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Soil Colour as a Pedo-Transfer Function of Soil Organic Carbon and Fertility in a Typic Plinthaqualf

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Abstract - The need to guide the land users on the appropriate usage of land and fertility maintenance is very imperative in addressing food sufficiency. Thus, a study was conducted to investigate the erroneous belief by local farmers' that soil colour can effectively predict soil productivity. Three land use types namely: arable cropping (land use 1), oil palm (land use 2), and secondary forest (land use 3) were studied. Profile pits (3 per land use type) were dug at the three predominant land types encountered on the site viz: crest, middle slope, and valley bottom. Soil colour (moist and dry) was determined using the munsell colour chart. The results revealed that pedons at the crest and middle slope are more reddish to brownish while that of valley bottom are greyish. This changes with depth across the soil profiles. The hue varies with land use type, with land use 1 having higher hue at the valley bottom than other land use types. While this decreases as the slope increases in land use 1, the reverse was the trend in oil palm site. However, in land use 3, the hue was generally low at the valley bottom and not as high as in land use 1.

Keywords : soil colour, pedo- transfer, organic carbon, fertility, typic plinthaqualf.

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Three land use types namely: arable cropping (land use 1), oil palm (land use 2), and secondary forest (land use 3) were studied. Profile pits (3 per land use type) were dug at the three predominant land types encountered on the site viz: crest, middle slope, and valley bottom. Soil colour (moist and dry) was determined using the munsell colour chart.

The results revealed that pedons at the crest and middle slope are more reddish to brownish while that of valley bottom are greyish. This changes with depth across the soil profiles.

The hue varies with land use type, with land use 1 having higher hue at the valley bottom than other land use types. While this decreases as the slope increases in land use 1, the reverse was the trend in oil palm site. However, in land use 3, the hue was generally low at the valley bottom and not as high as in land use 1.

In land use 1, the exchangeable bases increase as the hue 10YR – 25YR decreases in the surface soils except for valley bottom soils, where the reverse is the trend.

Organic carbon and exchangeable acidity increases with decrease in hue irrespective of the land type in land use 1. However, phosphorous value decreases as the hue decreases in all the land types, while Zn is constant.

At land use 2, the exchangeable bases except for calcium follow the reverse trend as in land use 1. While organic carbon increases in land use 1, the reverse is the trend in the land use 2, with nitrogen following the same sequence as organic carbon.

Exchangeable acidity, phosphorous and Zinc only decreases with decreasing soil hue in valley bottom soils, and increases in the other land types.

At land use 3, only sodium and potassium increase with decreasing hue (7.5YR – 25YR) at the crest and middle slope sections, while at valley bottom soils the reverse is the trend.

While magnesium increases with decreasing soil hue across the land types, organic carbon, calcium, zinc and copper decreases with decreasing soil hue. Nitrogen, phosphorous and pH KCl as well as exchangeable acidity follow the same sequence with sodium and potassium in land use 3.

It was obvious from the study that soil colour is not a sufficient parameter in ascertaining soil fertility status. Therefore, land use analysis remains the vital tool in assessing fertility status of the soil before optimal and sustainable production can be attained.

Keywords : soil colour, pedo-transfer, organic carbon, fertility, typic plinthaqualf.

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I. Introduction

The general erroneous concept of soil fertility status by peasant farmers through the colour of the soil calls for urgent investigation especially at this era of soil pollution. This is because sewage sludge and to some extent heavy metals such as lead (Pb) also constitute to the colour of the soil. Anthropogenic activities as well as fluctuating water level also play major role in the colour of the soil (Majlis, 1967).

Farmers generally believe that dark colour is synonymous to fertile loamy soil. They tend to attribute fertility with colour without ascertaining the physical and chemical properties of the soil. Colour reflects an integration of chemical, biological and physical transformations and translocations that have occurred within a soil (Scheonberger et al., 2002).

The colour of the soil is usually determined by the nature of the fine material. Generally, the colour of the soil is determined by the quantity and state of the iron and/or the organic matter. Hematite (Fe_2O_3) for example is responsible for the red colour in many soils developed under strongly aerobic conditions in tropical and sub-tropical areas (Majlis, 1967). However, the mineral responsible for most of the inorganic colouration in aerobic soils is goethite (Fe O-OH), with colours ranging from reddish – brown to yellow as it's hydration increases.

Many grey, olive and blue colours occur in the soils of partially or completely anaerobic situations and originate from the presence of iron in the reduced or ferrous state. Sometimes, substances with blue colour such as vivianite may form under these conditions and therefore contribute to the colouration (Ojo-Atere et al., 2009).

The colour of the upper horizons usually changes from brown to dark brown to black, as the organic matter content increases, and there is a tendency for the organic matter to become darker in colour with increased humification (Ojo-Atere et al., 2009; Noma et al., 2010).

Horizons low in calcium and organic matter are often pale in colour, whereas in the presence of large quantities of calcium or sodium, dark colours will form even with small quantities of organic matter. Dark colours are produced also through the presence of manganese dioxide, or by the presence of elemental carbon following burning, Pale grey and white colours originate through the lack of alteration of grey or white parent materials, deposition of calcium carbonate, and efflorescences of salts (Ojo-Atere et al., 2009).

However, in view of other influences affecting the colour of the soil besides organic matter there is therefore the need to investigate the soil colour as pedo-transfer functions of soil chemical constituents including organic carbon with the aim of guiding the land users in the appropriate usage of land and its fertility maintenance.

II. Materials and Methods

a) Description of the Study Area

The research was conducted at Olabisi Onabanjo University Main Campus, Ago-Iwoye. The area lies on latitudes 6°55′ and 7°00′N and longitudes 3°45′ and 4°05′E. The area has a bimodal rainfall, with peaks between June – July and September – October. It has an annual rainfall of about 1150mm and it is located in the rainforest belt. Mean relative humidity of the area is generally high (about 80%) with the peak between May and October. The annual mean temperature is 27°C. Sunshine hour also follows the same trend as that of the temperature with the highest number of hours during dry season and the lowest during the wet season.

The natural vegetation of the area consists mainly of secondary forest except where human interference through annual uncontrolled bush burning and small scale farming methods have reduced the original forest to secondary ones, bush re-growth and thickets. The original forest is now mostly confined to river channels and swamps.

The site is generally undulating with a few gentle to steep slopes. Most of the soils in the survey area developed from undifferentiated igneous and metamorphic, pre-Cambrian basement complex rocks such as granite, biotite gneiss, biotite schist, quartz schist and quartzite. The rocks are fairly deeply weathered and the occurrence of rock out-crops in the survey area is not widespread. A major part of the site is generally well drained through the existing river channels.

The soil investigation of the site shows that most of the soils derived from coarse grained rocks are generally characterized by their varying amounts of quartz and/or ironstone gravel with some occasional stones in the top one meter of the profile. Varying quantities of gravel and stones may be found in the surface of these soils.

b) Field Work

Three land use types namely: Arable cropping (land use 1), Oil palm (land use 2) and secondary forest (land use 3) were studied.

At each of the chosen land use type, profile pits were dug at the three predominant different land type or slope segment encountered. These were crest, middle slope, and valley-bottom.

The general site description such as climate, vegetation, land use, gradient of slope, drainage type, soil surface form, type and degree of erosion, field texture, micro-relief and depths to ground water table were recorded. The pits were described, sampled and the samples analysed following standard procedures. A total of 9 profile pits were dug (3 at each land use) and 30 profile samples were collected for laboratory analysis.

c) Laboratory Analysis

The soil samples were air-dried and sieved with a 2mm - mesh sieve. Some portion of the sieved samples was further passed through 0.5mm - mesh sieve for organic matter and total N determination.

Soil samples were analysed for the following parameters: Soil pH was determined in both water and 0.01M potassium chloride solution (1:1) using glass electrode pH meter (Mclean, 1965). Total nitrogen was determined by the macro-kjeldahl digestion method of Jackson (1962), available P was extracted using Bray-1 extract followed by molybdenum blue colorimetry. Exchangeable cations were extracted with 1M NH_4OAC (pH 7.0), potassium, calcium and sodium were determined using flame photometer and exchangeable Mg by atomic absorption spectrophotometer (Sparks, 1996). Exchangeable acidity was determined by the KCl extraction method (Mclean, 1965), organic carbon was determined using dichromate wet oxidation method (Walkley and Black, 1934). Organic matter was got by multiplying the percent organic carbon by 1.72. Cation exchange capacity (CEC) was calculated from the sum of all exchangeable cations. Available micronutrients were determined by Atomic Absorption Spectro-photometer (AAS) method after leaching on NH_4Cl (Water and Sammer, 1948). Saturated hydraulic conductivity was determined using a constant head method, bulk density by core method, soil porosity was estimated from the bulk density data at an assumed particle density of 2650kgm-3. Water retention at 15 bar was determined in order to calculate available water holding capacities of the soil profile horizons (Mbagwu, 1985). Particle size analysis was by the Bouyoucos hydrometer (1951) method using calgon as dispersing agent.

d) Soil Colour Determination

The soil colour (moist and dry) were determined by the use of the Munsell colour chart in which a soil is held next to the chips to find a visual match and assigned the corresponding Munsell notation.

III. Results and Discussion

a) Morphological Properties

i. *Soil Colour*

The soils of the land use types were characterized by brown (5YR 5/4 – 10YR 6/4), sandyloam / loamysand, topsoil over reddish brown (2.5YR 4/8 – 7.5YR 6/8) sandy clayloam to sandy clay subsoil. The hue was generally 10YR for lowland arable soils, and 5YR to 7.5YR for the middle slope, while it ranges from 2.5YR to 7.5YR for the upland section. The reverse was the trend for land use 2, with lowland portion having a hue of 5YR, while the middle portion ranges from 7.5YR to 10YR.

However, in the secondary forest land use type, both the middle and summit sections were characterized with 7.5YR hue, while the toes slope / valley bottom section ranges between 2.5YR to 7.5YR hue (Table 1).

In addition, some sections of the valley bottom of both the arable and oil palm land use types exhibited some level of mottling as evidence of water saturation at some period of the year.

The colour difference showed that pedons on the crest and middle slopes were more reddish to brownish but greyish at the valley bottom. This variation in soil colour was due to the obvious sequences of drainage. This is in agreement with Noma et al., (2010). Besides, the influence of drainage on soil colour variation, it has been reported by Majlis (1967) that soil colour has been expressed too as a function of iron and organic matter contents, pH and type of clay mineral in the soil.

The fluctuating water table in the lower slope and valley bottom soils also resulted in the occurrence of hydromorphic mottles in these areas. The colours of the studied soils vary with depth. This is in conformity with Brady and Well (1999), who reported that soil colour typically changes with depth through the various horizons in a soil profile.

ii. *Physical Properties of the Soils*

The main physical properties of the soils are presented in tables 2 – 4. The land use 2 were generally more sandy than other land use types (i.e. land use 2 > land use 3 > land use 1). This decreases with depth, except in some cases, particularly at the sub-soil horizon (>50 in depth), where high percentage of sands were concentrated.

The high percentage of soil texture (41.8 – 91.2%) in all the land use types which is sandy is a good indication of the observable high infiltration rate and low water holding capacity of the soils, thereby resulting into moisture stress as reported by Senjobi, 2007. In addition, this scenario enhance rapid leaching of soil nutrients beyond roots exploration of the planted crops thereby threatens increase in food productivity and security.

The clay content increases down the profile. It ranges from 4.8 – 38% in both the surface and sub-surface soils. The differences in clay contents account for varied drainage pattern in the study site. Thus, while the valley bottom soils are poorly drained, the middle slope and crest are well drained across the land use types. The higher clay content at the valley bottom soils reduces infiltration rate of water as confirmed by Ahn, 1970 and Senjobi, 2007.

The water holding capacity of the soils increases with increase in clay content of the soils. The silt content in the soil is generally low and there is no definite sequence in its distribution within the profile. The silt: clay ratios are generally low.

The gravel content was very high ranging from 6.0 to 89.9% in nearby all the pedons. The pedons are composed of concretions, ferruginous nodules, quartz gravel and stones which concentrate as stone lines or stone layers (Sharpe, 1938; and Nye, 1954).

The erosion exposes a sheet of gravel mantle, which is subsequently buried by the sedimentation of fine textured materials. Stonelines interfere considerably with manual soil tillage and thereby limits the aggregate size of farmland that a farmer can put under cultivation. According to Babalola and Lal (1976) and Stoop (1987), this type of physical feature is, permanent and difficult to change.

The porosity of the land use soils is directly proportional to percent sand and gravel concentration, whereas the permeability is inversely proportional to the clay content. The bulk density and hydraulic conductivity are generally low with no definite sequence in their distribution within the profile.

iii. *Chemical Properties of the Soils*

The data on the chemical properties of the soils are given in Table 5 – 7. The pH values of the land use soils ranged between pH (H_2O (6.35 and 7.5) and KCl (5.10 and 6.46) in the surface layer. These values had no definite sequence in their distribution down the profiles.

The organic carbon fluctuates irregularly with depth for most of the pedons and this is an indication of continuous deposition of organic material. The value of organic carbon ranged from 0.27% to 1.66% in the surface layers, with the highest concentration on the surface soils in most pedons. The low organic carbon values in some pedons may be partly due to the high temperature and high relative humidity, which favour rapid mineralization. Organic matter has been reported

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to have positive influence on the CEC, base saturation, structure, pH, buffering capacity, soil colour and water holding capacity (Majlis, 1967 and Ahn, 1970). The organic matter content of the surface horizons in all the land use types is appreciable. This may be due to the fact that most of the organic residues in both cultivated and virgin soils are incorporated or deposited on the surface. The organic matter content of soils under secondary forest and oil palm cultivation are higher than those of arable cultivation. This may be because the soils under those land use systems are always covered and they have not been subjected to intense cultivation as in arable land use type.

The incorporation of organic residues into the soils through tillage practices at the arable land use type has contributed to the relatively higher level of organic matter in this site.

The total nitrogen content in all the soils of land use types is generally low (0.01 – 0.19%) compared with the critical value of 0.15% (Agboola and Corey, 1973). The intense cultivation of the soils normally increases the rate of mineralization of the organic matter, thus negatively affect the level of total N content in the soil. The available P is generally moderate in most of the pedons and high in the remaining pedons compared with the critical level of 10 – 16 ppm (Adeoye and Agboola, 1985).

The exchangeable cations Ca, Mg, K and Na are generally low in all the pedons. This may be attributed to intense cultivation, leaching of nutrients and weathering. Hence, the inherent low fertility status of the soils.

iv. *The relationship between soil colour and some selected soil chemical properties*

In land use 1, the exchangeable bases increases across the crest and middle slope land types as the hue 10YR – 25YR decreases in the surface soils except for Mg. However, at the valley bottom soils, the reverse is the trend.

Organic carbon on the other hand increases with decrease in the hue of the soils irrespective of the land type in land use 1. The same trend was observed for exchangeable acidity. However, phosphorous value decreases as the hue decreases in all the land types, while Zn is constant.

At land use 2, the exchangeable bases except for calcium follow The, reverse trend as compared to the trend in land use 1. While organic carbon increases in land use 1, the reverse is the trend in the land use 2, with nitrogen following the same sequence as organic carbon.

Exchangeable acidity, phosphorous and Zinc only decreases with decreasing soil hue in valley bottom soils, and increases in the other land types.

At land use 3, only sodium and potassium increase with decreasing hue (7.5YR – 25YR) at the crest and middle slope sections, while at valley bottom soils the reverse is the trend.

While magnesium increases with decreasing soil hue across the land types, organic carbon, calcium, zinc and copper decreases with decreasing soil hue. Nitrogen, phosphorous and pH KCl as well as exchangeable acidity follow the same sequence with sodium and potassium in land use 3.

IV. Conclusion

It was evident from the study that the colour of soils is not a sufficient parameter in determining the organic carbon accumulation and fertility status of the soil. Furthermore, the complex relationship between soil colour and some selected chemical properties of the soil revealed that land use analysis or soil testing programme remains the vital tool in assessing fertility status of the soil for optimal and sustainable production. This in turn will guide in the area of fertilizer recommendation and soil nutrient management.

The occurrence of heavy metals in the soil beyond their critical levels is in no doubt contributing to the colour of the soil. This may misguide the absolute reliance on soil colour as pedo-transfer functions for soil fertility status especially in this age of global pollution as the case were in the past when there was little or no pollution history.

Further studies are needed using a wide range of soil colour before ascertaining possible relationship between soils of this area and those elsewhere and in addition, the chemical parameters.

Furthermore, organic agriculture and precision farming will however go a long way to improve and sustain the fertility status of the soil for optimal and sustainable production. Thus, a good organic matter management involving residues incorporation through the addition of large quantities of farm yard manure and the practice of green manuring that could impact dark colour to soil should be encouraged.

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Table 4.1 : Morphological Properties of the Pedons and Soils under the Different Land Uses

Profile No.	Parent Material	Land Use	Horizon Designation	Depth (cm)	Colour Moist	Colour Dry	Boundary	Textural Class	Structure	Consistency	Quartz	Concretions	Roots	Drainage	Mottles
					Slope (10%)										
P_1 (VB)	Basement Complex	Fallow/Cassava	Ap	0-46	10YR 6/4	10YR 5/6	cl	SCL	Sg – sbk	ss, sp, vfr, Io	-	c	vf, f	pd	-
			Bc	46-76	10YR 5/6	–	gs	SCL	P	ns, np, Io	f	vm	vf, vf	pd	5YR 5/4
			Bt	76-126	10YR 5/6	–	cl	SCL	Co	s, p, h	f	f	vf, vf	pd	5YR 4/2
					Slope (5%										
P_2 (MS)	”	Cassava/Plantain	Apc	0-18	7.5YR 3/2	–	ab, s	SC	G	ns, np, Io	f	vm	vf, f	wd	-
			Btc	18-57	5YR 5/4	–	cl, w	SC	Ab	s, p, fr	-	vm	vf, vf	wd	-
			Bt	57-118	5YR 5/6	–	ir	SCL	Sg	st, sp, fr	-	c	vf, vf	wd	-
					Slope (1%)										
P_3 (C)	”	Cassava/Maize	Apc	0-14	5YR 6/8	–	di, s	SCL	Ab	s, sp, f	f	vm	vf, vf	wd	-
			Bt	14-23	5YR 5/8	–	di, s	SCL	Ab	s, sp, f	f	vm	vf, vf	wd	-
			Btc	23-53	7.5YR 6/6	–	ab, s	SCL	G	vs, p, f	-	vm	vf, vf	wd	-
			Bt	53-112	2.5YR 4/8	–	cl	CL	M	vs, vp, vh	-	f	vf, vf	wd	-
					Slope (6%)										
P_4 (VB)	”	Oil Palm	Ap	0-30	5YR 4/3		ab, s	SL	Sg	ns, ns, Io, vf	-	vm	c – m	wd	-
			Btc	30-110	5YR 6/6	5YR5/8	s	SCL	g/m	s, p, fr	-	vm	vf, vf		
					Slope (3%)										
P_5 (MS)	Basement Complex	Oil Palm	Ap	0-34	5YR 2/2	5YR4/2	ab, s	S	Sg	ns, np, vfr		f	m, me-co	wd	-
			AB	34-69	5YR 4/4	5YR6/3	cl, ir	LS	sg	ns, np	-	c	c, me	wd	-
			B	69-113	7.5YR 5/6	7.5YR5/8	g, ir	LS	g	ns, np	-	vm	f,m-c0	wd	-
			BC	113-137	7.5YR 5/6	10YR6/6	di	LS	g-cr	ns, np	f	vm	vf,vf	wd	5YR 3/2
					Slope (0.5%)										
P_6 (C)	”	Oil Palm	Ap	0-33	7.5YR 3/2	7.5YR4/4	cl, s	S	sbk –gb	ns, np	f	c	m, f-co	wd	-
			BC	33-65	7.5YR 5/6	7.5YR6/4	cl, w	SC	ab	ns, np, Io	f	vm	f, f–me	wd	-
			Bt	65-112	10YR 5/8	7.5YR5/8	di, s	SC	m	vs, p, fr	-	vm	vf, vf	wd	-

Profile No.	Parent Material	Land Use	Horizon Designation	Depth (cm)	Colour Moist	Colour Dry	Boundary	Textural Class	Structure	Consistency	Quartz	Concretions	Roots	Drainage	Mottles
							Slope (2%)								
P_8 (MS)	Basement Complex	Fallow	Apc	0-19	5YR 5/6	–	ab, w	LS	g	ss, Io	f	vm	f, vf	wd	-
			Bc	19-43	5YR 6/4	–	cl, s	SL	g	ss, fr	f	vm	vf, vf	wd	-
			Bt_1	43-64	7.5YR 6/8	–	g w	LS	m	s, f	-	vm	-	wd	-
			Bt_2	64-108	7.5YR 5/6		W	SL	m	vs, p, vf	-	vm	-	wd	-
							Slope (4%)								
P_9 (C)	”	Fallow	Apc	0-41	5YR 5/4	–	cl, s	S	g	ns, io	f	vm	m,f-co	wd	
			Bc	41-64	5YR 5/6	–	ab, s	SL	sbk	ns, io, vf	-	vm	m,f-me	wd	
			Btc_1	64-147	7.5YR 6/8	–	g, di	SL	sbk	ns, io	-	vm	m,f-me	wd	
			Btc_2	147-167	10YR 7/6	–	Di	SCL	m	ss, fr	-	vm	vf, vf	wd	
							Slope (4%)								
P_{10} (VB)	”	Secondary Forest	Apc	0-31	7.5YR 5/8	-	ab, s	SL	g	vs, fr	f	f	f, vf	wd	
			Btc	31-108	2.5YR 4/8	–	di, ir	SL	sg	Vs	-	f	vf, vf	wd	
							Slope (2%)								
P_{11} (MS)	”	Secondary Forest	Ap	0-30	7.5YR 5/8	-	ab, s	LS	sg	ns, lo	-	f	f, f-me	wd	-
			B	30-62	7.5YR 5/6	-	g, w	LS	sg	ns, lo	-	f	vf, vf	wd	-
			Btc	62-112	7.5YR 7/8	-	di	SL	g	vs, vf	f	vm	c,me-co	wd	-
							Slope (1%)								
P_{12} (C)	Basement Complex	Secondary Forest	Ap	0-50	7.5YR 6/8	–	cl, w	LS	sbk	vs, f	f	f	f, vf	wd	-
			Bt	50-86	7.5YR 5/8	–	di,	SCL	m	vs, vp, vf	-	f	vf, vf	wd	-
			Btc	86-128	7.5YR 5/6	–	g, w	LS	sg	ns, lo	-	vm	vf, vf	wd	-

+ Boundary: ab = abrupt, cl = clear, g = gradual, di = diffuse, s = smooth, w = wavy, ir = irregular.

[1] Textural class: LS = loamy sand, s = sand, SL = Sandy loam, SC = Sandy clay, SCL = Sandy clay loam.

[2] Structure: sbk = Subangular blocky, ab = angular blocky, sg = single grain, m = massive, co = coarse, p = prismatic, cr = crumb, g = granular.

[3] Consistency: ns = non-sticky, np = non-pastic, lo = loose, s = sticky, p – plastic, f = firm, h = hard VS = very sticky, vp – very plastic, vh = very hard, fr = friable, vfr = very friable, sp = slightly plastic, ss = slightly sticky.

[4] Quartz: f = few, - = Absent

[5] Concretions: f = few, c = common, m = many, vm = very many.

[6] Roots: vf = very few, f = few, c = common, m = many (concentration) vf = very fine, f = fine, me = medium, co = coarse (size).

[7] Drainage: wd = well drained, pd = poorly drained.

[8] VB=Valley-Bottom, MS=Middle Slow and C=Crest

Table 2 : Physical Properties of the Soil under Cassava

Profile No.	Horizon Designation	Depth (cm)	Gravel	Sand (g/kg)	Silt	Clay	Silt: Clay Ratio	Porosity (%)	Textural Class	WHC (%)	BD (g/cm^3)	HC (cm/hr)	Permeability
P_1 (VB)	Ap	0-46	226	508	202	290	0.70	50.6	SCL	24.1	1.31	1.68	13.6
	Bc	46-76	775	642	148	210	0.70	47.4	SCL	28.3	1.40	1.53	12.5
	Bt	76-126	102	522	118	360	0.33	44.2	SC	28.5	1.41	1.55	12.2
P_2 (MS)	Apc	0-18	687	472	158	370	0.43	51.9	SC	34.8	1.28	2.82	23.8
	Btc	18-57	663	508	142	350	0.41	55.8	SC	31.6	1.17	0.54	3.24
	Bt	57-118	201	468	202	330	0.61	43.4	SCL	35.0	1.50	1.08	4.43
P_3 (C)	Apc	0-14	808	492	220	288	0.76	41.7	SCL	33.3	1.55	1.32	12.1
	Bt	14-23	593	672	120	208	0.58	45.9	SCL	38.9	1.44	0.99	7.4
	Btc	23-53	487	532	188	280	0.67	43.5	SCL	38.8	1.43	0.10	6.8
	Bt	53-112	135	418	202	380	0.53	42.6	CL	47.5	1.42	0.10	6.7

p = ploughed, c = concretion, t = illuvial accumulation of clay

LS = loamy sand, s = sand, SL = sandy loam, SC = sandy clay, SCL = Sandy Clay loam

VB=Valley-Bottom, MS=Middle Slow and C=Crest

WHC = water holding capacity (%), BD = bulk density (g/cm^3), HC = hydraulic conductivity (cm/hr)

Table 3 : Physical Properties of the Soil under Oil Palm

Profile No.	Horizon Designation	Depth (cm)	Gravel	Sand (g/kg)	Silt	Clay	Silt:Clay Ratio	Porosity (%)	Textural Class	WHC (%)	BD (g/cm^3)	HC (cm/hr)	Permeability
P_4 (VB)	Ap	0-30	893	612	320	68	4.71	53.2	SL	43.8	1.24	0.57	5.01
	Btc	30-110	705	558	142	300	0.47	49.9	SCL	55.4	1.07	0.40	3.12
P_5 (MS)	Ap	0-34	174	912	40	48	0.83	30.6	S	18.6	1.84	0.84	6.12
	AB	34-69	253	872	80	48	1.67	37.4	LS	23.5	1.66	0.75	5.16
	B	69-113	631	872	40	88	0.45	41.0	LS	29.8	1.57	0.78	5.43
	Bc	113-137	612	812	140	48	2.92	42.8	LS	23.5	1.52	0.48	2.85
P_6 (C)	Ap	0-33	251	912	40	48	0.83	42.5	S	28.7	1.53	0.54	3.39
	Bc	33-65	627	508	142	350	0.41	35.1	SC	25.7	1.72	1.13	9.90
	Bt	65-112	899	532	120	348	0.34	53.4	SC	38.7	1.24	0.85	7.90

Table 4 : Physical Properties of the Soil under Secondary Forest

Profile No.	Horizon Designation	Depth (cm)	Gravel	Sand (g/kg)	Silt	Clay	Silt: Clay Ratio	Porosity (%)	Textural Class	WHC (%)	BD (g/cm^3)	HC (cm/hr)	Permeability
P_{10} (VB)	Apc	0-31	133	712	160	128	1.25	42.5	SL	23.8	1.53	1.05	7.89
	Btc	31-108	99	752	120	128	0.94	43.8	SL	23.1	1.49	2.22	18.48
P_{11} (MS)	Ap	0-30	60	812	140	48	2.92	54.2	LS	35.5	1.22	1.74	14.01
	B	30-62	157	812	120	68	1.76	38.9	LS	26.1	1.62	2.40	20.13
	Btc	62-112	444	672	140	188	0.74	31.2	SL	21.9	1.83	1.11	8.43

P_{12} (C)	Ap	0-50	143	872	80	48	1.67	44.0	LS	53.2	1.49	0.69	1.77
	Bt	50-86	95	672	120	208	0.58	40.5	SCL	43.2	1.57	0.57	3.81
	Btc	86-128	495	872	80	48	1.67	45.5	LS	34.0	1.45	0.30	1.38

Table 5 : Chemical Properties of Soils under Cassava/Maize/Plantain/Banana

Profile No.	Horizon Designation	Depth (cm)	pH H_2O	pH KCl	Exchange Bases cmol.kg^{-1}				Ex AC	ECEC (soil)	B. Sat %	% C	Total N (%)	P	Zn mg.kg^{-1}	Cu
					Na	K	Ca	Mg								
P_1 (VB)	Ap	0-46	7.20	5.10	0.34	0.21	1.04	2.06	0.05	3.70	98.65	0.32	0.02	4.71	5.70	5.60
	Bc	46-76	7.15	4.75	0.48	0.30	1.18	1.60	0.05	3.64	98.63	0.38	0.04	1.88	5.40	5.30
	Bt	76-126	7.05	5.65	0.29	0.19	0.86	1.73	0.05	3.12	98.40	0.29	0.02	5.18	6.90	5.10
P_2 (MS)	Apc	0-18	7.00	6.15	0.39	0.43	1.15	1.73	0.06	3.76	98.40	1.54	0.13	2.82	6.20	5.60
	Btc	18-57	7.25	6.10	0.30	0.36	0.78	1.87	0.05	3.36	98.51	0.29	0.03	13.65	5.80	3.70
	Bt	57-118	6.05	5.10	0.25	0.24	1.14	1.21	0.11	2.95	96.27	1.22	0.13	10.35	4.60	5.20
P_3 (C)	Apc	0-14	6.35	5.20	0.36	0.41	1.10	2.00	0.09	3.96	97.73	1.66	0.16	1.88	5.00	5.60
	Bt	14-23	5.95	5.20	0.27	0.21	1.16	1.19	0.11	2.94	96.26	0.40	0.03	10.35	7.00	6.10
	Btc	23-53	6.15	5.05	0.24	0.15	1.23	1.50	0.10	3.22	96.89	1.10	0.10	6.12	6.10	5.60
	Bt	53-112	6.05	4.95	0.23	0.14	1.18	1.65	0.11	3.31	96.68	1.13	0.11	7.06	6.40	4.80

P = ploughed, c = concretion, t = illuvial accumulation of clay

VB=Valley-Bottom, MS=Middle Slope and C=Crest

Table 6 : Chemical Properties of Soils under Oil Palm

Profile No.	Horizon Designation	Depth (cm)	pH H_2O	pH KCl	Exchange Bases cmol.kg^{-1}				Ex AC	ECEC (soil)	B. Sat %	% C	Total N (%)	P	Zn mg.kg^{-1}	Cu
					Na	K	Ca	Mg								
P_4 (VB)	Ap	0-30	7.10	6.15	0.25	0.21	1.05	1.56	0.05	3.12	98.40	1.57	0.16	11.76	5.30	5.90
	Btc	30-110	6.65	5.05	0.47	0.29	1.15	1.83	0.08	3.82	97.91	0.43	0.05	3.29	5.00	5.20
P_5 (MS)	Ap	0-34	6.70	5.65	0.20	0.12	1.14	1.38	0.08	2.92	97.26	1.01	0.10	14.12	6.20	5.70
	AB	34-69	6.60	5.75	0.21	0.10	1.25	1.44	0.08	3.08	97.40	1.31	0.13	7.06	5.80	6.50
	B	69-113	6.70	5.90	0.28	0.14	0.90	1.71	0.08	3.11	97.43	0.16	0.01	10.35	4.80	3.90
	Bc	113-137	6.95	5.90	0.24	0.14	0.89	1.89	0.06	3.22	98.14	0.38	0.04	10.00	4.90	4.50
P_6 (C)	Ap	0-33	7.50	6.20	0.31	0.30	1.04	1.75	0.04	3.44	98.84	0.99	0.10	5.18	6.00	4.90
	Bc	33-65	6.90	6.00	0.26	0.13	0.96	1.79	0.06	3.20	98.13	0.48	0.05	8.47	6.20	4.70
	Bt	65-112	6.80	5.90	0.26	0.15	0.99	1.19	0.07	2.66	97.37	0.50	0.06	6.59	6.00	6.50

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Table 7 : Chemical Properties of Soils under Secondary Forest

Profile No.	Horizon Designation	Depth (cm)	pH H_20	pH KCl	Exchange Bases cmol.kg^{-1}				Ex AC	ECEC (soil)	B. Sat %	% C	Total N (%)	P	Zn mg.kg^{-1}	Cu
					Na	K	Ca	Mg								
P10 (VB)	Apc	0-31	6.70	5.45	0.28	0.18	1.08	1.48	0.08	3.10	97.42	1.33	0.13	8.94	6.20	5.60
	Btc	31-108	6.40	5.65	0.23	0.13	1.03	1.38	0.09	2.86	96.85	0.67	0.07	5.18	6.00	5.40
P11 (MS)	Ap	0-30	6.90	6.45	0.32	0.50	1.08	1.93	0.06	3.89	98.46	0.27	0.03	3.76	5.70	5.30
	B	30-62	6.80	5.80	0.23	0.15	1.06	1.98	0.07	3.49	97.99	0.32	0.03	1.14	4.80	4.70
	Btc	62-112	6.65	5.75	0.33	0.28	0.90	1.87	0.08	3.46	97.69	0.21	0.02	0.94	4.80	4.50
P12 (C)	Ap	0-50	6.80	5.60	0.28	0.24	1.01	1.93	0.07	3.40	97.50	0.54	0.05	8.47	5.10	4.10
	Bt	50-86	6.75	5.80	0.26	0.29	0.91	1.93	0.08	3.47	97.69	0.66	0.06	13.17	5.30	4.40
	Btc	86-128	6.30	5.30	0.36	0.21	0.99	1.73	0.09	3.38	97.34	0.61	0.06	1.14	5.40	4.40

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