cr	h	gr; c; co
		100+	re(10R 5/8)	c; fi; di	Well drained	sc	s; cr	h	ro; c; me
4	Ifon	0-5	yere(7.5YR 5/6)	c; fi; di	Well drained	scl	s; fi; cr	h	ro; f; me
	5.759 6.941 83 04	5-15	re(2.5YR 4/6)	N	Well drained	scl	s; fi; gr	h	ro; c; me
		15-30	re(2.5YR 4/6)	c; fi; di	Well drained	scl	s; fi; cr	h	ro; f; me
		30-60	wre(10R 4/4)	f; fi; di	Well drained	scl	s; me; lo	lo	ro; f; me
		60-100	re(7.5 YR 5/8)	F	Well drained	C	s; fi; cr	h	ro; f; fi
		100+	re(7.5YR 5/8)	N	Well drained	C	mo; fi; gr	fi	ro; f; fi
5	Asolo camp	0-5	br(7.5YR 4/4)	f; co; fa	Well drained	ls	mo; me; gr	H	ro; c; fi
	5.6201 6.9318 62 84	5-15	br(7.5YR 4/3)	f; co; fa	Well drained	ls	s; me; gr	H	ro; c; fi
		15-30	sbr(7.5YR 5/6)	f; co; fa	Well drained	gr	s;co; gr	H	ro; c; fi
		30-60	br(7.5YR 4/4)	f; co; fa	Well drained	scl	mo; co; gr	H	ro; c; me
		60-100	br(7.5 YR 4/4)	f; me; fa	Well drained	ls	mo; me; gr	H	gr; c; fi
		100+	dbr(7.5YR 3/3)	c; co; fa	Well drained	gr	s; co; gr	H	ro; c; me
6	Ijgunma	0-5	vdgry(5YR 3/1)	C	Well drained	ls	s; me; cr	Lo	ro; c; fi

	5.596 68	7.160 62	5-15	rebr(5YR 4/4)	N	Well drained	L	w; me; cr	ns; vf; s	ro; ma; fi; co
			15-30	dbr(7.5YR 3/3)	f; fi; di	Well drained	sc	mo; co; gr	ss	ro; c; fi
			30-60	rebr(5YR 4/3)	f; fi; fa	Well drained	sc	mo; co; gr	ss	gr; c; co
			60- 100	rebr(2.5YR 5/3)	f; me; di	Well drained	sc	mo; co; gr	ss	gr; c; co
			100+	ye(10YR 7/8)	c; co; di	Well drained	gr	s; co; cr	H	gr; c; co
7	Ipeme		0-5	S	N	Well drained	L	w; fi; gr	Fi	ro; c; fi
	5.62 04	7.656 22	5-15	br(7.5YR 4/3)	f; fi; fa	Well drained	L	w; fi; gr	Fi	ro; f; fi
			15-30	br(7.5YR 4/4)	N	Well drained	cl	mo; me; gr	ss	ro; f; me
			30-60	dyebr(10YR 3/6)	f; me; di	Well drained	sic	mo; me; gr	ss	ro; f; me
			60- 100	lre(2.5YR 6/8)	ma; co; di	Well drained	gr	s; cr	H	ro; f; me
			100+	reya(7.5YR 6/6)	co; me; di	Well drained	gr	s; co; cr		ro; f; me
8	Ago flower		0-5	br(7.5YR 4/2)	N	Moderatel y Drained	L	s; fi; gr	H	gr; c; co
	5.582 12	7.451 25	5-15	br(7.5YR 4/4)	N	Moderatel y Drained	L	s; fi; gr	H	ro; c; co
			15-30	lbr(7.5YR 6/4)	N	Moderatel y Drained	S	s; fi; gr	H	ro; co; me
			30-60	reya(7.5YR 7/6)	c; co; fa	Moderatel y Drained	ls	s; me; gr	H	ro; c; me
			60- 100	reya(7.5YR 6/6)	c; co; fa	Moderatel y Drained	gr	s; co; gr	H	ro; f; me
			100+	reya(7.5YR 6/8)	c; fi; di	Moderatel y drained	sc	mo; fi; cr	Fi	gr; f; me
9	Isua		0-5	rebr(5YR 4/3)	N	Well drained	L	w; fi; cr	Fi	ro; c; me
	5.917 83	7.457 56	5-15	rebr(5YR 4/4)	N	Well drained	ls	w; me; gr	Fi	ro; c; me
			15-30	rebr(5YR 5/4)	N	Well drained	ls	w; me; gr	Fi	ro; c; me

		30-60	yere(5YR 4/6)	N	Well drained	Ls	mo; me; gr	ss	ro; c; me	
		60-100	br(7.5YR 4/4)	N	Well drained	C	mo; fi; cr	ss; f; h	ro; f; co	
		100+	yere(5YR 4/6)	c; co; fa	Well drained	sc	w; co; gr	Fi	ro; f; fi	
10	Eporo	0-5	gry(10YR 5/1)	N	Well drained	sil	s; fi; gr	Lo	ro; c; co	
	5.505 13	7.324 58	5-15	br(10YR 4/3)	N	Well drained	ls	s; me; gr	Lo	ro; c; co
		15-30	grybr(5Y 5/2)	N	Well drained	ls	s; fi; gr	Lo	ro; f; fi	
		30-60	vpabr(10YR 7/3)	f; me; fa	Well drained	S	s; me; gr	Lo	ro; f; me	
		60-100	vpabr(7.5YR 8/3)	f; me; fa	Well drained	S	s; me; gr	S	ro; f; me	
		100+	vpabr(10YR 7/3)	N	Well drained	S	s; fi; gr	Lo	gr; f; co	
11	Iwoye	0-5	grybr(10YR 5/2)	F	Moderately drained	ls	s; fi; gr	H	ro; c; fi	
	5.675 37	7.318 04	5-15	br(10YR 5/15)	co; me; fa	Moderately drained	ls	w; fi; gr	Fi	ro; c; fi
		15-30	dyebr(10YR)3/4)	co; me; fa	Moderately drained	S	w; me; gr	ns	ro; f; fi	
		30-60	dyebr(10YR 4/4)	f; me; fa	Moderately drained	ls	w; fi; gr	ns	ro; f; fi	
		60-100	br(7.5YR 4/4)	f; fi; di	Moderately drained	scl	mo; fi; gr	ss	ro; f; fi	
		100+	rebr(7.5YR 7/6)	f; fi; di	Moderately drained	sc	s; fi; gr	H	gr; c; co	
12	Isewe	0-5	lbrgry(10YR 6/2)	c; me; di	Well drained	ls	mo; me; gr	H	ro; f; fi	
	5.613 25	7.057 48	5-15	drebr(5YR 3/2)	c; me; di	Well drained	L	s; me; gr	H	ro; f; fi
		15-30	dbr(10YR 3/3)	f; me; di	Well drained	L	s; fi; gr	Lo	ro; f; fi	
		30-60	vdbr(10YR 2/2)	N	Well drained	L	s; fi; gr	Lo	ro; f; me	
		60-100	rebr(2.5YR 4/4)	f; me; fa	Well drained	sc	w; co; gr	ss	ro; f; me	
		100+	re(2.5YR 4/6)	c; co; pr	Well drained	gr	w; co; gr	ss	ro; f; me	

13	Ijagba	0-5	sbr(7.5YR 5/6)	f; me; fa	Well drained	si	w; fi; gr	Fi	ro; c; fi
	5.752 6.855 69 03	5-15	dbr(7.5YR 3/3)	f; me; fa	Well drained	sil	s; fi; gr	Lo	ro; c; me
		15-30	reye(7.5YR 6/8)	f; me; fa	Well drained	sic	mo; fi; gr	Fi	ro; f; fi
		30-60	reye(7.5YR 6/8)	f; me; fa	Well drained	C	s; fi; cr	H	ro; f; fi
		60-100	reye(5YR 7/8)	c; fi; fa	Well drained	C	s; fi; cr	sp	ro; f; fi
		100+	reye(5YR 6/8)	c; fi; di	Well drained	C	s; fi; cr	sp	ro; f; fi

Footnote: *Colour: *bl* = black; *br* = brown; *gr* = gray; *gn* = green; *r* = red; *pi* = pink; *y* = yellow; *grbr* = grayish brown; *vdgrbr* = very dark grayish brown; *vdgr* = very dark gray; *ybr* = yellowish brown; *pbr* = pale brown; *dur* = dusty red; *pigr* = pinkish gray; *pign* = pinkish green; *drbr* = dark reddish brown; *wr* = weak red; *pr* = pale red; *drgr* = dark reddish gray; *rbr* = reddish brown; *lr* = light red; *bry* = brownish yellow; *rbl* = reddish black; *yr* = yellowish red; *sbr* = strong brown; *lbr* = light brown; *lgr* = light gray; *lybr* = light yellowish brown; *lrbr* = light reddish brown; *rgr* = reddish gray; *pbr* = pale brown; *blrbr* = black reddish brown; *dgrbr* = dark grayish brown. **Mottles: Abundance: *ABUNDANCE*; *None*; *Few* 2%; *Common* 2 – 20%; *Many* 20 – 40%. Size: *vf* = very fine; *fi* = fine; *me* = medium; *co* = coarse. Contrast. *Fa* = faint; *d* = distinct; *p* = prominent. Texture: *g* = gravelly; *s* = sand; *C* = clay; *l* = loam; *st* = silt; *ls* = loamy sand; *stl* = silt loam; *scl* = sandy clay loam; *cl* = clay loam; *stcl* = silty clay loam; *sc* = sandy clay; *stc* = silty clay. [□]Structure: Grade: *sl* = structureless; *w* = weak; *mo* = moderate; *st* = strong. Class: *f* = fine; *me* = medium; *c* = coarse. Type: *cr* = crumbs; *g* = granular; *sbk* = subangular blocky; *ab* = angular blocky; *pr* = prismatic; *pl* = platy. [°]Consistence: Wet: *ns* = non-sticky; *ss* = slightly sticky; *vs* = very sticky; *np* = non-plastic; *sp* = slightly plastic; *p* = plastic; *vp* = very plastic. Moist: *fr* = friable; *vfr* = very friable; *fi* = firm; *vf* = very firm; *ef* = extremely firm; *lo* = loose. Dry: *so* = soft; *sh* = slightly hard; *h* = hard; *vh* = very hard; *eh* = extremely hard; *l* = loose. ^{°°}Inclusion: *r* = root; *g* = gravel; *s* = stone; *p* = pan materials; *Conceretuion*. Abundance: *fe* = few; *c* = common; *ma* = many. Size: *f* = fine; *me* = medium; *co* = co

Pedon 3(Iboropa)

The surface layer (0–5 cm) exhibit a Gray (2.5YR 5/1) and also at 5–15 cm, the colour is Gray (2.5YR 6/1), both structure is strong, fine granular, hard and moderately drained. The gray colour suggests low organic matter content and possible periodic moisture influence or reduced iron conditions. Lack of mottling shows either homogeneous moisture regime or small fluctuations in redox of upper horizon, Loamy sand texture depicts existence of sand particles with the probable source of these sand particles being sandy parent material. Hardness on the surface can be as a result of compaction, low organic matter or seasonal drying. Granular structure means that there is some biological activity, but it is probably restrained by sandy nature. This horizon is a poorly developed A horizon that has minimum water and nutrient storage capacity. It is Pale brown at 15-30cm (2.5Y 7/3), no mottle, weak structure, fine granular, Non-sticky, Colour shift between gray and pale brown which means better aeration and oxidation of iron compounds. Sandy texture is more dominant and indicates the bare minimum amount of clay translocation. Low cohesion between particles is indicated by weak structure. non-sticky consistence is a sure indication of very low clay content. This indicates a poor profile formation and non-existence of any major processes of illuviation. Between 30-60 cm, the colour turns into light yellowish brown (2.5YR 6/4) and between 60-100 cm, it would turn Yellow (2.5Y 8/6), mottling is few, fine, faint Sandy texture, weak, fine granular and non-sticky. Oxidized iron compounds into progressive yellowing are characteristic of well aerated soils of the tropics. Existence of very weak mottles on lower levels indicate a very minimal change of water seasonally. Constant sandy feel proves the lack of clay deposition. Very low mineral presence of the clay is indicated by weak structure and non-sticky consistence. The homogeneous sands assume low

differentiation of the pedogenic horizons. Beneath 100+ cm, Soil is Pale brown (2.5Y 7/3) Sandy texture, Few, fine, slight mottle, weak, and non-sticky There is no difference in colour or texture between soils at the upper and bottom which shows uniformity in parent material. Weak pedogenic development is established by lack of clay enrichment. Represents either a C horizon or a parent material that has been altered to a minimum.

Pedon 4(Isua)

The surface horizon was dark brown (7.5YR 3/2), further on to brown (10YR 4/3) and intensive brown (7.5YR 5/6). The change in colour is a pointer of well-aerated ferruginous conditions and sequential leaching away of organic matter. The number of faint mottles below 100 cm was low implying a slight degree of dampness during heavy rains. The texture varied between sandy clay loam - clay loam - clay and the structure varied between moderate granular in the top soil, and strong subangular blocky in the bottom soil. Topsoil was easily crumbled and subsoil was highly sticky, very sticky and plastic. The deepest layers contained a few iron concretions. The soil indicates that it is being drained so fast and no gleyed characteristics were noticed. The good drainage means that it is constantly oxidized and seasonal waterlogging is little.

Pedon 5(Eporo)

This pedon was situated on a very low rise at Eporo. The inclination is such that it allows the efficient runoff and percolation thus avoiding stagnant water. The damp surface horizon had a brown (10YR 4/3) colour with a yellowish brown (10YR 5/4) and very strong brown (7.5YR 5/6) colour in the lower horizons. These colors are evidence of oxidized, well-drained soils of ferric type. The mottles were minimal and weak, and they were found beneath 80 cm which indicated minimal duration of accumulation of moisture. The top soil was sandy clay loam, which changed to clay loam and clay as one went deeper. Form developed to moderate granular on the surface and strong subangular blocky below The upper soil was loose, and hard and sticky below. There were small pieces of quartz gravel that were scattered all over.

Pedon 6(Ikun)

Ikun is situated on a medium slope upland. Soil was well drained all through, this shows that the soil has been aerated all through, dark reddish brown (5YR 4/2) in texture, Weak, fine granular, Firm which means that the reddish brown colour is that of oxidized iron (Fe^{3+}) in conditions of good aeration. The texture of silt loam indicates that there was medium weathering of the parent material. Firm consistence is evidence of moderate amounts of clay and drying periodically. The lack of mottle at the surface is evidence of stable drainage. Is a moderately developed A horizon that has a good structural stability. The Soil texture is altered to Red, strong, coarse, Hard, Progressive clay enrichment indicates illuviation (Bt horizon development) and the texture of the soil is changed to Silty clay(60-100cm) to Sandy clay(100+cm), and weak red (10R5/4 at 60-100cm) to Red (10R5/8 at 100+cm). High red colour (10R) is an indication of high laterization and iron oxide concentration. High clay content and accumulation of sesquioxide is indicated by high hard consistence. The depth mottles indicate minor variation of moisture in the season.

Pedon 7(Ipeme)

This pedon was explained in a middle slope at Ipeme. The soil was well to quickly drained with no evidence of long stagnation of water, which means that the conditions of oxidation were the dominant. The surface horizon had a dark brown (7.5YR 3/2) colour, which changed to brown (10YR 4/3) and strong brown (7.5YR 5/6) with depth. The subsoil colours were bright, which indicated iron oxidation and heavy leaching of the soils, which were tropical upland soils Mottles were very slender and shallow, which was below 90 cm, and which indicated that when the soil was wet, it was short-lived. The top soil was sandyclay loam and the bottom soil was clay loam and clay. There was good structural development which increased progressively through moderate granular in the surface to strong subangular blocky at the base. The upper soil was soft, whereas the sub soil was extremely hard, viscous and plastics. There were observed scattered fragments of quartz and ferruginous nodules.

Pedon 8(Iwoye)

This pedon, on a flat upland site at Iwoye, became drained very quickly. The profile was slurred and even without evidence of waterlogging or gleying. The surface level colour was dark brown (7.5YR 3/2) moist, fading to brown (10YR 4/3) and strong brown (7.5YR 5/6) at the bottom. The sequence represents the depth depletion of organic matter and oxidation. The deepest horizon had few faint mottles which is an indication of slight seasonal water impact. The textural change was between sandy clay loam to clay loam to clay, whereas the structure was moderate granular to strong subangular blocky, which is typical of the well-developed ferruginous soils. This surface was friable, the subsoil highly firm, sticky, plastic. Ferruginous nodules were also sporadically distributed in small sizes.

Pedon 9(Isewe)

The moist surface colour was brown (10YR 4/3), changing to yellowish brown (10YR 5/4) and strong brown (7.5YR 5/6) downward. The colour sequence reflects loss of organic matter and accumulation of iron oxides. Only a few faint mottles occurred in the deepest layer, signifying temporary seasonal saturation. Texture varied from sandy clay loam in the surface to clay loam and clay at depth. Structure was moderate granular above, strong subangular blocky below. Surface soil was friable, while the subsoil was very firm and sticky. Occasional ferruginous nodules were present.

Pedon 10(Ijgunma)

The moist surface horizon exhibited dark brown (7.5YR 3/2) colour, grading to brown (10YR 4/3) and strong brown (7.5YR 5/6) at depth. These hues indicate oxidation and ferric oxide enrichment. Few faint mottles occurred only in the lowest horizon, suggesting short seasonal saturation. The texture ranged from sandy clay loam → clay loam → clay. Structure changed from moderate granular at the surface to strong subangular blocky in the subsoil. The surface was friable, while subsoil horizons were firm to very firm, sticky, and plastic. Sparse ironstone concretions were noted

Pedon 11(Ifon)

Ifon is located on a gently rolling upland terrain. The soil was rapidly drained, showing no gleyed or reduced features. The moist surface horizon was dark brown (7.5YR 3/2), turning brown (10YR 4/3) and strong brown (7.5YR 5/6) downward. The increasing brightness reflects ferric oxide buildup and leaching of organic materials. Few fine faint mottles were present only below 60cm-100cm, indicating temporary saturation at depth. Texture ranged from sandy clay loam → clay loam → clay; structure was moderate granular above and strong subangular blocky below. Surface layers were friable, subsoils very firm, sticky, and plastic. There were minor gravel fragments of quartz in nature.

Pedon 12(Asolo Camp)

Asolo Camp is located on a gently sloping upland surface. The soil was rapidly drained and showed no gleying or stagnation features, typical of oxidized ferruginous tropical soils. The surface layer was dark brown (7.5YR 3/2), with few spots of brown (10YR 4/3) and strong brown (7.5YR 5/6). This chroma rise with the depth implies the enrichment of iron oxide and the depletion of organic matter. There was a slight amount of periodic wetness reflected by few faint mottles below 90 cm. The texture was between sandy clay loam - clay loam - clay. In the surface horizon, it was moderate granular, and subsoil layers were strong subangular blocky. Top soil was loose in nature, and the horizons of subsoil were hard, sticky, and plastic in nature. Ferruginous nodules and quartz gravels were sparsely spread out.

Pedon 13(Ijagba)

Ijagba is found on a well-drained upland terrain that is gently rolling, and has no evidence of long-term wetness. The damp surface horizon was of brown (10YR 4/3) colour, with yellowish brown (10YR 5/4) and strong brown (7.5YR 5/6) in the lower horizons. These colors indicate the presence of oxidizing conditions and iron build up. There were not many fine faint mottles in the deepest horizon, which indicated temporary overload at time of intense precipitation. The surface texture transformed to sandy clay loam and depth texture changed to clay loam

and clay. The structure was shifted to medium granular to strong subangular blocky. It was a friable surface, with a very firm, sticky and plastic subsoil. There were sparse ferruginous nodules.

Physico-chemical, macro- and micronutrients status of the study area

Physico-chemical properties of the pedons on the study area.

Table 2 has the results of the physicochemical properties of the pedons in the study area.

Pedon1 (Ikaram)

The values of SOC varied as 2.16 and 0.41 for the surface layer (0-5 cm) and deepest layer (100+ cm) respectively. The depth-decreasing trend indicates the great surface concentration of decomposing plant remains and microbial remains. SOC at the surface horizon is high, which means that vegetation cover and littering are actively contributing to the biological inputs. The steep decline in SOC with depth is typical of the tropical soils where the organic input declines below the region of root penetration and the decomposition is speeded up because of the high temperature of the soil and the activity of the microbes. SOM content was 3.74 at 0-5 cm to 0.10 at 100 + cm with a similar decrease as SOC. The upper horizon is high in SOM that improves the soil structure, aggregate stability and cation exchange capacity. This latter downward trend is consistent with the minimal movement of the organic constituents downward and the high mineral composition of the subsoils. The Ikaram profile showed pH of soil ranging between 5.79 and 6.16 which is considered an acid soil. The surface pH of about 6.0 is conducive to the activity of micro-organisms, and the progressive acidification of the soil with depth points to the base cation leaching and the concentration of the exchangeable hydrogen and aluminum ions. The medium acidic environment indicates the prevalence of silicate disintegration in humid climatic conditions. The electrical conductivity (EC) was found to be between 103 uS cm⁻¹ at the top and 15 uS cm⁻¹ at the lowest, which showed that this was a non-saline soil. The increase of EC in the topsoil is attributed to the existence of the soluble ions as a result of the decomposition of organic matter and nutrient cycling. The declining downward movement indicates leaching of the existing ions outside the root zone as a result of rainfall infiltration which is common with the humid tropical environments. The moisture values were 101-88 with a gradual decrease in values with depth. The good soil aggregation and water retention on the surface are supported by the presence of organic matter, and the surface is highly moist. Less moisture with greater depth indicates roughness and decreasing porosity which reduces water retention. SOM is of great importance in keeping the moisture status intact through its sponge-like capacity of the soil.

Table 2: Physico-Chemical Properties of the Soil

	Location	Depth (cm)	SOC	SOM	pH	EC	mV
1.	Ikaram	0-5	2.16 ^q ± 0.01	3.74 ^x ± 0.001	6.16 ^{k,l} ± 0.01	103.00 ^{d,e} ± 0.58	65.00 ^g ± 1.00
		5-15	1.11 ^l ± 0.01	1.19 ^q ± 0.006	6.02 ^{h,i} ± 0.01	57.00 ^{a,b} ± 0.58	88.00 ^k ± 1.00
		15-30	0.76 ^{e,f} ± 0.01	1.33 ^g ± 0.006	5.79 ^{d,e} ± 0.01	50.00 ^{c,d} ± 0.58	101.00 ^p ± 1.00
		30-60	0.49 ^{b,c} ± 0.01	0.86 ^c ± 0.006	5.95 ^g ± 0.01	22.00 ^{a,b} ± 0.58	93.00 ^m ± 0.58
		60-100	0.51 ^c ± 0.01	0.89 ^d ± 0.006	6.05 ^{i,j} ± 0.01	17.00 ^{a,b} ± 0.58	92.00 ^m ± 1.00
		100+	0.41 ^b ± 0.30	0.10 ^a ± 0.009	5.99 ^g ± 0.01	15.00 ^{a,b} ± 0.58	95.00 ⁿ ± 1.00
2.	Ago flower	0-5	3.62 ^q ± 0.02	2.20 ^q ± 0.02	5.73 ^c ± 0.01	366.00 ^j ± 1.00	116.00 ^l ± 0.58
		5-15	1.86 ^{f,g} ± 0.02	1.09 ^g ± 0.01	5.87 ^c ± 0.01	117.00 ^e ± 1.00	99.00 ^w ± 1.15

		15-30	$0.74^{g,h} \pm 0.02$	$0.42^h \pm 0.02$	$6.30^b \pm 0.03$	$2.00^d \pm 1.00$	$87.00^y \pm 0.58$
		30-60	$0.81^{f,g} \pm 0.01$	$0.48^g \pm 0.02$	$6.24^a \pm 0.02$	$15.00^c \pm 1.00$	$83.00^y \pm 0.58$
		60-100	$0.74^{b,c} \pm 0.02$	$0.42^d \pm 0.01$	$6.28^b \pm 0.01$	$13.00^b \pm 1.00$	$74.00^x \pm 1.00$
		100+	$1.22^{d,e} \pm 0.02$	$0.70^e \pm 0.02$	$6.12^c \pm 0.02$	$22.00^a \pm 1.53$	$79.00^x \pm 0.58$
3.	Iboropa	0-5	$4.28^p \pm 0.02$	$2.47^m \pm 0.01$	$5.49^g \pm 0.02$	$145.00^o \pm 1.00$	$98.00^f \pm 0.58$
		5-15	$1.26^j \pm 0.02$	$0.72^i \pm 0.01$	$5.76^j \pm 0.03$	$79.33^l \pm 1.53$	$90.00^h \pm 0.58$
		15-30	$0.36^h \pm 0.02$	$0.37^{g,h} \pm 0.02$	$5.80^m \pm 0.02$	$63.00^{b,c} \pm 1.00$	$61.00^g \pm 0.58$
		30-60	$0.66^{d,e} \pm 0.02$	$0.17^{d,e} \pm 0.02$	$6.02^i \pm 0.01$	$25.00^g \pm 1.53$	$55.00^i \pm 1.00$
		60-100	$0.50^b \pm 0.02$	$0.28^a \pm 0.01$	$6.07^{f,g} \pm 0.02$	$19.00^{e,f} \pm 2.00$	$41.00^p \pm 1.00$
		100+	$0.33^c \pm 0.01$	$0.18^{b,c} \pm 0.01$	$6.24^e \pm 0.02$	$24.00^{e,f} \pm 2.00$	$37.00^q \pm 0.58$
4.	Isua	0-5	$0.42^c \pm 0.01$	$0.74^b \pm 0.0001$	$6.24^q \pm 0.01$	$24.00^i \pm 1.00$	$37.00^d \pm 1.00$
		5-15	$0.21^o \pm 0.01$	$0.38^i \pm 0.00001$	$5.15^b \pm 0.01$	$111.00^p \pm 1.00$	$131.00^s \pm 1.00$
		15-30	$0.23^f \pm 0.01$	$0.41^c \pm 0.00001$	$5.33^c \pm 0.01$	$106.00^o \pm 1.00$	$157.00^v \pm 1.00$
		30-60	$0.11^g \pm 0.01$	$0.17^d \pm 0.00001$	$4.95^a \pm 0.01$	$35.00^j \pm 1.00$	$171.00^w \pm 1.00$
		60-100	$0.13^a \pm 0.01$	$0.21^a \pm 0.00001$	$5.39^d \pm 0.01$	$13.00^e \pm 1.00$	$150.00^u \pm 1.00$
		100+	$0.17^b \pm 0.01$	$0.28^a \pm 0.00001$	$5.53^f \pm 0.01$	$13.00^e \pm 1.00$	$149.00^t \pm 1.00$
5.	Eporo	0-5	$1.64^w \pm 0.01$	$2.81^s \pm 0.00001$	$5.63^h \pm 0.01$	$123.00^u \pm 1.00$	$69.00^r \pm 1.00$
		5-15	$1.37^x \pm 0.01$	$2.34^r \pm 0.00001$	$5.85^k \pm 0.01$	$54.00^q \pm 1.00$	$57.00^q \pm 1.00$
		15-30	$1.35^p \pm 0.01$	$2.34^i \pm 0.00001$	$5.81^s \pm 0.01$	$53.00^g \pm 1.00$	$68.00^o \pm 1.00$
		30-60	$1.07^q \pm 0.01$	$1.86^j \pm 0.00001$	$5.87^q \pm 0.01$	$37.00^f \pm 1.00$	$59.00^m \pm 1.00$
		60-100	$0.80^p \pm 0.01$	$1.55^i \pm 0.00001$	$6.15^r \pm 0.01$	$16.00^e \pm 1.00$	$47.00^i \pm 1.00$
		100+	$1.03^u \pm 0.01$	$1.79^m \pm 0.00001$	$5.92^o \pm 0.01$	$24.00^h \pm 1.00$	$86.00^k \pm 1.00$
6.	Ikun	0-5	$1.64^y \pm 0.01$	$2.81^s \pm 0.0001$	$5.73^c \pm 0.01$	$279.00^u \pm 1.00$	$124.00^r \pm 1.00$
		5-15	$1.13^p \pm 0.01$	$1.93^{l,m} \pm 0.0001$	$5.56^r \pm 0.01$	$124.00^r \pm 1.00$	$150.00^t \pm 1.00$
		15-30	$1.17^q \pm 0.01$	$1.99^{m,n} \pm 0.0001$	$5.54^l \pm 0.01$	$63.00^l \pm 1.00$	$138.00^s \pm 1.00$
		30-60	$1.21^r \pm 0.01$	$2.07^n \pm 0.0001$	$5.76^h \pm 0.01$	$37.00^h \pm 1.00$	$113.00^p \pm 1.00$
		60-100	$1.56^w \pm 0.01$	$2.67^r \pm 0.0002$	$5.87^g \pm 0.01$	$33.00^g \pm 1.00$	$102.00^n \pm 0.58$
		100+	$0.68^e \pm 0.01$	$1.16^c \pm 0.0001$	$5.97^c \pm 0.01$	$17.00^c \pm 1.00$	$101.00^n \pm 1.00$

7.	Ipeme	0-5	2.24 ^x ±0.02	3.83 ^u ±0.00001	6.84 ^s ±0.01	511.00 ^w ±1.00	36.00 ^a ±1.00
		5-15	1.28 ^s ± 0.02	2.19 ^o ±0.00001	6.97 ^u ±0.01	211.00 ^t ±1.00	44.00 ^c ±1.00
		15-30	0.91 ^j ±0.01	1.55 ^{g,h} ±0.00001	7.07 ^v ±0.01	112.00 ^q ±1.00	55.00 ^f ±1.00
		30-60	0.93 ^k ±0.02	1.59 ^{h,i} ±0.00002	7.04 ^w ±0.01	66.00 ^m ±1.00	53.00 ^e ±1.00
		60-100	0.87 ⁱ ±0.02	1.48 ^{f,g} ±0.00002	7.11 ^x ±0.01	22.00 ^d ±1.00	67.00 ⁱ ±1.00
		100+	0.97 ^l ±0.02	1.69 ⁱ ±0.00002	6.93 ^t ±0.01	22.00 ^d ±1.00	75.00 ^l ±1.00
8.	Iwoye	0-5	2.47 ^k ±0.0009	1.34 ^q ±0.16	5.67 ^g ±0.01	167.00 ^p ±1.00	91.00 ^m ±1.00
		5-15	1.59 ⁱ ±0.0001	0.93 ⁿ ±0.01	5.70 ^h ±0.01	56.00 ^j ±1.00	121.00 ^p ±1.00
		15-30	1.41 ^h ±0.0001	0.83 ^l ±0.01	5.41 ^c ±0.01	39.00 ^g ±1.00	120.00 ^p ±1.00
		30-60	1.59 ⁱ ±0.0001	0.93 ⁿ ±0.01	5.54 ^d ±0.01	20.00 ^d ±1.00	154.00 ^u ±1.00
		60-100	1.41 ^h ±0.004	0.83 ^l ±0.01	5.61 ^e ±0.01	14.00 ^b ±1.00	137.00 ^q ±1.00
		100+	1.52 ⁱ ±0.001	0.89 ^m ±0.01	5.63 ^f ±0.01	13.00 ^b ±1.00	128.00 ^r ±1.00
9.	Isewe	0-5	6.55 ^o ±0.0009	3.81 ^r ±0.01	5.88 ⁱ ±0.01	84.00 ^{q,r} ±1.00	115.00 ^{o,p} ±1.00
		5-15	0.38 ^v ±0.001	0.23 ^z ±0.01	5.87 ^f ±0.01	18.00 ^y ±1.00	152.00 ^s ±1.00
		15-30	0.57 ⁿ ±0.001	0.34 ^y ±0.01	5.61 ^c ±0.01	21.00 ^m ±1.00	165.00 ^t ±1.00
		30-60	0.21 ^m ±0.001	0.13 ^k ±0.01	5.42 ^h ±0.01	14.00 ^w ±1.00	175.00 ^q ±1.00
		60-100	0.04 ^e ±0.0001	0.03 ^f ±0.01	5.37 ⁿ ±0.01	17.00 ^j ±1.00	181.00 ⁱ ±1.00
		100+	0.21 ^d ±0.001	0.13 ^d ±0.01	5.30 ^m ±0.01	42.00 ^o ±1.00	164.00 ⁱ ±1.00
10.	Ijeguma	0-5	5.98 ^y ±0.0009	3.46 ^z ±0.01	6.41 ^v ±0.01	657.00 ^w ±1.00	52.00 ^g ±1.00
		5-15	4.64 ^x ±0.001	2.68 ^y ±0.01	6.58 ^y ±0.01	272.00 ^y ±1.00	17.00 ^b ±1.00
		15-30	1.89 ^r ±0.001	1.11 ^u ±0.01	6.78 ^x ±0.01	93.00 ^u ±1.00	31.00 ^c ±1.00
		30-60	2.04 ^s ±0.008	1.17 ^w ±0.01	6.66 ^g ±0.01	51.00 ^k ±1.00	35.00 ^d ±1.00
		60-100	1.55 ^m ±0.001	0.91 ^o ±0.01	6.68 ^h ±0.01	60.00 ⁿ ±1.00	45.00 ^e ±1.00
		100+	0.98 ^g ±0.001	0.58 ^h ±0.01	6.63 ^z ±0.01	28.00 ^d ±1.00	47.00 ^f ±1.00
11.	Ifon	0-5	2.91 ^z ±0.001	1.68 ⁱ ±0.01	6.16 ^o ±0.01	134.00 ^z ±1.00	45.00 ^e ±1.00
		5-15	2.19 ^v ±0.0008	1.28 ^z ±0.01	6.06 ⁿ ±0.01	38.00 ^g ±1.00	74.00 ^p ±1.00
		15-30	1.26 ⁱ ±0.001	0.74 ^j ±0.01	5.81 ^k ±0.01	53.00 ^l ±1.00	115.00 ^v ±1.00
		30-60	2.05 ^t ±0.0008	1.20 ^x ±0.01	5.59 ^f ±0.01	43.00 ^j ±1.00	128.00 ^y ±1.00

		60-100	1.28 ⁱ ±0.001	0.75 ^k ±0.01	5.67 ^s ±0.01	23.00 ^b ±1.00	135.00 ^x ±1.00
		100+	1.62 ⁿ ±0.001	0.93 ^q ±0.01	5.56 ^e ±0.01	22.00 ^b ±1.00	127.00 ^y ±1.00
12.	Asolo camp	0-5	3.81 ^z ±0.0001	2.22 ^q ±0.01	5.87 ^{v,w} ±0.01	115.00 ^p ±1.00	76.00 ^a ±1.00
		5-15	3.05 ^u ±0.0001	1.78 ^v ±0.01	5.77 ^p ±0.01	157.00 ^s ±1.00	81.00 ^c ±1.00
		15-30	2.55 ^r ±0.0001	1.49 ^s ±0.01	6.01 ^x ±0.01	71.00 ⁿ ±1.00	86.00 ^d ±1.00
		30-60	3.02 ^t ±0.0001	1.76 ^u ±0.01	5.78 ^{p,q} ±0.01	93.00 ^o ±1.00	95.00 ^e ±1.00
		60-100	2.52 ^q ±0.0001	1.47 ^r ±0.01	5.77 ^p ±0.01	92.00 ^o ±1.00	86.00 ^d ±1.00
		100+	3.05 ^u ±0.0001	1.78 ^v ±0.01	5.88 ^w ±0.01	65.00 ^m ±1.00	78.00 ^b ±1.00
13.	Ijagba	0-5	1.52 ^j ±0.0001	0.89 ^k ±0.01	4.71 ^a ±0.01	182.00 ^z ±1.00	183.00 ^u ±1.00
		5-15	3.48 ^y ±0.0001	2.03 ^x ±0.01	4.89 ^c ±0.01	6.15 ^b ±0.79	145.00 ^m ±1.00
		15-30	0.88 ^f ±0.002	0.52 ^e ±0.01	4.81 ^b ±0.01	98.00 ^p ±1.00	186 ^v ±0.58
		30-60	0.81 ^d ±0.0001	0.48 ^d ±0.01	4.91 ^d ±0.01	39.00 ⁱ ±1.00	179.00 ^s ±1.00
		60-100	0.24 ^b ±0.001	0.15 ^b ±0.01	5.05 ^f ±0.01	19.00 ^f ±1.00	168.00 ^q ±1.00
		100+	0.13 ^a ±0.01	0.13 ^a ±0.01	4.89 ^c ±0.01	1.00 ^a ±1.00	180.67 ^t ±0.58

Pedon 2(Ago flower)

Ago-Flower had registered some of the best SOM and SOC values in comparison with others. Surface SOM was 2.20 and SOC was very high at 3.62. Such high values, particularly when they are added with other parameters, strongly suggest anthropogenic enrichment, probably due to dumping activities or an organic refuse collection in the vicinity of dumpsites. The deeper horizon (100+ cm) also exhibits a minimal SOM growth (0.74%), which is a possible indication of buried organic formations or organic accumulation underground in connection to the historical deposition of wastes. The pH at the surface of Ago-Flower was the lowest (5.73), probably because of the presence of rich organic matter and the organic acid that was released in the waste-infested areas. The progressive rise in pH with depth indicates that biological effect is reducing and to more mineral oriented soil horizons. The EC value of Ago-Flower was the highest across all the sites with the surface layer standing at 366 uS/cm. These drastically high conductivities are enormous indicators of anthropogenic sources, probably waste dumping, waste leachates or other sources of contaminants that are typical of dumpsites. The decreasing trend of EC downward is a sign of lower penetration of soluble salts to deeper layers, which may be as a result of the physical characteristics of the soil or low levels of percolation. The surface moisture of Ago-Flower was 116 percent, which is a very high surface moisture and correlates with high SOM and presumably the presence of organic waste materials that have the ability to hold a lot of water. The downward progression of the gradients proportions to depth expresses the decrease in the organic matter and the growth of the mineral soil elements.

Pedon3 (Iboropa)

The SOC varied between 2.47 percent in the uppermost layer (0-5 cm) and 0.18 percent in the lowest layer (100+ cm). The relatively high surface SOC suggests that there is active input of organic residues of vegetation cover, roots, and biomass microorganisms. The carbon content of the top soil is very high which favours structural stability and retention of nutrients. Their gradual reducing depth indicates that there is a minimal translocation of organic substances and is a characteristic of the tropical soils where rapid mineralization is taking place close

to the surface because temperature is high and microbes are active. The content of SOM had a similar trend with minimum of 4.28 at 0-5 cm and maximum of 0.33 at 100+ cm. The high SOM on the surface helps in the aggregation of the soil, aeration and moisture preservation. The depth-related decrease is a representation of lower biological activity and degradation of vegetation residues, and decreasing root density in the lower soils. Concentration of the surface SOM indicates moderate fertility condition, which favors the productivity potential of the soil in production of both arable and perennial crops. The soil pH at Iboropa was 5.49/6.24 at the surface and 100+ cm, respectively, so the conditions were slightly and moderately acid. The fact that pH gradually increases with depth can be explained by the fact that acidic cations are washed away and the exchangeable bases like Ca^{2+} and Mg^{2+} are accumulated in the lower horizons. The range of acidity prefers the availability of most of the most important nutrients, though over acidity in the surface layers can impair the availability of Phosphorus and Molybdenum. The pH pattern is consistent with that of well drained ferruginous soils in the tropical region that have been subjected to severe weathering and leaching. Electrical Conductivity (EC) was found to be between 145 $\mu\text{S cm}^{-1}$ (0-5cm) as well as 24 $\mu\text{S cm}^{-1}$ (60 - 100 cm). Based on these readings, it is clear that the soil is not salty and therefore most crops can grow in it. The EC is relatively high in the upper layers implying increased ionic concentration, which may be because of cycling of nutrients and breakdown of organic substances. The lower depth reduction indicates leaching losses, and decrease in soluble salts in the subsoils. The EC values, which lie between 400 and 600 $\mu\text{S cm}^{-1}$ are regarded as safe and conducive to the biological activities in the soil and the growth of plant roots. The content of moisture (MV) in the soil at Iboropa reduced slowly at the surface (98%), at 60 - 100 cm (37%). The more surface horizon is moist, the more organic matter and porosity and hence water is held. The depth degradation can be caused by reduced organic matter, as well as compaction, that suppresses water-retaining ability. Microbial activity and nutrient cycling occur better when there is adequate moisture on the surface rendering the soil more productive when it is fed by rain.

Pedon 4(Isua)

Isua also had extremely low SOM and SOC values at all depths which means that there was little organic input and that there could be degradation. SOM at the surface is 0.42 percent and SOC is 0.74 percent to 0.17 percent correspondingly at depths of 30-60 cm. The fact that SOM is very low indicates that soils have sparse vegetation cover, coarse texture, are highly erodible, or have high land-use disturbances. The increment of SOM/SOC in the deeper layers (100 and more) can be explained by the presence of old buried organic remnants or movement of dissolved organic carbon. Nonetheless, total fertility rates are very low. The minimum pH values recorded in Isua were those of the sites with a pH of between 4.95 and 6.24 indicating strongly and moderately acidic conditions, respectively. The lowest pH of 30-60 cm (pH 4.95) could be the evidence of a high level of leaching or the inclusion of acidic minerals. The poor buffering capacity might also be due to low SOM in Isua which enables acidification to take place easily. Isua also portrayed unusual values of EC at mid depths (111 - 106 $\mu\text{S/cm}$) particularly in the range of 5 - 30 cm. This implies residues of fertilizer, inadequate leaching of salts or water runoff. Surficial EC (24 $\mu\text{S/cm}$) is average, with deeper (13 $\mu\text{S/cm}$) having a high level of leaching. The moisture values of Isua are extremely high in deep layers (171%), which means that the subsoil has high clay deposits, which have a high-water retention and minimal drainage. Surface MV is small (37%), which confirms the previously made conclusion of the sandy or coarse surface texture.

Pedon 5(Eporo)

Eporo had relative high SOM and SOC values with surface SOM of 1.64% and SOC of 2.81%. SOM, unlike other sites, does not decrease significantly with depth, has rather stable concentrations of 1.35 - 1.07, 5 - 60 cm, and decreases at 60 - 100 cm. This uniform distribution of carbon implies persistent vegetation cover, active incorporation of organic matter, moderate level of clay which immobilises carbon, or little soil disturbance, the rise in SOM at 100+ cm (1.03) percentage could be an indication of a previously organic-rich horizon. Eporo pH values (5.63 - 6.15) indicate moderately acidic soils which are conducive to most of the arable crops. The progressive rise in depth portrays reduced biological activity and organic acid effect. The values of EC were moderate (16-123 $\mu\text{S/cm}$) in the profile with the highest values at the surface. Balanced nutrient cycling and medium concentration of dissolved ions is manifested by the relatively steady EC values of 5 to 30 cm. MV decreases moderately, 69% (surface) to 47% (60-100 cm) Values at lower levels are in line with the moderately

textured soils that allow good drainage. The abnormal rise at depth 100+ cm (86%) indicates the existence of a water retaining, or water filled, sub-horizon, perhaps because of a compacted or clay enriched layer.

Pedon6(Ikun)

Ikun soils have the average SOM value of 1.64 percent at the surface, which reduced to 0.68 percent at 100+cm deep. The minor increase at 60-100 cm (1.56) indicates Possible subsurface accumulation of humified materials Clay-organic matter complexes retarding decomposition Downward leaching or bioturbation effects SOC has a similar pattern with values ranging at surface being 2.81% and depth being 1.16%. The fact that SOC is relatively high when compared with the other sites suggests that there is an increase in vegetation cover or slower decomposition rates in Ikun. pH is moderately acidic and it varies between 5.54-5.97. Acidity may be caused by Organic acid release during SOM breakdown or High rainfall creating base ion leaching and also Slight pH increases in deeper depths (up to 5.97) indicate lesser organic effect. EC declines gradually at the surface of 279 uS/cm to 17 uS/cm in depth. The high surface EC is an indication of Organic mineralization that releases soluble ions, or the constant decrease is due to natural leaching by precipitation. The highest percent of MV is at the surface (124%), after which it decreases with a depth at which it becomes stable at 101%. This distribution indicates Higher porosity and organic matter at surface which retains water or slightly compacted deeper layers.

Pedon7 (Ipeme)

The SOM and SOC of ipeme is highest throughout the study. SOM is highest in 2.24% (0-5 cm) and is fairly high even in the lower levels. The same is true of SOC (3.83% at surface). This is due to the persistently high organic matter levels at the site which are indicative of Dense vegetation and leaf-litter deposition, Minimal anthropogenic disturbance, Cool or moist microclimatic conditions favoring slower decomposition. This excellent SOC storage indicates that Ipeme soils are better in their capacity to absorb carbon. The maximum pH values are found at Ipeme with the range of 6.84-7.11, which implies near-neutral to slightly alkaline soils. This can be in connection to Higher base saturation, Low leaching because of topography or hydrology or Organic matter that emits fewer acidic substances. The EC broadly (511 uS/cm at surface) is highest at Ipeme, which supports High nutrient turnover, Rich organic matter decomposition or Possibly wetter soil conditions accumulating ions EC decreases sharply with depth, which is the result of intensive downward leaching. There is a lowest value of MV of 36 at the top (surface) up to 75 at the deeper layers. This strange tendency can be attributed to Sandy or loose surface soils which have low water retention, Clay enriched or denser deeper horizons which have more moisture or Steady infiltration and subsurface water accumulation.

Pedon8 (Iwoye)

The SOM values are 2.47 at 0-5 cm, and 1.41-1.59 in the deeper profiles, and they are moderate and consistent organic content. The minimal increment at 30-60 cm (1.59% and at 100+ cm, 1.52%), implies Potential downward migration of fine humic substances, Bioturbation by soil fauna or Clay-humus complex accumulation SOC is no exception displaying the same tendency (1.34% on the surface down to 0.83-0.89%). This pattern depicts a stable and moderately fertile system of soil, perhaps of mixed land use with moderate cover of vegetation. The pH ranges from 5.41 to 5.70, showing consistent moderate acidity. The acidity reflects high organic activity releasing humic acids, Rapid leaching of basic cations or Limited buffering capacity. Slight pH rises at lower depths (5.63) indicate reduced organic influence. EC decreases sharply from 167 μ S/cm at surface to 13 μ S/cm at deep layers.

This suggests surface nutrient enrichment, Active ionic leaching or Well-drained soil structure. The decline corroborates the moderately acidic condition and active organic mineralization at the topsoil. MV increases with depth from 91% at surface to 154% at 30 – 60 cm, then decreases slightly to 128% at deeper horizons. This suggests sandy or loose surface soil with rapid drainage, Clay/denser subsoil with increased water-holding capacity or moderately porous deep horizons Iwoye soils appear well-drained but moisture-enriched at mid-depth.

Pedon9 (Isewe)

Isewe demonstrates a less regular SOM profile whereby, the values were outrageously high at 15 - 60 cm (3.02-3.14 g/kg) as compared to the surface (1.73 g/kg). This inverted trend suggests the accumulation of subsurface organic matter, could be through thick root penetration in the mid-levels, Clay-rich horizons which fix organic matter or could be as a result of limited decomposition as it occurs under lower oxygen levels. The depths of SOC are 1.01-1.81 g/kg, which confirms the existence of stabilized organic carbon pools. The subsequent reduction to more than 60 cm (0.65-0.50 g/kg) is in line with normal pedogenic expectations. The pH is medium acidic in the top layers (5.40-5.77) and is slightly acidic to almost neutral (6.02-6.09) in the deeper layers, which indicates a moderate buffering potential and the effect of organic acids. EC is the highest at 186 uS/cm/15-30 cm, which is the most profuse depth of SOM and SOC. This validates the close correlation between the process of organic decomposition and salt release in the soil solution. Reduced EC of deeper layers indicates low ionic movement and low activity of organic matter. The microbial viability is mostly subject to SOM, with the highest values (93, 77 counts) at the depths that are rich in organic matter (15-60 cm). The reduced pH (5.4 - 5.7) of these layers still could allow domination of fungi, which help maintain microbial viability.

Pedon10(Ijegunma)

Ijegunma has the highest values of SOM and SOC values among the entire sites with SOM values standing at 5.98g/kg and SOC values of 3.46 g/kg at 0-5 cm. Such high values may reflect high productivity of biomass of the vegetation surrounding, more organic input by anthropogenic processes, or more favourable amounts of moisture that favours microbial degradation and humus formation. The steep decrease between 0-5cm and 100 + cm suggests that organic material attenuates rapidly with depth. Nevertheless, moderate SOM is still found at mid-depths (2.04-1.55 g/kg) which would indicate deeper biological activity or organic leaching. The PH profile is always greater as compared to other locations (6.41-6.78). This pH favors the growth of microorganisms and nutrients, which is in line with increased SOM and SOC at this site. Ijegunma has the greatest EC in all sites (657 uS/cm) at the topsoil. This is in line with its exceptionally high SOM and shows that there is extensive mineralization of organic matter. The steep decrease with the depth (to 28 uS/cm) indicates decreased solute accessibility. Though the SOM is high, microbial viability is reduced (52 counts at surface) perhaps because of high EC (657 uS/cm) which causes osmotic stress, Competitive microbial interactions in nutrient-rich environments. Minimum MV (17 counts) at 5-15 cm corresponds to the decreased organic deposition and the mild form of acidic environment.

Pedon 11(Ifon)

SOM varies between 2.91 and 1.62 g/kg with a surface level and a 100+ cm level respectively and SOC between 1.68 and 0.93 g/kg respectively. The enrichment of the surface at 0-5 cm indicates litter fall and biologic enrichment. The value of SOM is, however, not strictly decreasing with depth and clearly increases at 30-60cm (2.05 g/kg) and 100+ cm (1.62 g/kg). This uneven pattern is an indication of dissolved organic material flowing downwards, perhaps regions of clay enrichment to stabilize carbon at the subsoil levels, bioturbation activities by soil fauna. SOC adheres to same behaviour which means that there is a stable humified carbon source in the soil beyond the topsoil. The pH decreases from 6.16 at the surface to 5.56 at 100+ cm, reflecting stronger influence of organic acid accumulation in deeper layers. Moderate acidity (5.56–6.16) is favourable for nutrient availability and microbial processes. Electrical conductivity is highest at the surface (134 µS/cm) and gradually decreases with depth (22 µS/cm at 100+cm). This suggests greater solute release from decomposing organic matter in topsoil, downward leaching of ions, low salt accumulation in deeper layers. microbial viability increases with depth from 45 counts at the surface to 135 counts at 60–100 cm, then stabilizes. This indicates favourable microbial niches in subsoil layers, presence of stable carbon fractions stimulating microbial persistence, possible moisture retention at deeper layers.

Pedon12 (Asolo Camp)

SOM is between 2.52-3.81 with the greatest amount in the 0-5 cm layer. The intermediate consistency of depths indicates consistent organic deposition and little erosion. Small increases in the deeper levels (100+) can be a sign of biomass of roots in the soil or dissolved organic compounds that are transferred through leaching. SOC

is 1.47 - 2.22 percent which means moderate amount of carbon usually found in Ferralsols or Alfisols in the tropical Nigeria. Little changes in deeper layers indicate constant carbon pools. pH is constant (5.77 - 6.01), which is appropriate to nutrient availability and microbial activity. This small rise at 15-30 cm is characteristic of the areas of leaching where organic acids of an acidic nature are reduced. Moderate Electrical conductivity (65 - 157 uS / cm) indicates a comparatively steady ion build up. The maximum conductivity value of 5-15 cm could be a sign of high nutrient horizons. The range of microbial viability is 76-95 mV which means that soils are well-aerated and that they contain moderate microbial activity. No signs of waterlogging.

Pedon13 (Ijagba)

SOM is very heterogeneous (0.13-3.48%), meaning there is heterogeneous organic input. The steep decrease beyond 5-15 cm implies that there was a high-surface activity and low-subsurface organic stabilization. High levels of loss of SOM in deeper layers (0.13%), suggest that the area was highly decomposing and had low carbon sequestration potential. SOC is highly variable (0.13-2.03%). Low carbon of less than 30 cm indicates poor humification as well as ineffective carbon stabilization. The most acidic site (pH 4.71-5.05) is ijagba, potentially restricting the presence of nutrients (e.g., P, Ca, Mg) and promoting the solubility of toxic metals (Al^{3+} , Mn^{2+}). The regular acidity indicates a high leaching or parent material effect. The electrical conductivity varies over a broad range (1-182 uS/cm). The low EC at deeper layers and high EC at surface layers (182 uS/cm) could be evidence of nutrient depletion and anthropogenic impact or localized organic breakdown respectively. The highest value of Microbial viability, up to 186 mV was obtained in the site indicating very well-drained, highly oxidizing soil conditions. This could speed up SOM decay, which is in line with depths of SOM that are very low.

Micro and macro nutrients properties of the pedons in the study area.

The results of the micro and macro nutrients properties of the pedons in the study area are presented in the Table 3.

Pedon 1(Ikaram)

Copper (Cu) values 0.21% – 0.24% are fairly uniform across all depths. Copper is strongly adsorbed to organic matter and clay minerals indicating stable parent material influence, limited leaching due to adsorption to Fe/Mn oxides and moderate organic matter stabilization in surface layers. Zinc (Zn) slightly increases with depth 2.55 – 2.74%, this is due to downward movement through leaching explaining the slightly higher values in the subsoil and also interaction with clay minerals at deeper layers. Manganese (Mn) remains consistent 4.82% – 4.89% all through the depth, this is influenced by redox conditions, and the stable values indicate well-drained conditions without prolonged waterlogging, it also suggests minimal redox fluctuation. Chromium (Cr) is generally low 0.02% – 0.21% across all the depth, this may be due to the parent material origin and low concentration, also indicates reduction in anthropogenic contamination. Iron (Fe) values are relatively stable 1.13 – 1.24% in all the depth, this is typical of tropical ferruginous soils, and iron oxides accumulate due to intense weathering, this stability also indicates strong laterization processes. The Organic Nitrogen (ON) decreases across the depth 3.74% – 0.10% suggesting surface accumulation from litter decomposition and reduction in organic inputs at deeper layers, it is also as a result of rapid mineralization under tropical temperatures. Phosphorus (P) varies Moderately 5.12mg/kg–7.25mg/kg. this shows that phosphorus P fixation by Fe/Al oxides is common in tropical soils and the slight accumulation at mid-depth may indicate translocation. Sodium (Na) remains around 0.87–1.03 due to low sodicity, and it indicates good drainage and minimal salinity hazard. Magnesium (Mg) relatively high 8.42–9.96 suggesting that it is likely to be inherited from parent material and it shows limited. leaching when compared to Calcium. Calcium (Ca) Moderate values 1.23–1.35 this indicates that calcium is susceptible to leaching in humid environments and its moderate presence indicates partial retention. The Ikaram soil profile shows relatively stable micronutrient concentrations across depths, moderate base cation levels, and decreasing organic-related parameters with depth.

Pedon 2(Ago-Flower)

At Ago-Flower, sodium Na ranged between 5.11 and 6.04 cmol/kg this suggests that the soil is void of sodicity, Calcium (Ca) shows strong fluctuations with higher Calcium content at the top soil (0-5cm) 10.27%, 0.70% at

30-60 cm and 2.03% at 60-100 cm, this can be due to surface liming or ash addition, and also leaching in subsoil and anthropogenic disturbance. Magnesium Mg ranged between 1.09 and 1.36 cmol/kg as a result of leaching of the parent material while potassium K was consistently high (1.24–1.34 cmol/kg), reflecting nutrient-rich surface horizons beneficial for root development. Copper Cu amount decreases with depth (0.09 – 0.15 mg/kg) due to surface enrichment from organic residues and fertilizer inputs, while zinc Zn ranged between 2.85 and 3.42 mg/kg, shows adequate fertility this suggest Possible fertilizer contribution and Parent material enrichment. Ago Flower soil shows higher Zinc than Ikaram. Manganese Mn values are stable (4.62–4.81 mg/kg) as a result of organic matter mineralization while iron Fe (1.26–1.38 mg/kg) was slightly elevated in deeper layers, reflecting Fe oxide accumulation indicative of ferruginous tropical soils. There was a rise in chromium Cr (0.13–0.46 mg/kg) with depth, which showed the natural lithogenic concentration and weathering concentration, in the subsoil. Organic Nitrogen (ON) Very low below the surface because of intensive cultivation, rapid decomposition and inadequate management of organic matter. Phosphorus (P) is Moderate yet erratic due to the presence of Phosphorus fixation by Fe oxides suggesting the presence of fertilizer history.

Table 3: Micro and Macro Nutrients Properties of the Soil

Loca tion	Dep th	Cu	Zn	Mn	Cr	Fe	On	P	Na	Mg	Ca	K
Ikara m	0-5	0.24 ^{n,o} ±0.013	2.55 ^f ±0.011	4.86 ^o ±0.08	0.02 ^a ±0.012	1.13 ^{o,p} ±0.009	3.74 ^x ±0.0001	0.16 ^o ±0.01	6.52 ^q ±0.008	1.03 ^{g,h} ±0.012	8.89 ^x ±0.009	1.35 ^r ±0.012
	5-15	0.22 ^{l,m} ±0.008	2.64 ^o ±0.010	4.82 ⁿ ±0.010	0.12 ^{b,c} ±0.010	1.15 ^{q,r} ±0.009	1.91 ^q ±0.0001	0.22 ^q ±0.01	5.12 ^{c,d} ±0.010	0.87 ^d ±0.010	8.42 ^s ±0.009	1.23 ^{j,k} ±0.012
	15-30	0.23 ^{m,n} ±0.009	2.59 ^h ±0.011	4.82 ⁿ ±0.009	0.21 ^{e,f} ±0.012	1.24 ^t ±0.009	1.33 ^g ±0.0001	0.13 ^m ±0.01	6.12 ⁿ ±0.009	0.93 ^c ±0.012	9.96 ^v ±0.009	1.26 ^{n,o} ±0.012
	30-60	0.24 ^{n,o} ±0.009	2.73 ^m ±0.008	4.86 ^o ±0.009	0.02 ^a ±0.011	1.16 ^r ±0.009	0.86 ^c ±0.0001	0.08 ^g ±0.01	7.25 ^w ±0.009	1.02 ^{g,h} ±0.011	9.54 ^y ±0.009	1.23 ^{k,l} ±0.012
	60-100	0.22 ^{l,m} ±0.009	2.74 ^m ±0.012	4.88 ^p ±0.009	0.09 ^{a,b} ±0.008	1.16 ^o ±0.009	0.89 ^d ±0.0001	0.18 ^{i,j} ±0.01	6.69 ^s ±0.009	1.01 ^g ±0.008	9.93 ^z ±0.009	1.29 ^{p,q} ±0.009
	100+	0.21 ^{k,l} ±0.010	2.68 ^j ±0.008	4.89 ^q ±0.009	0.10 ^{c,d} ±0.009	1.14 ^{p,q} ±0.009	0.10 ^a ±0.0001	0.17 ^p ±0.01	6.62 ^r ±0.009	1.02 ^{g,h} ±0.009	8.68 ^u ±0.009	1.23 ^{j,k} ±0.009
Ago flow er	0-5	0.15 ⁱ ±0.008	3.40 ^z ±0.010	4.81 ⁿ ±0.010	0.13 ^{a,b} ±0.009	1.36 ⁿ ±0.008	0.18 ^h ±0.009	0.15 ^c ±0.001	5.79 ^u ±0.010	1.29 ^{l,m} ±0.009	10.27 ^z ±0.008	1.24 ^y ±0.009
	5-15	0.12 ^c ±0.009	3.01 ^v ±0.011	4.72 ^k ±0.008	0.20 ^{e,f} ±0.010	1.30 ^m ±0.008	0.09 ^g ±0.0001	0.09 ⁱ ±0.001	5.11 ^q ±0.008	1.25 ^q ±0.010	2.05 ^g ±0.008	1.31 ^w ±0.009
	15-30	0.13 ^d ±0.013	2.85 ^v ±0.009	4.62 ^h ±0.008	0.16 ^{d,e} ±0.008	1.38 ^o ±0.008	0.04 ^d ±0.0001	0.11 ^k ±0.001	5.13 ^k ±0.008	1.36 ^r ±0.008	1.54 ^e ±0.008	1.34 ^z ±0.009
	30-60	0.11 ^f ±0.011	3.42 ^y ±0.010	4.69 ⁱ ±0.008	0.26 ^{b,c} ±0.011	1.26 ^p ±0.008	0.04 ^d ±0.0001	0.15 ^p ±0.001	5.50 ^s ±0.008	1.35 ^p ±0.011	0.70 ^b ±0.008	1.29 ^u ±0.012
	60-100	0.09 [±] 0.010	3.14 ^z ±0.009	4.74 ^l ±0.008	0.34 ^{d,e} ±0.009	1.29 ^q ±0.008	0.02 ^c ±0.0001	0.24 ^r ±0.001	6.04 ^t ±0.008	1.12 ^q ±0.009	2.03 ^f ±0.008	1.31 ^{v,w} ±0.012
	100+	0.09 ^c ±0.011	2.98 ^u ±0.011	4.79 ^m ±0.009	0.46 ^{f,g} ±0.009	1.35 ^o ±0.008	0.06 ^c ±0.0001	0.16 ^q ±0.001	5.47 ^s ±0.009	1.09 ^p ±0.009	0.84 ^c ±0.008	1.29 ^u ±0.012
Iboro pa	0-5	0.06 ^d ±0.011	0.57 ^f ±0.011	4.80 ^g ±0.008	1.02 ^{a,b} ±0.01	1.41 ^{i,j} ±0.012	0.21 ⁱ ±0.0008	0.05 ^f ±0.001	6.61 ^c ±0.010	1.11 ^f ±0.01	2.35 ^s ±0.008	1.17 ^e ±0.011

	5-15	0.01 ^a ±0.010	0.89 ^b ±0.012	4.69 ^c ±0.008	1.02 ^{a,b} ±0.01	1.48 ^{l,m} ±0.12	0.06 ^u ±0.0001	0.04 ^c ±0.001	6.49 ⁱ ±0.012	1.06 ^c ±0.01	0.97 ^b ±0.008	1.18 ^f ±0.011
	15-30	0.03 ^b ±0.009	1.53 ^u ±0.012	4.67 ^d ±0.08	1.04 ^d ±0.010	1.47 ^{k,l} ±0.012	0.03 ^l ±0.0008	0.01 ^a ±0.001	6.77 ^j ±0.009	1.15 ^g ±0.010	4.39 ^u ±0.008	1.17 ^e ±0.011
	30-60	0.01 ^a ±0.009	0.73 ^g ±0.010	4.62 ^c ±0.011	1.08 ^f ±0.011	1.49 ^{m,n} ±0.011	0.02 ^c ±0.0009	0.01 ^a ±0.001	6.20 ^m ±0.011	1.13 ^g ±0.011	1.44 ^g ±0.011	1.17 ^e ±0.011
	60-100	0.03 ^b ±0.011	0.71 ^g ±0.010	4.54 ^b ±0.008	1.15 ^g ±0.09	1.49 ^{m,n} ±0.011	0.03 ^g ±0.0001	0.02 ^b ±0.001	5.91 ⁿ ±0.008	1.21 ^h ±0.09	1.44 ^g ±0.012	1.18 ^f ±0.011
	100+	0.06 ^d ±0.010	1.17 ^v ±0.012	4.48 ^b ±0.08	1.23 ^{i,j} ±0.011	1.49 ^{m,n} ±0.011	0.02 ^c ±0.0001	0.02 ^b ±0.001	5.88 ^{n,o} ±0.08	1.33 ^j ±0.011	1.19 ^f ±0.008	1.21 ^h ±0.011
Isua	0-5	0.08 ^a ±0.010	0.39 ^b ±0.012	4.74 ^l ±0.009	0.02 ^{a,b} ±0.010	1.50 ^{n,o} ±0.012	0.04 ^{c,f} ±0.0001	0.11 ^g ±0.001	5.59 ^k ±0.009	1.45 ^c ±0.010	5.49 ⁱ ±0.012	1.17 ^u ±0.011
	5-15	0.08 ^a ±0.010	0.65 ^m ±0.011	4.60 ^m ±0.008	0.09 ^d ±0.011	1.52 ^{p,q} ±0.012	0.02 ^{c,d} ±0.00001	0.14 ⁱ ±0.001	5.69 ^m ±0.008	2.15 ^l ±0.011	1.72 ^h ±0.012	1.19 ^x ±0.011
	15-30	0.12 ^d ±0.008	0.49 ^j ±0.009	4.45 ^k ±0.008	0.08 ^c ±0.011	1.53 ^s ±0.012	0.02 ^{c,d} ±0.0001	0.07 ^f ±0.001	5.94 ^u ±0.008	1.50 ⁿ ±0.011	1.42 ^c ±0.012	1.17 ^s ±0.011
	30-60	0.11 ^c ±0.009	0.51 ⁱ ±0.009	4.46 ^k ±0.008	0.03 ^b ±0.010	1.57 ^{u,v} ±0.010	0.01 ^{a,b} ±0.0001	0.06 ^c ±0.001	6.06 ^w ±0.008	1.96 ^h ±0.010	2.12 ^g ±0.010	1.19 ^x ±0.011
	60-100	0.09 ^b ±0.010	0.54 ⁱ ±0.008	4.52 ^o ±0.009	0.13 ^f ±0.011	1.59 ^x ±0.012	0.01 ^{a,b} ±0.00009	0.05 ^d ±0.001	5.52 ^j ±0.009	1.36 ^g ±0.011	1.52 ^f ±0.012	1.18 ^w ±0.011
	100+	0.11 ^c ±0.010	0.52 ^k ±0.008	4.71 ^o ±0.008	0.04 ^b ±0.011	1.60 ^z ±0.012	0.01 ^{a,b} ±0.00008	0.12 ⁱ ±0.001	6.31 ^y ±0.008	1.21 ^f ±0.011	0.15 ^c ±0.012	1.15 ^q ±0.011
Eporo	0-5	0.09 ^b ±0.010	0.52 ^p ±0.008	4.75 ^w ±0.008	0.14 ^c ±0.011	1.57 ^m ±0.010	0.14 ^t ±0.009	0.09 ^h ±0.001	5.68 ^o ±0.008	1.66 ^v ±0.011	0.14 ^h ±0.010	1.16 ^k ±0.012
	5-15	0.13 ^b ±0.011	0.43 ^a ±0.008	4.76 ^x ±0.009	0.04 ^a ±0.011	1.63 ^{o,p} ±0.010	0.12 ^r ±0.008	0.05 ^c ±0.001	6.32 ⁱ ±0.009	1.24 ⁿ ±0.011	2.60 ^m ±0.010	1.17 ^{l,m} ±0.012
	15-30	0.27 ^j ±0.08	1.52 ^v ±0.09	4.66 ^v ±0.012	0.19 ^e ±0.010	1.64 ^p ±0.011	0.12 ^r ±0.0001	0.13 ^j ±0.001	5.51 ^k ±0.012	1.35 ^q ±0.010	0.54 ⁱ ±0.011	1.17 ^{l,m} ±0.012
	30-60	0.22 ⁱ ±0.008	1.49 ^t ±0.009	4.52 ^s ±0.012	0.22 ^{f,g} ±0.011	0.08 ^{c,d} ±0.011	0.09 ^{e,f} ±0.0001	0.09 ^h ±0.001	6.03 ^p ±0.012	1.32 ^p ±0.011	2.62 ^q ±0.011	1.15 ^h ±0.012
	60-100	0.21 ⁱ ±0.08	1.26 ^t ±0.09	4.45 ^r ±0.010	0.22 ^{f,g} ±0.011	0.08 ^{c,d} ±0.011	0.08 ^d ±0.00009	0.09 ^h ±0.001	5.68 ^r ±0.010	1.30 ^o ±0.011	0.10 ^g ±0.011	1.17 ^{l,m} ±0.012
	100+	0.25 ^j ±0.08	1.55 ^v ±0.09	4.62 ^u ±0.010	0.23 ^h ±0.011	0.02 ^a ±0.009	0.09 ^{c,f} ±0.00012	0.06 ^f ±0.001	7.02 ^q ±0.010	1.42 ^t ±0.011	2.20 ^k ±0.009	1.12 ^f ±0.012
Ikun	0-5	0.31 ^b ±0.010	0.71 ^s ±0.011	4.79 ⁿ ±0.012	0.68 ^c ±0.011	0.03 ^b ±0.010	0.14 ^q ±0.0009	0.37 ^h ±0.001	6.63 ^x ±0.012	2.31 ^m ±0.011	0.08 ^b ±0.010	1.21 ^{f,g} ±0.012
	5-15	0.33 ^d ±0.011	0.72 ^u ±0.009	4.68 ^p ±0.008	0.70 ^f ±0.010	0.02 ^a ±0.010	0.09 ^d ±0.0008	0.04 ^c ±0.001	6.12 ⁱ ±0.008	2.82 ^q ±0.010	1.68 ⁱ ±0.010	1.21 ^{f,g} ±0.012
	15-30	0.39 ^f ±0.011	0.63 ^t ±0.008	4.79 ⁿ ±0.012	0.69 ^d ±0.008	0.02 ^a ±0.010	0.10 ^c ±0.00010	0.02 ^b ±0.001	6.45 ^f ±0.012	1.87 ^l ±0.008	1.33 ^f ±0.010	1.21 ^{f,g} ±0.012

	30-60	0.37 ^e ±0.011	0.36 ^p ±0.008	4.81 ^t ±0.012	0.71 ^g ±0.008	0.03 ^b ±0.010	0.10 ^c ±0.00008	0.01 ^a ±0.001	6.26 ^b ±0.012	1.77 ^k ±0.008	0.10 ^d ±0.010	1.16 ^{d,e} ±0.011
	60-100	0.40 ^h ±0.011	0.43 ^r ±0.008	4.83 ^r ±0.012	0.76 ⁱ ±0.008	0.11 ^f ±0.010	0.13 ^p ±0.0010	0.01 ^a ±0.001	6.73 ^c ±0.012	1.76 ⁱ ±0.008	3.11 ^m ±0.010	1.25 ^{j,k} ±0.012
	100+	0.44 ⁱ ±0.011	0.72 ^u ±0.009	4.91 ^s ±0.012	0.72 ^k ±0.008	0.08 ^d ±0.010	0.06 ^c ±0.0008	0.06 ^c ±0.008	7.04 ^y ±0.012	1.82 ^j ±0.008	8.80 ^s ±0.010	1.29 ^{m,n} ±0.012
Ipem e	0-5	0.46 ^o ±0.009	0.33 ^v ±0.009	4.91 ^y ±0.012	0.04 ^c ±0.010	0.04 ^c ±0.010	0.19 ^k ±0.0011	0.04 ^c ±0.001	6.38 ^h ±0.012	1.90 ^r ±0.008	0.89 ^u ±0.010	2.25 ^w ±0.012
	5-15	0.46 ^o ±0.009	0.26 ^p ±0.009	4.76 ^j ±0.012	0.37 ^k ±0.008	0.03 ^c ±0.010	0.11 ⁱ ±0.0011	0.00 ^z ±0.001	6.27 ^a ±0.012	1.92 ^l ±0.008	0.89 ^u ±0.010	1.52 ^k ±0.012
	15-30	0.48 ^r ±0.009	0.27 ^r ±0.009	4.75 ^h ±0.012	0.40 ^m ±0.008	0.05 ^g ±0.010	0.08 ^g ±0.0011	0.02 ^a ±0.001	6.30 ^d ±0.012	1.97 ^j ±0.008	0.92 ^w ±0.010	1.31 ^h ±0.012
	30-60	0.48 ^r ±0.009	0.30 ^t ±0.009	4.75 ^h ±0.012	0.48 ^r ±0.008	0.02 ^a ±0.010	0.08 ^g ±0.0011	0.03 ^c ±0.001	6.14 ^{g,h} ±0.012	1.97 ^j ±0.008	8.34 ^z ±0.010	1.28 ^g ±0.012
	60-100	0.52 ^u ±0.008	0.64 ^k ±0.009	4.89 ^s ±0.012	0.47 ^p ±0.008	0.03 ^c ±0.010	0.07 ^d ±0.0008	0.08 ^g ±0.001	7.23 ^q ±0.012	2.06 ^w ±0.008	0.13 ^h ±0.010	1.31 ^h ±0.012
	100+	0.54 ^w ±0.008	0.47 ^y ±0.009	4.93 ^z ±0.012	0.50 ^t ±0.008	0.03 ^c ±0.010	0.08 ^g ±0.0011	0.12 ⁱ ±0.001	6.85 ^v ±0.012	2.16 ^y ±0.008	6.67 ^l ±0.010	1.27 ^f ±0.012
Iwoy e	0-5	0.65 ^h ±0.009	0.57 ^p ±0.008	4.79 ^j ±0.012	0.64 ⁱ ±0.008	0.03 ^c ±0.001	0.12 ^k ±0.0011	0.03 ^c ±0.011	6.18 ^{a,b} ±0.012	2.51 ^s ±0.008	2.35 ^k ±0.001	1.38 ^p ±0.012
	5-15	0.61 ⁱ ±0.009	0.66 ^q ±0.008	4.59 ^l ±0.012	0.50 ⁱ ±0.008	0.02 ^b ±0.001	0.08 ^g ±0.0008	0.01 ^a ±0.009	6.01 ^a ±0.012	2.48 ^p ±0.008	0.52 ^h ±0.001	1.26 ⁱ ±0.012
	15-30	0.63 ^k ±0.009	1.41 ^u ±0.008	4.66 ^u ±0.012	0.58 ^f ±0.008	0.12 ^h ±0.001	0.07 ^{e,f} ±0.0001	0.03 ^c ±0.008	7.62 ^{a,b} ±0.012	2.75 ^m ±0.008	1.58 ⁱ ±0.001	1.22 ^g ±0.012
	30-60	0.65 ^h ±0.009	0.72 ^r ±0.008	4.41 ^v ±0.012	0.53 ^h ±0.008	0.06 ^d ±0.001	0.08 ^g ±0.001	0.02 ^b ±0.009	5.22 ^{a,b} ±0.012	2.58 ^o ±0.008	0.19 ^d ±0.001	1.20 ^d ±0.012
	60-100	0.71 ^p ±0.009	1.05 ^s ±0.008	4.70 ^t ±0.012	0.58 ^f ±0.008	0.14 ^l ±0.010	0.07 ^{e,f} ±0.001	0.12 ^g ±0.0156	7.47 ^{f,g} ±0.012	2.75 ^m ±0.008	1.76 ⁱ ±0.010	1.20 ^d ±0.012
	100+	0.66 ^r ±0.009	0.91 ^k ±0.008	4.79 ^z ±0.012	0.48 ^d ±0.008	0.07 ^f ±0.001	0.07 ^{e,f} ±0.0009	0.05 ^c ±0.012	7.06 ^{b,c} ±0.012	2.69 ⁿ ±0.008	0.21 ^f ±0.001	1.29 ^m ±0.012
Isew e	0-5	0.04 ^d ±0.001	2.57 ^o ±0.008	4.47 ^p ±0.012	0.43 ^f ±0.009	0.12 ⁿ ±0.008	0.09 ^g ±0.0009	0.18 ^h ±0.010	5.70 ^o ±0.012	0.02 ^k ±0.009	4.38 ⁱ ±0.008	0.04 ^d ±0.008
	5-15	0.06 ^f ±0.001	3.68 ^p ±0.008	4.46 ^o ±0.012	0.61 ^h ±0.009	0.18 ^o ±0.008	0.12 ^l ±0.006	0.22 ^x ±0.012	5.43 ^v ±0.012	0.04 ^m ±0.009	0.11 ^f ±0.008	0.11 ^e ±0.008
	15-30	0.09 ^g ±0.001	4.02 ^r ±0.008	4.55 ^m ±0.011	0.62 ⁱ ±0.009	0.14 ^h ±0.008	0.15 ^x ±0.001	0.18 ^y ±0.012	6.82 ^y ±0.011	0.32 ^k ±0.009	1.48 ^c ±0.008	0.02 ^b ±0.008
	30-60	0.09 ^g ±0.001	3.21 ^s ±0.008	4.65 ^q ±0.011	0.71 ^k ±0.009	0.31 ⁱ ±0.008	0.16 ^w ±0.001	0.23 ^y ±0.009	6.05 ^g ±0.011	0.42 ^m ±0.009	0.34 ^h ±0.008	0.03 ^c ±0.008
	60-100	0.07 ⁱ ±0.001	1.07 ^m ±0.008	4.65 ^q ±0.012	0.75 ^m ±0.009	0.35 ^k ±0.008	0.03 ^{b,c} ±0.001	0.31 ^z ±0.012	6.35 ^c ±0.012	0.61 ^o ±0.009	4.06 ⁿ ±0.008	0.02 ^b ±0.008
	100+	0.07 ⁱ ±0.001	1.07 ^m ±0.008	4.65 ^q ±0.012	0.75 ^m ±0.009	0.35 ^w ±0.008	0.03 ^{b,c} ±0.001	0.26 ^q ±0.012	6.84 ^d ±0.012	0.76 ⁿ ±0.008	1.61 ^m ±0.009	0.13 ^g ±0.008

Ijegu ma	0-5	0.01 ^a ±0. 012	0.76 ^h ±0. .008	4.71 ^v ±0. .012	0.77 ^t ±0. .011	0.56 ^g ±0. 012	0.30 ^w ±0. 001	0.12 ^k ±0. .013	8.08 ^z ±0. 011	0.73 ^o ±0.0 11	2.55 ^h ±0. 012	0.21 ^u ±0. .008
	5-15	0.01 ^a ±0. 012	0.68 ⁱ ±0. 008	4.60 ⁿ ±0. .011	0.88 ^g ±0. .011	0.54 ^k ±0. 009	0.23 ^q ±0. 001	0.04 ^p ±0. .010	6.31 ^q ±0. 012	0.82 ^s ±0.0 11	8.85 ^w ±0. .009	0.08 ^p ±0. .008
	15- 30	0.07 ^f ±0. 011	0.74 ⁱ ±0. 008	4.49 ^k ±0. .011	0.05 ^d ±0. .010	0.52 ^l ±0.0 10	0.09 ^d ±0. 0009	0.08 ⁿ ±0. .009	6.29 ^w ±0. 012	0.89 ^k ±0.0 10	2.23 ^p ±0. 010	0.05 ^d ±0. .008
	30- 60	0.05 ^d ±0. 011	1.03 ^t ±0. 09	4.47 ^h ±0. .012	0.12 ^p ±0. .010	0.51 ^v ±0. 010	0.10 ^g ±0. 0001	0.09 ^u ±0. .010	7.75 ^y ±0. 009	0.83 ⁿ ±0.0 10	0.18 ^r ±0. 010	0.04 ^b ±0. .009
	60- 100	0.08 ^g ±0. 009	0.56 ^x ±0. .009	4.47 ^h ±0. .011	0.11 ^s ±0. .008	0.58 ^o ±0. 011	0.08 ^c ±0. 0001	0.11 ^f ±0. .010	7.43 ^x ±0. 011	0.83 ⁿ ±0.0 08	0.60 ^u ±0. 011	0.03 ^a ±0. .009
	100 +	0.00 ^d ±0. 015	0.85 ^m ±0. .011	4.55 ^u ±0. .012	0.05 ^d ±0. .010	0.49 ^c ±0. 011	0.05 ^c ±0. 0009	0.07 ^g ±0. .011	6.25 ^p ±0. 011	0.67 ⁱ ±0.0 10	2.45 ^v ±0. 011	0.05 ^d ±0. .009
Ifon	0-5	0.02 ^{a,b} ±0. .009	1.37 ^c ±0. .011	4.65 ^x ±0. .011	0.35 ^g ±0. .009	0.46 ^p ±0. 008	0.14 ^{c,f} ±0. 0008	0.03 ^{a,b} ± 0.009	8.05 ^x ±0. 011	0.49 ^c ±0.0 09	3.75 ^f ±0. 008	0.08 ^m ± 0.010
	5-15	0.04 ^{f,g} ±0. .012	0.85 ^p ±0. .012	4.58 ^u ±0. .011	0.46 ^b ±0. .009	0.51 ^t ±0.0 08	0.11 ^b ±0. 0008	0.07 ^{c,f} ± 0.012	7.63 ^u ±0. 008	0.85 ⁿ ±0.0 09	6.71 ^w ±0. .008	0.04 ^o ±0. .010
	15- 30	0.01 ^a ±0. 009	0.96 ^v ±0. .008	4.59 ^j ±0. .012	0.39 ^c ±0. .010	0.54 ^k ±0. 009	0.06 ^c ±0. 001	0.02 ^a ±0. .012	7.01 ⁱ ±0.0 08	0.47 ^f ±0.0 10	5.47 ^h ±0. 009	0.01 ^a ±0. .010
	30- 60	0.01 ^a ±0. 013	1.03 ^y ±0. .012	4.50 ^{r,s} ± 0.012	0.41 ^d ±0. .010	0.54 ^k ±0. 009	0.10 ^d ±0. 001	0.04 ^{b,c} ± 0.011	6.78 ^{s,t} ±0. 011	0.43 ⁱ ±0.0 10	2.95 ^t ±0. 009	0.01 ^a ±0. .010
	60- 100	0.01 ^a ±0. 013	1.03 ^y ±0. .008	4.49 ⁱ ±0. .011	0.37 ^c ±0. .011	0.09 ^a ±0. 009	0.06 ^c ±0. 001	0.05 ^{c,d} ± 0.009	6.08 ⁱ ±0.0 09	0.87 ^m ±0.0 11	0.28 ^r ±0. 009	0.00 ^d ±0. .010
	100 +	0.02 ^{a,b} ±0. .008	1.12 ^x ±0. .012	4.54 ⁿ ±0. .012	0.32 ^f ±0. .010	0.37 ^g ±0. 008	0.08 ^g ±0. 0009	0.02 ^a ±0. .011	5.56 ⁿ ±0. 011	0.44 ^q ±0.0 10	2.08 ⁱ ±0. 008	0.00 ^d ±0. .010
Asol o camp	0-5	0.07 ^b ±0. 0012	2.57 ^x ±0. .011	4.72 ^z ±0. .012	0.26 ^p ±0. .010	0.03 ^{c,d} ±0. .008	0.19 ^r ±0.0 009	0.01 ^{a,b} ± 0.008	6.72 ⁿ ±0. 012	0.41 ^h ±0.0 10	3.13 ^q ±0. 008	0.07 ^{g,h} ± 0.010
	5-15	0.13 ^g ±0. 011	1.31 ^w ±0. .011	4.68 ^u ±0. .011	0.15 ^s ±0. .008	0.03 ^{c,d} ±0. .008	0.15 ^w ±0. 0008	0.03 ^{c,d} ± 0.008	6.41 ^u ±0. 011	0.28 ^f ±0.0 08	0.82 ^o ±0. 008	0.06 ^f ±0. .010
	15- 30	0.12 ^h ±0. 012	1.66 ^s ±0. 012	4.65 ^{r,s} ± 0.011	0.25 ⁿ ±0. .009	0.05 ^{c,f} ±0. 008	0.13 ^o ±0. 0008	0.02 ^{b,c} ± 0.012	7.33 ^s ±0.0 11	0.25 ^c ±0.0 09	1.42 ^p ±0. 008	0.07 ^{g,h} ± 0.010
	30- 60	0.08 ^f ±0. 010	1.32 ^t ±0. 012	4.65 ^{r,s} ± 0.011	0.26 ^p ±0. .009	0.12 ^{i,j} ±0. 012	0.15 ^w ±0. 0001	0.04 ^f ±0. .012	6.82 ^u ±0. 011	0.32 ^d ±0.0 09	0.87 ^j ±0. 012	0.11 ^k ±0. .010
	60- 100	0.16 ^d ±0. 010	0.91 ^m ±0. .011	4.54 ^q ±0. .012	0.31 ^o ±0. .008	0.07 ^{f,g} ±0. 011	0.13 ^o ±0. 00009	0.04 ^f ±0. .009	4.35 ^r ±0.0 12	0.31 ^c ±0.0 08	0.321±0. 011	0.04 ^a ±0. .010
	100 +	0.16 ^d ±0. 010	1.23 ^q ±0. .012	4.69 ^v ±0. .012	0.36 ^m ± 0.008	0.08 ⁱ ±0.0 10	0.15 ^w ±0. 00008	0.04 ^f ±0. .009	5.76 ^v ±0. 012	0.31 ^c ±0.0 08	0.45 ^w ±0. .010	0.15 ^m ± 0.008
Ijagb a	0-5	0.15 ^a ±0. 008	0.93 ^d ±0. .009	4.46 ^k ±0. .012	0.43 ^h ±0. .009	0.24 ^{b,c} ±0. .011	0.08 ^d ±0. 0001	0.09 ^h ±0. .007	6.36 ⁿ ±0. 012	0.30 ^q ±0.0 09	9.61 ^v ±0. 011	0.06 ^{b,c} ± 0.009
	5-15	0.18 ^c ±0. 009	1.42 ^k ±0. .009	4.64 ^y ±0. .012	0.52 ^k ±0. .009	0.24 ^{b,c} ±0. .011	0.17 ^j ±0.0 008	0.17 ^k ±0. .008	7.87 ^z ±0. 012	0.82 ^r ±0.0 09	0.18 ⁱ ±0. 011	0.14 ^{g,h} ± 0.009

	15-30	0.18 ^c ±0.009	0.93 ^e ±0.009	4.35 ^f ±0.012	0.52 ^k ±0.009	0.25 ^{e,f} ±0.011	0.04 ^b ±0.00008	0.09 ^h ±0.011	6.44 ^w ±0.012	0.24 ^l ±0.009	9.74 ^m ±0.011	0.13 ^{e,f} ±0.009
	30-60	0.17 ^{d,e} ±0.008	0.92 ^e ±0.008	4.34 ^d ±0.012	0.64 ^h ±0.009	0.24 ^{b,c} ±0.008	0.04 ^b ±0.00008	0.12 ^k ±0.012	6.52 ^q ±0.012	0.20 ^k ±0.009	2.44 ^o ±0.008	0.06 ^{b,c} ±0.009
	60-100	0.17 ^{d,e} ±0.008	1.21 ^m ±0.009	4.37 ^b ±0.011	0.72 ⁱ ±0.009	0.58 ^{k,l} ±0.009	0.01 ^a ±0.00001	0.09 ^h ±0.008	7.52 ^x ±0.011	0.42 ^m ±0.009	0.35 ^e ±0.009	0.07 ^d ±0.009
	100+	0.17 ^{d,e} ±0.008	1.01 ^h ±0.008	4.17 ^a ±0.012	0.75 ^l ±0.008	0.13 ⁱ ±0.008	0.01 ^a ±0.00008	0.05 ^e ±0.011	6.83 ^y ±0.012	0.08 ^d ±0.008	1.52 ⁱ ±0.008	0.11 ^f ±0.009

Values are means of three replicates $\pm$ standard deviation; Alphabets in superscripts denotes statistically significant groupings from ANOVA and Duncan test. Means with superscript letter are not significantly different at $P < 0.05$, while those with different letters are; Cu=Copper, Zn=Zinc, Mn=Manganese, Cr=Chromium, Fe=Iron, ON= organic Nitrogen, P=Phosphorus, Na=Sodium, Mg=Magnesium, Ca=Calcium, K=Potassium

Pedon 3 (Iboropa)

The sodium (Na) in the soils of Iboropa has moderate values of 5.88 to 6.77 cmol/kg suggesting that there is a fairly uniform distribution of Na throughout the soil profile. This implies that there will be little leaching and potential contribution by weathered parent material (feldspathic). The content of Copper Cu was low (0.01 mg/kg -0.06 mg/kg) and this indicates poor availability of Cu, which is common with highly weathered tropical soils. Zinc Zn, values were between 0.57 and 1.53 mg/kg and peaked at 15-30 cm, which can be taken to suggest that translocation and accumulation of zinc in the subsoil was small, as a result of the decomposition and complexation of organic matter. Manganese Mn was not so erratic (4.48-4.80 mg/kg), as the redox equilibrium of well-aerated soils. There was a slight variation of chromium Cr according to depth (1.02-1.23 mg/kg) which might be a result of its lithogenic nature. The moderate level of Exchangeable Ca (0.97-4.39 cmol/kg) and Mg (1.06-1.33 cmol/kg) was accompanied by uniform Potassium K (1.17-1.21 cmol/kg) which showed that the exchange of cations and good retention of nutrients at depth are balanced.

Pedon 4 (Isua)

The Sodium Na ranged at 5.52-6.31 cmol/kg at Isua, as in Iboropa with no deep gradient in Sodium, indicating a well-mixed soil profile, there is no problem of sodicity, and the parent material has probably been brought down. Copper Cu quantities differ between 0.08 and 0.12 mg/kg and exhibit minimal depth changes. Copper is strongly adsorbed to organic matter and iron oxides. The low values suggest poor organic matter content and prolonged leaching which can lead to possible Cu deficiency, while Zn (0.39–0.65 mg/kg) was generally deficient, reflecting strong Zn fixation in Fe–Mn oxides, Zn is mobile in acidic tropical soils which is likely lost through vertical leaching. Mn concentrations (4.45–4.74 mg/kg) were stable with depth, indicating well-drained conditions, no evidence of prolonged waterlogging (which would cause fluctuation). Chromium (Cr) Very low (0.02–0.13). suggesting Lithogenic origin from parent material, no anthropogenic contamination evident. Mg (1.21–2.15 cmol/kg) and Ca (0.15–5.49 cmol/kg) exhibited some variation, suggesting partial leaching of base cations from surface to subsoil. The peak Ca value at the surface reflect organic matter enhancement of cation exchange. Potassium K (1.15–1.19 cmol/kg) is stable, suggesting minimal K depletion. Organic Nitrogen (ON) is very low and decreases with depth (0.04 $\rightarrow$ 0.01) indicating low organic input, rapid mineralization under tropical temperature and Poor humus stabilization. Phosphorus (P) is average though variable (5.52-6.31) as a result of Phosphorus fixation by iron oxides and slight accumulation mid profile that point to down movement.

Pedon 5 (Eporo)

Eporo soils demonstrated moderate variation of Sodium Na (5.51-7.02 cmol/kg), the highest value was in the deepest horizon (100+ cm). The copper Cu rises by 0.09 to 0.27 mg/kg by depth, which means that it is downward and attaches to clay fractions, as well as it may be affected by fertilizer input. Zinc Zn (0.43155 mg/kg) was highest in the subsoil (100+ cm), indicating that there is no leaching and Possible fertilizer residue, so it can also be considered as clay accumulation zone. Manganese Mn (4.45-4.76 mg/kg) was constant, and Chromium Cr was

between 0.04 and 0.27mg/kg, indicating that it is lithogenic origin and weathering residual accumulation. The value of Magnesium Mg (1.24-1.66 cmol/kg) and Calcium (Ca) are extremely inconsistent (0.10-2.62cmol/kg) due to biocycling and surface amendment history in the area and depth leaching. Due to Strong laterization process, Iron (Fe) is quite stable (1.57-1.64). The level of Organic Nitrogen (ON) at depth is low showing little or no recycling of organic matter and may also be a result of constant cultivation. Phosphorus (P) value differs (5.51-7.02) due to Phosphorus fixation and the upward shift of the value in the lower depth could be the outcome of the eluviation-illuviation process. These trends indicate the presence of a moderate leaching pressure soil system with cationic balance because of fine-textured mineral composition.

Pedon 6 (Ikun)

Sodium Na (6.12-7.04 cmol/kg) was also similar with greater values in depth (100+ cm). The values of Copper Cu are high and rising down the depth (0.31-0.44 mg/kg) indicating a high degree of mineralogical control and also Zinc Zn values (0.36-0.72 mg/kg) were moderate and steady indicating a constant adsorption to clay minerals. Manganese Mn (4.68-4.91mg/kg) exhibited a slight variation, which implies the homogenous redox condition. The level of Chromium Cr (0.68-0.76 mg/kg) is comparatively high with other places; probably because of the parent rock input and concentration as a result of weathering. The values of Magnesium Mg (1.76-2.82 cmol/kg) are high indicating that there was either a rich Mg parent material or there was low leaching of the soil. Ca (0.08-8.80 cmol/kg) showed a great variety with a drastic increase at 100+ (8.80) suggesting localised calcium deposition and Limited leaching at deep horizon. The values of potassium K (1.16-1.29 cmol/kg) were stable indicating overall nutrient stability. Iron (Fe) Relatively low at surface but stable due to Possibly mixed mineralogy and Not intensely laterized. The Organic Nitrogen (ON) tends to be low that implies low turnover of the organic matter. Fixation of Fe and Al oxides and a Slight enrichment at depth give Phosphorus (P) Moderate (6.12-7.04).

Pedon 7 (Ipeme)

At Ipeme, Sodium (Na) has moderate value (1.90-2.16 cmol/kg) due to the source of Parent material and no trace of sodicity hazard. Cu (0.46-0.54 mg/kg) was moderate as due to the mineral richness of the parent material and a potential role of agrochemicals whereas this is not the case with Zinc (Zn) (0.26-0.64 mg/kg) given that it is high in the top soil (0-5 cm) and is high at 60-100 cm (0.64) since it is increasing downward. Mn (4.75-4.93 mg/kg) remained consistent. The values of chromium Cr (0.18-0.50 mg/kg) showed a positive relation to depth, which indicated a steady parent material amount and concentration of weathering. There was variability of Exchangeable Mg (1.90-2.16 cmol/kg) and Ca (0.13-8.34 cmol/kg), which is probably because of uneven weathering and translocation of cations. The levels of Potassium K (1.27-2.25 cmol/kg) was usually moderate indicating that there was no lack of fertility. The values of iron (Fe) are low to moderate (0.02-0.05) because of lower ferruginous than other locations. The levels of Organic Nitrogen (ON) are very low with depths implying rapid mineralization and potentially under continuous cropping. Phosphorus (P) was between Moderate and high (6.14-7.23) due to Phosphorus fixation as dominant and Slight deep. The Ipeme soils are characterized by semi-saturation levels of base and a relatively stable level of trace metal, and are capable of being productively used sustainably when there is a balanced fertilization.

Pedon 8(Iwoye)

Sodium Na medium (5.22-7.62 cmol/kg) though with some peaks at 15-30cm, 60-100cm and 100+cm is a pointer of a base-rich substrate. The high value of copper (0.61-0.71) is slightly decreasing back which means that the mineralogy is under control and bound to clay fraction. The pulse of Zinc Zn at 15-30 cm (1.41mg/kg) indicates that there is probably a clay illuviation zone where Zinc is accumulated. Manganese Mn is stable (4.41-4.79mg/kg) which implies well drained soil with low redox variability. Value of chromium (Cr) indicates moderation (0.48-0.64) that points to Lithogenic origin and remaining concentration during weathering. Magnesium Mg is high (2.48-2.75 cmol/kg) suggests limited leaching Iron Fe is generally low (0.02-0.14 mg/kg) except occasional small rises at 15-30cm and 60-100cm indicating less intense laterization compared to other locations. Calcium Ca value varies but low-moderate in many horizons (0.19-2.35 cmol/kg) as a result of surface biological cycling with subsoil leaching. Potassium K is moderate (1.20-1.38 cmol/kg) indicating

adequate fertility. Phosphorus(P) is higher at deeper layers (7.47–7.62) suggesting Possible downward migration and fixation.

Pedon 9 (Isewe)

Sodium Na values range from 5.43–6.84 cmol/kg indicating well-drained conditions that prevent sodicity accumulation. Copper Cu is very low (0.04–0.09 mg/kg) suggest strong leaching and low organic retention. Zinc Zn value ranges from 1.07–4.02 mg/kg, at depths 15–30 cm, it is high 4.02mg/kg, then lower at depth 60-100cm and 100+ cm suggests surface enrichment or fertilizer input. Manganese Mn values range from 4.46–4.71 mg/kg suggesting a strong lithogenic origin. Chromium Cr increases slightly with depth (0.43–0.82 mg/kg) indicates residual accumulation. Magnesium Mg increases at deeper horizons (0.02–0.76 cmol/kg) indicating leaching, Iron Fe pulses at certain horizons (0.12–0.45 mg/kg), this shows ferruginous profile. Calcium Ca varies (0.11–4.38 cmol/kg) suggest less acidic parent materials and clay mineral contribution. Potassium K is moderately low in some horizons with values ranging from 0.02–0.13 cmol/kg as a result of advanced leaching.

Pedon 10(Ijegunma)

Sodium Na is high (6.25–8.08 cmol/kg) indicating leaching of sodium from high rainfall. Copper Cu very low to negligible (0.00–0.08 mg/kg) showing a potential deficiency and severe depletion, very low Cu suggests micronutrient management is needed. Zinc Zn is moderately low (0.56–1.03 mg/kg) as a result of downward leaching. Manganese Mn 4.47–4.71 mg/kg is stable indicating consistent redox conditions. Chromium Cr ranges widely (0.05–0.88 mg/kg) with a high value at 5–15 cm (0.88 mg/kg) showing possibility of lithogenic activity and residual accumulation. Magnesium Mg is moderately low (0.67–0.89 cmol/kg) suggesting parent material weathering. Calcium Ca shows an increase at 5–15 cm (8.85 mg/kg) suggests Ca accumulation and leaching dominance, Iron Fe value varies (0.49–0.56 cmol/kg) reflecting intense tropical weathering. Potassium K is low (0.03–0.21 cmol/kg) as a result of surface fixation. Organic nitrogen is moderately high at the surface as a result of surface enrichment from liter.

Pedon 11 (Ifon)

Sodium Na is high (5.56–8.05 cmol/kg) suggest well-drained conditions preventing sodicity accumulation. Copper Cu is very low (0.01–0.04 mg/kg) indicating deficiency risk as a result of leaching during heavy rainfall. Zinc Zn is moderate (0.85–1.37 mg/kg) reflecting adsorption to clay minerals. Manganese Mn is about 4.49–4.65 mg/kg suggesting lithogenic origin. Chromium Cr is low (0.32–0.46 mg/kg). Magnesium Mg low to moderate (~0.43–0.87 cmol/kg) as a result of leaching. Iron Fe moderate (0.37–0.54 mg/kg). Calcium Ca moderate (0.28–6.71 cmol/kg) with notable surface and subsurface peaks. Potassium K very low (0.00–0.08 cmol/kg). Very low K and Cu suggest deficiencies likely to constrain yield; Ca and Na distributions imply a base-rich but possibly imbalanced cation system. K fertilization and Cu monitoring advised; evaluate irrigation/surface inputs for Na contribution.

Pedon 12 (Asolo Camp)

At Asolo Camp, sodium (Na) concentrations ranged from 4.35 mg/kg to 7.33 mg/kg this shows moderate variation with depth. This implies that there was little leaching and potential depositions of surface runoff or mineral weather. The copper values were low (0.07-0.16 mg/kg), which indicate geogenic background values and no anthropogenic additive values. Zinc (Zn) decreased with depth as 2.57 mg/kg at 0-5 cm, and 0.91mg/kg at 60-100 cm showed that there was surface enrichment of organic matter or fertilizer residues and leached away down the depth. Manganese (Mn) was relatively stable (4.54-4.72 mg/kg) indicating that there was no significant movement in redox balance. Chromium (Cr) changed insignificantly with depth (0.15-0.36 mg/kg), meaning that it accumulated in the subsoils through adsorption on Fe/Mn oxides. Magnesium (Mg) was low (0.25-0.41mg/kg) which was in accordance with moderate weathering. The levels of iron (Fe) were low (0.03-0.12 mg/kg) which indicated good drainage and oxidation. Surficial calcium (Ca) was highest in the surface layer (3.13 mg/kg) but decreased drastically below 15 cm indicating surface cycling and intense leaching. Potassium (K) level was also extremely low (0.04-0.15 mg/kg) which is a sign of severe nutrient loss. The Asolo Camp soils are moderately acidic and poor in fertility and slightly enriched in surface bases and leached subsoils.

Pedon 13 (Ijagba)

Sodium (Na) was rather high in the whole profile, 6.36 to 7.87 mg/kg, which means moderate salinity potential and parent rock material impact. The copper (Cu) levels were consistent (0.15-0.18 mg/kg) and within the normal background levels. There was no definite vertical trend in zinc (Zn) values as they varied between 0.92 and 1.42 mg/kg indicating a balanced leaching and replenishment. The manganese (Mn) levels remained at 4.17-4.64mg/kg indicating that there were no changes in the redox conditions. It showed a progressive increase with depth of chromium (Cr), between 0.43mg/kg and 0.75mg/kg, which could suggest that chromium in the bottom horizons is immobilized. The levels of magnesium (Mg) were average (0.08-0.82mg/kg) and went downwards indicating release of magnesium during weathering and further leaching off. Calcium (Ca) showed high irregularity, and extremely high on the surface (9.61 at 0-5 and and 9.74 mg/kg at 15-30 cm) and then drastically declined in subsoils, probably because of carbonate deposition and later leaching. Potassium (K) was mostly low (0.06-0.14mg/kg) as is characteristic of tropical leached soils. Ijagba soils exhibit moderate fertility potential, high Ca and Na at the surface and low Ca and Na at the base of the subsoil which are leached.

3D Digital Soil Maps of Soil Properties for the study area.

Three-dimensional digital soil mapping (3D DSM) represents a paradigm shift from traditional two-dimensional soil representations toward volumetric modeling of soil properties across lateral and vertical dimensions. There are various attempts to map the vertical distributions of different soil properties. These properties are often mapped for multiple depth intervals, and can be interpreted three-dimensionally (Viscarra Rossel et al., 2015). However, such a vertical discretization does not provide continuous 3D information (Liu et al., 2016). Such models are thus limited in their vertical resolution, which can lead to issues with the interpretability of the soil as a volume and with the accuracy of the predicted soil properties (Kempen et al., 2011). For spatial soil modeling, three relevant scales or ranges of scale are combined, quasi-local soil formation processes (pedon scale), processes that are independent of the spatial context, short-range catenary or hillslope processes, and long-range processes related to climate and large-scale terrain settings (Behrens et al. 2018, 2019).

The figure 3 represents a three-dimensional (3D) block diagram illustrating the vertical distribution of Soil Organic Carbon (SOC) concentration with increasing soil depth. The depth intervals represented include 0–5 cm, 5–15 cm, 15–30 cm, 30–60 cm, 60–100 cm, and >100 cm. SOC concentration is depicted using a color gradient, ranging from high concentrations (dark brown) to low concentrations (pink). The graph shows clearly the gradual decrease in the concentration of SOC as the depth increases. The uppermost layer (0-5 cm) has the highest level of SOC content (0.96-1.59%), which is manifested as a dark brown color. This high surface concentration can be explained by the constant deposition of vegetal residues, litter fall, root exudates and biomass accumulation of the microbes. The contributions of organic matter are usually highest at the surface of the soil and therefore carbon is sequestered better in this layer. The SOC concentrations are lowered rather moderately in the below layers (5-15 cm and 15-30 cm) as depicted by the lighter brown yellow and blue color bands (0.77-0.96 and 0.52-0.81). The decreasing SOC of the depths is mainly attributed to the decrease in the inputs of organic matter and the rise in mineralization processes. At more depths (30-60 cm and 60-100 cm), the SOC values decrease and become in the range of 0.25-0.77%. The direct organic inputs of these layers are also minimal, and the carbon amounts found in these depths are mostly obtained through the biomass turnover of roots and through downward translocation of dissolved organic carbon. The most profound layer (> 100 cm) has the lowest SOC.

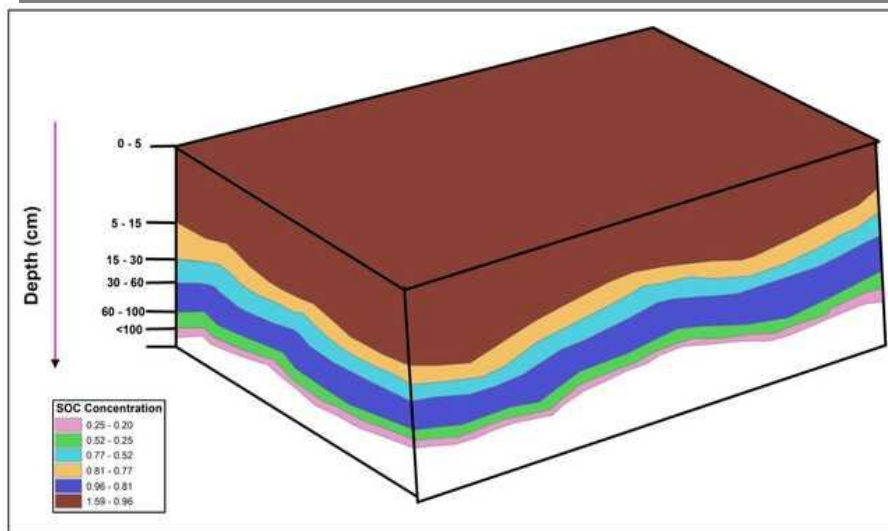


Fig. 3: 3D Model of SOC in the Study Area

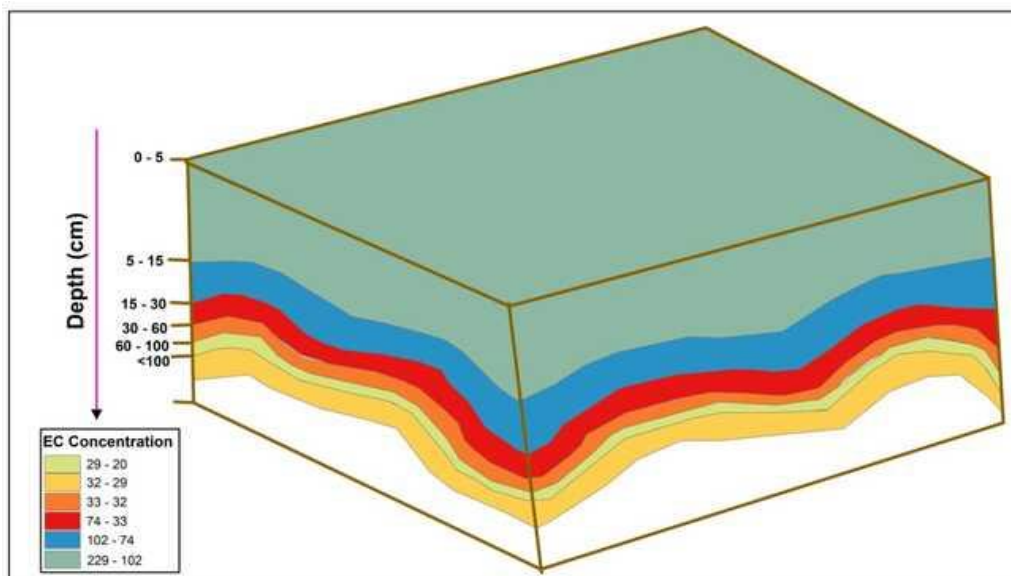


Fig. 4: 3D Model EC in the Study Area.

concentration (0.20-0.25%), which is depicted by the pink coloration. This low carbon level is indicative of low levels of biological activity, less penetration of roots and the stabilization of organic matter is also less at depth. The wavering effect of the colored layers implies that there is slight spatial dissimilarity in the distribution of SOC in the pedon. This difference can be conditioned by micro-topography, root patterns distribution, drainage conditions, or textural differences which impact on the accumulation and rate of organic matter. The vertical gradient observed proves that the SOC is mostly located in the top soil and that concentration is exponential with depth. This trend is characteristic of well-drained tropical soils where the rapid decomposition process is observed due to hot and damp climatic characteristics. The fact that the concentration of carbon is focused close to the surface is one that highlights how vulnerable SOC is to land-use alterations, erosion, and improper management practices. Conservation measures in the form of mulching, low tilling, cover cropping, and organic additions are necessary in terms of soil management to preserve or improve SOC in the upper horizons. Moreover, the model emphasizes the significance of depth-specific carbon dynamics in estimating total soil carbon stock in the sequestration of carbon through the model. The stratified nature of SOC in the soil profile can be fully visualised with the 3D model. The depth-dependent declining trend indicates the diminished inputs of organic matter and biological activity of the subsurface horizons. This distribution pattern supports the known pedogenic principles and provides support to the fact that topsoil is extremely important in the storage of carbon and ensuring the sustainability of soil fertility. Figure 4 shows the change in the soil electrical conductivity (EC) with depth within the study area. EC is a temperature of the salinity of soil and ionic concentration that may

affect fertility of soil, water availability, and plant growth. The discussion of this figure shows vertical (depth-wise) and horizontal (spatial) structures of EC concentration. The EC values of the surface (0-5 m) are maximum (229 mS/cm) and it slowly declines in depth, this may be because of deposition of salts at the surface by evaporation, decomposition of organic matter, and potential fertilizer application. Between 5-15 m, EC decreases considerably to an average of 102 mS/cm, which results in a decrease in soluble salts or ionic content in comparison with the surface implying percolation and leaching of soluble salts within upper horizons, which is a usual phenomenon in well-drained soil. Further degradation of EC at intermediate layers (15-30 m) to the range of 74 mS/cm indicates ongoing leaching or dilution of salts and the deeper layers (30-60 m, 60-100 m, <100 m)

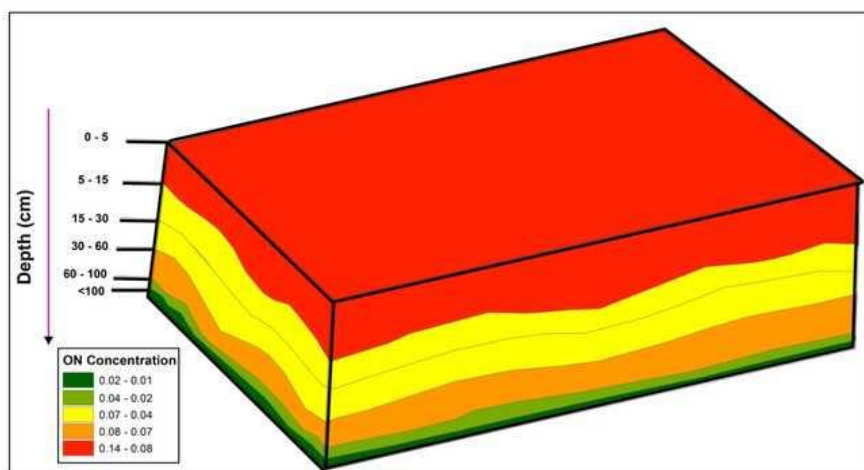


Fig. 5: 3D Model of ON in the Study Area

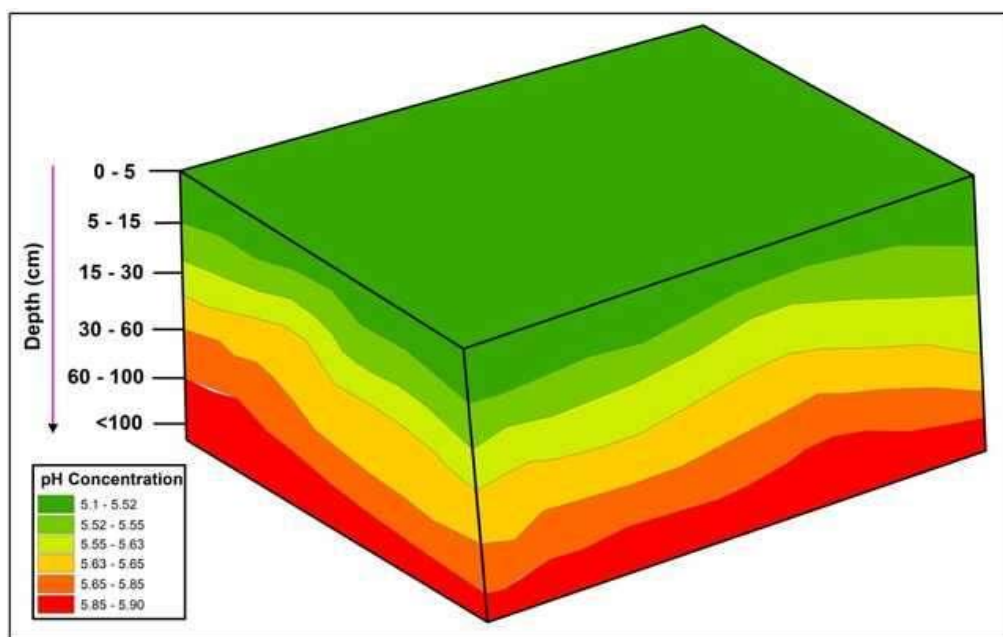


Fig. 6: 3D Model of pH in the Study Area

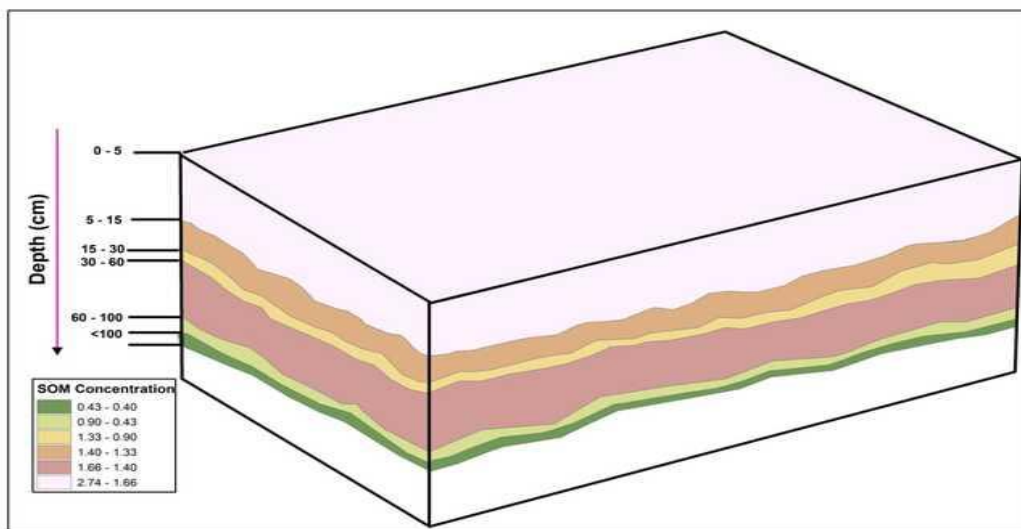


Fig. 7: 3D Model of SOM in the Study Area

show lower EC values (between 33-32 mS/cm) at lower levels, which means that little accumulation of salts at the lower levels means that there was little mineralization or salt-bearing parent materials. Horizontally, The EC depicts the occurrence of some undulating features in the study area at the depth layers and this represents localized areas of elevated or reduced salinity. Areas with surface runoff collection or with micro topographic depressions where the salts are concentrated and with Lower EC in the central portion at most depths may be the areas with a higher EC on the edges of the profile and more efficient drainage or less salt input in those areas. There is a normal leaching pattern as shown in the EC profile with high salinity in the upper horizons reducing with depth. Topical deposition shows how the agriculture production may require amendments or salinity control techniques to maintain its output. The spatial variability indicates specific management in areas where EC is high to get maximum crop development. Surficial 0-5 cm and 5-15cm -green shades depict pH between 5.1 and 5.55 (figure 6) which means that the conditions are relatively more acidic at the surface. This is common with the surface soils where decay of organic materials, rainfall washing, and microorganisms help in the acidification of soils. On the subsurface 15-30 cm and 30-60 cm layer, the profile moves to the yellow and yellow orange areas (pH 5.55-5.65), indicating slightly less acidic conditions, the shift is frequent due to the fact that accumulation of the leached bases (Ca^{2+} , Mg^{2+} , K^{+}) comes to intermediate depths increasing pH slightly. At the deep layers 60-100 cm and Below 100 cm, the lower profile also has orange to red color (pH 5.65-5.90), the least acidic area in the profile. An increased pH at the depth is usually indicative of decreased leaching, decreased organic metabolism and the existence of parent materials that are more basic cationic. The horizontal gradation is smooth meaning that no steep changes in the soil chemistry are observed on the horizontal plane. It implies that the soil forming processes, parent material or land use history of the sampled area have been relatively homogenized. The pattern of surface acidification corresponds with the pattern of high organic input, rainfall leaching, or cultivation in the pedologic level of the soils, the pattern of increasing pH at the mid depths of the soils indicates redistribution of bases in the upper layers, and the maximum pH at greater than 100 cm indicates the effects of parent material which has not been severely weathered and has undergone very little biogeochemical modification. This figure shows that there is a definite acid-less-acid gradient with depth, indicating natural processes of soil formation, leaching, organic matter, and parent material. It is a key stratified pH activity that is needed to understand nutrient availability, root activity, and soil management requirements within the study area.

The figure 7 shows spatial distribution of Soil Organic Matter at various depths of soils. The color bands are the concentrations of SOM, low (shades of green), and high (light pink). The topsoil 0-5 cm and 5-15 cm represents the maximum concentration of SOM, which is the light pink shade (around 1.66-2.74%), that is characteristic of the surface layer where plant remnants, root turnover, and microbial actions are the major contributors of organic matter deposition. The subsurface layer 15-30cm and 30-60cm, SOM concentration falls drastically to yellow, orange and brown colour (0.90-1.40) which means that there is less organic matter as the organic inputs decline with depth, as well as the microbial degradation is slow due to the lower presence of roots. At those deep layers which are 60-100 cm and transition at the depth of Below 100cm shifts to green shades (0.40-0.90%), which

means very low SOM. The layers have low inputs in the form of organic matter, and the depositional material is frequently washed away by the mineralic parent media. Across the Profile Block, Along the horizontal axis SOM layers are not discontinuous. This implies homogenous land use, vegetation covers and homogenous soil forming processes in the study area. There is a distinct expected gradient in SOM profile: high on the surface horizon and gradually decreasing with a depth. This is an indicator of natural organic inputs, biological activity and soil formation. The knowledge of this distribution is significant in assessing the soil fertility, carbon status and management practices in the study area.

In the figure 5, the spatial and vertical distribution of Organic Nitrogen (ON) in the soil profile was shown. The colors are of green (lowest ON concentration) to red (highest ON concentration). The presence of such gradients indicates that the topsoil 0-5 cm and 5-15cm concentrations of organic nitrogen are dominated by a deep red color that represents the highest level of ON concentration (0.14- 0.08%), Intensive concentration of organic nitrogen levels at the surface are anticipated and can be attributed to the accumulation of organic residues, active microbial decomposition, and an excellent root biomass and this region is the main zone of mineralization of nitrogen and organic matter turnover which leads to high levels of nitrogen. At 15-30 cm and 30- 60cm, ON decreases gradually to orange and yellow bands (0.08-0.04percent), Lower concentrations in these depths indicate low levels of inputs of organic matter because the root system density is decreasing and the organisms are less active as depth increases, and organic nitrogen is more stable and less mineralizable. 60-100 cm and Below (Deep Layers), The deepest layers are green, or light orange in color, which comprises the lowest levels of inputs of organic matter due to decreasing Throughout the Soil Block, The ON distribution seems horizontally continuous, and the layering and concentration do not abruptly change. This implies that there is a relative uniformity in land use, vegetation cover, soil type, and topography throughout the study area, the progressive lateral shift also shows that organic matter inputs and like dynamics of decomposition occur throughout the field. The soil profile shows that the Vertical Gradient of the Organic Nitrogen is strong, and the highest value is at the top of the soil and gradually declines towards the depth. The trend is similar to the natural processes in soil biology, the input of organic residues and nutrient cycle. The ON distribution offers valuable information on the soil fertility, availability of nitrogen as well as sustainable nutrient management approaches in the study area.

CONCLUSION

The majority of the pedons were in upland areas or topographically undulating terrains, which enhanced favorable surface and internal drainage. The colour of the soil was mostly brown to yellowish brown, the evidence of well-aerated soils and the prevalence of oxidized iron compounds. The mottles were either diminished or faintly portrayed and were mainly concentrated to lower levels depicting that the soils do not undergo permanent or permanent waterlogging but ad hoc waterlogging. The soil was friable in the upper horizons to being firm or very firm in depth, this was mainly due to the fact that the content of clay in the soil was higher and the iron formed was also accumulated in the subsoil. Iron concretions, nodules and quartz gravels that occur in a few pedons also suggest that there was serious weathering and accumulation of non-damaging materials. The study also critically assessed the vertical and spatial variability of such important physicochemical soil properties as soil organic matter (SOM), soil organic carbon (SOC), soil pH, electrical conductivity (EC) and redox potential (mV) at various sites in the region between Oyin Akoko and Elerinla. As indicated by the findings, it is evident that the quality of soil in the study area is heterogeneous and this indicates the differences in land use history, organic matter inputs, drainage conditions, parent material, and management practices. SOM and SOC were always greatest at the surface soils, and decreased with depth. This tendency bears the signs of superficial alienation of plant debris and other organic fertilizers, as well as the deceleration of biological processes and movement of carbon in the subsoil strata. The soil reaction within the study area varied between strongly acidic and slightly acidic with most of the soil having pH ranging between 4.7 and 6.9. Most of the profiles showed slight rises with depth in pH, presumably as a result of leaching of the basic cations in the surface horizons. The values of electrical conductivity were moderate to low, which means that soils are not salty and can be able to support agriculture. The increase in EC values in a few of the surface horizons is an indication of increased concentrations of soluble nutrients in connection with organic matter build-up and anthropogenic contributions. The depth-dependent decrease of EC indicates that soluble salts are washed away, and ion concentration decreases at the deeper layers of the subsoil. The redox potential (mV) values revealed that soils are mainly in oxidizing to moderately oxidizing conditions that are ideal environments where aerobic microbial

activities and the mineralization of organic matter occur. In general, the redox condition favors normal nutrient cycle activities in the soils. Finally, the soils under analysis are physically appropriate and chemically weak as they have developed because of the advanced weathering. Through proper fertility management and conservation, these soils have the potential to support sustainable agricultural production and it can make significant contributions towards land-use planning and food security in the study area.

REFERENCES

- Adewara, O. A., Adebayo-Olajide, T. C., Ayedun, J. S., Kotun, B. C., Adeleke, A. J., Brown, A. D., & Ogunbanwo, S. T. (2024). Soil formation, soil health, and soil biodiversity. In S. A. Aransiola, B. R. Babaniyi, A. B. Aransiola, & N. R. Maddela (Eds.), *Prospects for soil regeneration and its impact on environmental protection*. Springer Cham. 95–121.
- Abdulmanov, R., Miftakhov, I., Ishbulatov, M., Galeev, E., & Shafeeva, E. (2021). Comparison of the effectiveness of GIS-based interpolation methods for estimating the spatial distribution of agrochemical soil properties. *Environmental Technology & Innovation*, 24, 101970.
- Boie, F., Ducey, T. F., Xing, Y., Wang, J., & Rinklebe, J. (2024). Field-aged rice hull biochar stimulated the methylation of mercury and altered the microbial community in a paddy soil under controlled redox condition changes. *Journal of Hazardous Materials*, 472, 134446. <https://doi.org/10.1016/j.jhazmat.2024.134446>
- Barma, S. (2024). Effect of nano urea and seaweed extract in combination with conventional nitrogen fertilizer on growth and yield of kharif maize (Doctoral dissertation, Agronomy, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia-741252).
- Bouma, J., Bonfante, A., Basile, A., van Tol, J., Hack-ten Broeke, M. J. D., Mulder, M., ... & Hirmas, D. R. (2022). How can pedology and soil classification contribute towards sustainable development as a data source and information carrier? *Geoderma*, 424, 115988. <https://doi.org/10.1016/j.geoderma.2022.115988>
- Cardone, L., Castronuovo, D., Perniola, M., Scrano, L., Cicco, N., & Candido, V. (2020). The influence of soil physical and chemical properties on saffron (*Crocus sativus* L.) growth, yield, and quality. *Agronomy*, 10(8), 1154. <https://doi.org/10.3390/agronomy10081154>
- Chen, Q., Song, Y., An, Y., Lu, Y., & Zhong, G. (2024). Soil microorganisms: Their role in enhancing crop nutrition and health. *Diversity*, 16(12), 734.
- Choudhary, M., Chandra, P., Dixit, B., Nehra, V., Choudhary, U., & Choudhary, S. (2022). Plant growth-promoting microbes: Role and prospective in amelioration of salt stress. *Communications in Soil Science and Plant Analysis*, 53(13), 1692-1711.
- Corti, G., Cocco, S., Colombo, C., Comolli, R., Dazzi, C., Freppaz, M., & Vittori Antisari, L. (2024). Soil science in Italy from 2000 to 2024. In Dazzi, C., Benedetti, A., Corti, G., Costantini, E.A.C. (eds) *Soil Science in Italy*. Springer, Cham. 97-133.
- Dada, B. F., Ewulo, B. S., Awodun, M. A., Adebisi, T. D., & Ajayi, S. O. (2020). Physio-morphological characteristics of soil of Akure, Ondo State SW, Nigeria. *IJPSS*, 32, 82-97. DOI: 10.9734/IJPSS/2020/v32i1130346
- Dutta, A., Maity, A., & Bhattacharya, P. (2024). Understanding Soil Formation: A Comprehensive Analysis of Concepts, Pedogenic Processes, and Factors. *Agriculture Re-imagined: Innovations and Strategies for Sustainable Growth*, 111.
- Food and Agriculture Organization of the United Nations. (2006). *Guidelines for soil description* (4th ed.). FAO. <http://www.fao.org/3/a0541e/a0541e.pdf>
- Gavlak, R., Horneck, D., and Miller, R. O. (2005). *Soil, plant and water reference methods for the western region* (3rd ed.). Western Rural Development Center. [http:// www.soils.org/files_napt/western-states-method-manual-2005.pdf](http://www.soils.org/files_napt/western-states-method-manual-2005.pdf)
- Gondal, A. H., Hussain, I., Ijaz, A. B., Zafar, A., Ch, B. I., Zafar, H., & Usama, M. (2021). Influence of soil pH and microbes on mineral solubility and plant nutrition: A review. *International Journal of Agriculture and Biological Sciences*, 5(1), 71-81.
- Hicks-Pries, C. E., Ryals, R., Zhu, B., Min, K., Cooper, A., Goldsmith, S., & Berhe, A. A. (2023). The deep soil organic carbon response to global change. *Annual Review of Ecology, Evolution, and Systematics*, 54(1), 375-401.

16. Liu, M., Khan, S., & Zwiazek, J. J. (2024). Overexpression of *Nicotiana tabacum* PIP1; 3 enhances root aeration and oxygen metabolism in canola (*Brassica napus*) plants exposed to root hypoxia. *Plant Physiology and Biochemistry*, 216, 109122.
17. Lu, J. L., Jia, P., Feng, S. W., Wang, Y. T., Zheng, J., Ou, S. N., & Li, J. T. (2022). Remarkable effects of microbial factors on soil phosphorus bioavailability: A country-scale study. *Global Change Biology*, 28(14), 4459-4471.
18. Mesele, S. A., Soremi, P. A., Ayamba, B. E., Aderolu, J., & Olayiwola, V. A. (2024). Organic carbon and nutrient enrichment in clay-rich calcareous soils in self-regenerating fallows in humid tropical agroecology. *Arabian Journal of Geosciences*, 17(12), 313.
19. Mustapha, A. A., Abdulrahman, B. L., Dawaki, M. U., & Usman, A. (2022). Comparative determination of available phosphorus at different pH levels in Nigerian Savannah soils using Mehlich, Olsen, and Bray methods. *Nigerian Journal of Soil Environmental Research*, 21, 69-77.
20. Pondthai, P., Wongadsapaiboon, T., Boonsri, I., & Everett, M. E. (2025). Identification of Burials via GPR Signal Classification and Spatial Cluster Analysis at a Prehistoric Thai Site. *Archaeological Prospection*. <http://doi.org/10.1002/arp.70029>
21. Saha, S., & Pal, S. K. (2024). Degree of phosphorus saturation as environmental threshold for acidic soils of Eastern India. *Water, Air, & Soil Pollution*, 235(10), 1–16.
22. Saleem, A., Zulfikar, A., Saleem, M. Z., Ali, B., Saleem, M. H., Ali, S., & Mostafa, R. M. (2023). Alkaline and acidic soil constraints on iron accumulation by rice cultivars in relation to several physio-biochemical parameters. *BMC Plant Biology*, 23(1), 397. <https://doi.org/10.1186/s12870-023-04400-x>
23. Saleem, S., Mushtaq, N. U., Rasool, A., Shah, W. H., Tahir, I., & Rehman, R. U. (2023). Plant nutrition and soil fertility: Physiological and molecular avenues for crop improvement. In Tariq Aftab, Khalid Rehman Hakeem (Eds) *Sustainable plant nutrition*, Academic Press, 23–49.
24. Sparks, D. L., Page, A. L., Helmke, P. A., & Loeppert, R. H. (Eds.). (2020). *Methods of soil analysis, part 3: Chemical methods*. John Wiley & Sons. 1309
25. Srivastava, P. C., Joshi, D., Pachauri, S. P., Mehetre, S. T., & Shrivastava, M. (2024). Assessing micronutrients in soil with a new chemical extractant using isotopic dilution techniques: Linkages to labile fractions in soil. *Communications in Soil Science and Plant Analysis*, 55(18), 2736–2754.
26. Vakeri, S. M., Sinha, A., Greca, L. G., Salim, M. H., Mabrook, G., Ziyen, Z., ... & Tardy, B. L. (2025). Living sand: Microbial nanocellulose and chitin-rich mycelia enhance granular material properties.
27. Wan, Y., Chen, P., Qiu, Y., Zheng, K., & Yuan, M. (2025). Utilizing Indigenous Microorganisms to Stabilize Humus Soil from a Municipal Solid Waste Landfill with Optimized Microbial Strain Selection. *Water, Air, & Soil Pollution*, 236(2), 143.
28. White, T., & Provenza, A. (2024). Bedrock, Regolith, and Soil Continuum: Pedogenic Perspectives and Factors Controlling Spatial Distribution of Soils. *Critical Zone and Ecosystem Dynamics*, 149.
29. Yadav, D. S., Jaiswal, B., Gautam, M., & Agrawal, M. (2020). Soil acidification and its impact on plants. In Singh, P., Singh, S.K., Prasad, S.M. (Eds) *Plant Responses to Soil Pollution*. Springer, Singapore. 1–26.
30. Yousuf, M., Tian, Z. Y., Mansy, A. E., & Naseer, M. U. H. (2025). Soil Chemistry. In *Environmental Chemistry: Advanced Concepts and Applications* (pp. 217-261). Singapore: Springer Nature Singapore.
31. Yusuf, Y. M., Madukwe, D. K., & Kebede, F. (2023). Establishing phosphorus critical values for tomato (*Solanum lycopersicum*) fertilization with phosphate fertilizers on the Sudan savanna soils using three soil phosphorus extraction methods and field experimentation in Kano State, Nigeria. *Frontiers in Agronomy*, 5, 1181045. <https://doi.org/10.3389/fagro.2023.1181045>