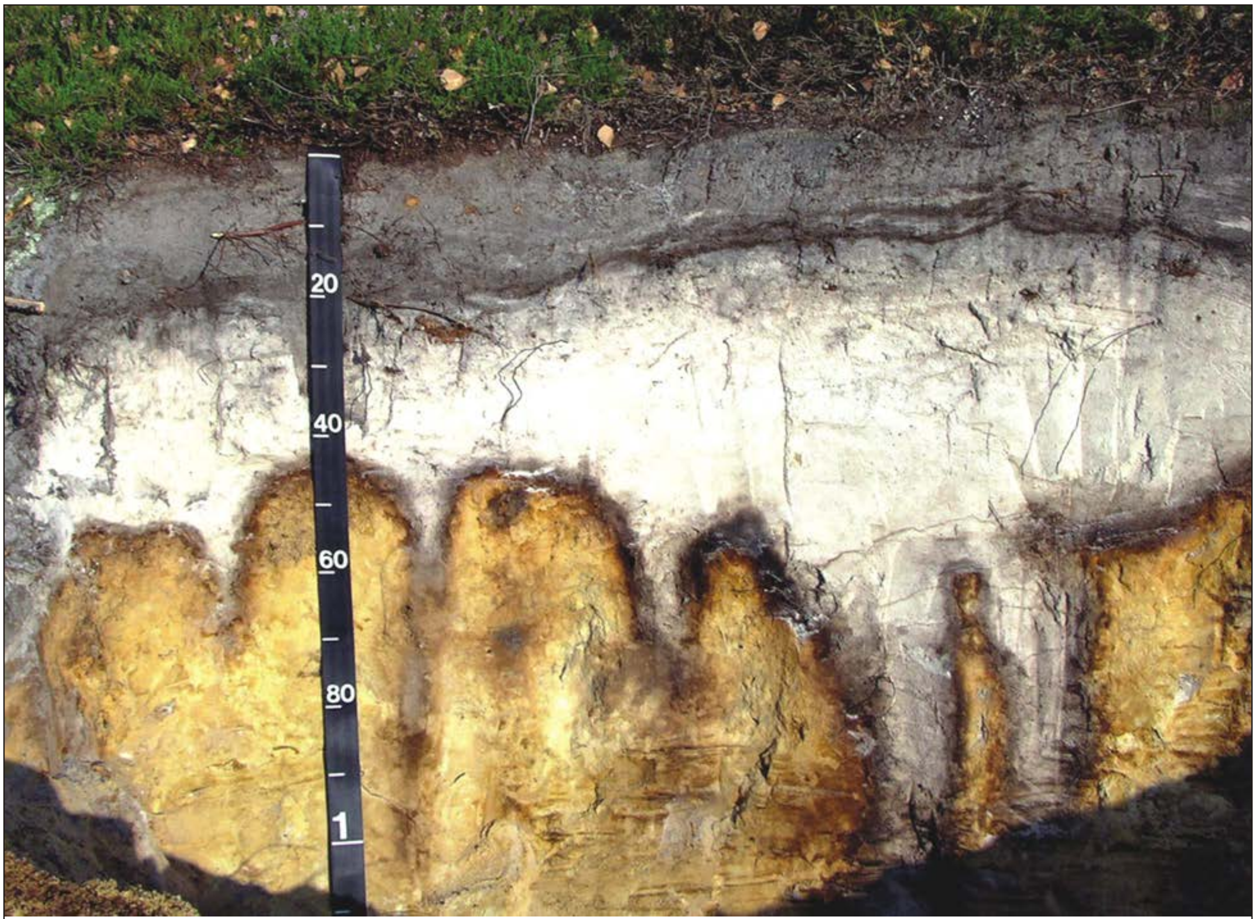

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Research Article
Pedogenesis of Soils of Two Tropical Microclimates in Owerri Area Southeastern Nigeria

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Abstract
We investigated pedogenic processes taking place in two microclimates in Owerri area, Southeastern Nigeria. Target sampling technique was used and a soil profile was sunk in each microclimate, namely mixed vegetation and pineforest. Each profile was dug and described according FAO procedure. Some soil properties were studied in the field and laboratory using routine analytical tools. Soil temperature and moisture were studied for 5 years and mean values were reported. Results showed dominance of littering, melanization, eluviation, illuviation, leaching and decomposition processes in the studied pedons although the rate varied among mixed vegetation and pineforest. Stronger and darker peds were recorded on soils developed under mixed vegetation. Soils were sandy in both vegetations. Clay bulge was distinct in soils developed under mixed forest and ranged from 90-150 g kg^{-1} unlike soils of the pine forest (50-120 g kg^{-1}). Soils under mixed vegetation were more porous (37-52%) compared with 31-47% recorded in soils under pine forest. High values of organic carbon (20 g kg^{-1}) was found in epipedons of soils under mixed vegetation compared with 11.0 g kg^{-1} obtained in soils of the pine forest. Base saturation, effective caution exchange capacity and calcium-magnesium ratio values were higher in soils under mixed vegetation. Soil temperature values were higher in pine forest ranging from 14.3-14.9% while the reverse was the case in soil moisture when compared values reported in mixed vegetation.

Key words: Biosequence, microclimate, pedogenesis, tropical soils

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Soil varies geospatially with its ultimate characteristics influenced by a balance of pedogenic processes taking place over time. Organisms in form of plants and/or animals exert strong influence on soil formation especially in the epipedon. Vegetation forms such as forest, grassland and desert biochores differ in the ways in which they cause differences in soil properties. Plant communities and even single tree stands create microclimates through shading of soil surface (Buol *et al*., 1997). These microclimates are important as they affect activities of soil biota (Coleman and Crossley, 1996). Trees restrict wind movement and regulate water loss through transpiration.

Biosequences are known to cause differences in soil morphology (Graham and Wood, 1991), basic cations biochemistry (Quideau *et al*., 1996) and mineralogy (Tice *et al*., 1996). Biosequences influence decomposition rates (Quideau *et al*., 2001) which depends on microbial activity (Vazquez *et al*., 2013) and surface residue characteristics (Abril *et al*., 2013).

Early pedogenesis may be greatly influenced by chemical and mineralogical characteristics of the lithologic material; but other factors such as vegetation may be more influential for pedogenic processes at late time (Maniyunda *et al*., 2014). Materials derived from *Tithonia diversifolia* and *Chromolena odorata* differed in chemical composition (Olowokere *et al*., 2014). It was earlier reported that *Tithonia divversifolia* release basic cations especially calcium and magnesium (Phiri *et al*., 2001). After primary succession in the ecosystem, plants are therefore of high significance in causing changes in soil properties via release of exudates, decay of plant parts as well as their rooting activities. Given that plants play substantial role in soil formation and soil properties, over a short time space, it could be argued some of the changes resulted from direct and indirect effects. When plants create varying local climates in response to their structure and chemical composition, it is posited that they entrain varied pedogenic pathways. Consequently, the major objective of this study was to investigate soil forming process and properties of soils under two microclimate as created by mixed vegetation and pine forest in Owerri area, Southeastern Nigeria.

MATERIALS AND METHODS

Study area: The study was conducted in Owerri area of Southeastern Nigeria, lying between Latitudes 5°10' and 5°45' N and Longitudes 6°45' N and 7°25' E, with an elevation below 100 m amsl. The soil study started from May 2014 and ended April 2015. Soils are formed from coasted plain sands (Benin formation) of the Oligocene-Miocene geological era. Owerri is located in the humid tropical climate with a mean annual rainfall of about 2500 mm and mean annual temperature of 29°C. Relative humidity is high during the rainy season. Tropical rainforest is the dominant vegetation in Owerri area although its density has drastically reduced due to anthropogenic activities such as urbanization, deforestation and agricultural activities. The vegetation is arranged in storeys with herbaceous plants forming the forest floor. Oil palm tree (*Elaeis guineensis*) is the dominant plant species in the area. Rivers Otamiri and Nworie play significant role in the hydrology of the area. Farming and cottage industrial activities dominate the socioeconomy of the inhabitants in the area. Farming is common at the banks of rivers. Land preparation ranges from slash-and-burn to slash-and-pack with crops planted on flats and sometimes on ridges. Mixed cropping is common in the area with maize, cassava, leafy vegetables and yams being common in the area.

Sampling sites: The field study started from May 2014 and ended April 2015. Two sites were chosen for the study, namely mixed vegetation (0-2% slope) and pine forest (0-2% slope) at Egbeada area of Owerri. Egbeada is a peri-urban settlement supplying food needs of Owerri, Nigeria Municipality in Imo State Nigeria. The mixed forest is over 20 years with a typical rainforest structure. It is characterized by a variety of plant species including oil bean tree (*Pentaclethra macrophyllum*), oil palm tree (*Elaeis guineensis*), mango (*Mangifera indica*) and a host of other tree species. Shrubs and grasses including elephant grasses (*Pennisetum purpureum*), guinea grass (*Panicum maximum*), star grass (*Cynodon nlemfuensis*), siam weed (*carolina odorata*), etc. These plants among others form a thick and dense canopy resulting to local and unique climate, which accommodates earthworms, millipedes, centipedes and tremendous faunal activities and fungal growth. The plants shed their leaves regularly.

On the other site is a pine forest of about 20 years old planted by Imo State Agricultural Development Program. The pine stands are over 30 m of mean height with good foliage. The pine forest has rich undergrowths including spear grass (*Imperata cylindrica*) and carpet grass (*Axonopus compressus*). The pines have long needles with many longer than 15 cm. The pines are deep rooted while rooting pattern in the mixed vegetation varied according to plant species. The mixed vegetation is about 1.5 ha while pine forest has a area coverage of 0.8 ha.

Field and laboratory studies: A soil profile pit was dug in each land unit. Soils were described and sampled using standard methods (Soil Survey Staff, 2010) in the two vegetation sites. Soil macro morphological properties were observed and noted. Soil colour was determined using Munsell colour chart under moist conditions. Soil consistence, soil structure and root abundance were observed and recorded. This was done for every horizon of a soil profile in both microclimates. Locations of the soil profiles were georeferenced using Global Positioning System (GPS) receiver (Garmin Ltd, Kansas, USA). Soil samples were collected based on horizonation. Core samples were collected for bulk density determinations. Soil thermometers were mounted at pre-determined depths of 10, 40, 50, 80 and 80^+ cm. Soil moisture content was estimated gravimetrically. Gravimetric moisture content of soils was measured at the same depth as above sampling depths of 10, 40, 50, 80 and 80^+ cm were purposively chosen as soil taxonomy recognizes them as standards (Soil Survey Staff, 2010). Laboratory determinations followed procedures as outlined in Soil Survey Staff (2010). Total porosity was calculated based on the relationship between bulk density and particles density (assumed to be 2.65 mg m^{-3}).

RESULTS AND DISCUSSION

Soil macromorphology: There were distinct macromorphological properties as presented in Table 1. In the mixed forest the epipedon was darker (Dark brown 7.5 YR $^3/_{2,}$) moist when compared to brown (7.5 YR $^4/_3$) moist, as observed in epipedon under pine forest. Peds in the epipedon under mixed vegetation were stronger and granular while soils under pine were weak and subangular. Friable consistence was reported in surface soils (0-10 cm) depth in epipedons under mixed forest unlike loose consistence exhibited by epipedons under pine forest. Roots were in abundance in epipedons in both soils but greater variety of roots in mixed vegetation.

Pedogenesis: There was outstanding littering pedogenic process leading to the formation on Oa (2-0 cm) horizon and this possibly conferred darker colouration (melanization) on A horizon (0-10 cm) in epipedon under mixed forest. Similar observations were made by Buol *et al.* (1997), who reported melanization under oak trees. Abundance of litter biomass under mixed forest and subsequent decomposition is responsible for formation of Oa. However, soils under pine forest had abundance of litter material but with less rapid decomposition such that decomposed organic materials were quickly incorporated into the A horizon (0-11 cm).

There was a distinct clay bulge at 40-80 cm depth in soils of mixed forest indicative of argillation, implying greater eluviation and illuviation processes in soils of the mixed forest (Table 2). Less eluviation was observed in AB horizon (11-35 cm) in soils under pine forest (clay = 110 g kg^{-1}) when compared to the AB horizon (10-40 cm) with 90 g kg^{-1} clay content (Table 2). Although clay accumulation and movement were less in soils under pine forest, both soils are highly weathered given the values of the silt: clay ratios. Higher values of total porosity in soils under mixed forest (Table 2) indicate potentials for easy movement of soil material from one horizon to another.

Table 3 shows chemical properties of soil of the two microclimates. Both soils are acidic with pH measured water ranging from 4.7-57 (mixed vegetation) and 4.3- 4.8 (pine forest). Higher values of organic carbon and total nitrogen were recorded in horizons under mixed vegetation. Values of carbon-nitrogen ratio were typical of west African soils (Ahn, 1979) ranging from 10.0-13.0 (soils of mixed vegetation) and 10.0-12.0 (soils of pine forest). The carbon-nitrogen ratio helps to determine quality of litter which serve as energy source to decomposers and goes to indicate status in the decomposition process. Results show that generally larger C:N ratios obtained from soils of mixed forest point to relatively higher decomposition. One can posit that differences in micor

Table 1: Macromorphology of soils

Horizons	Depth (cm)	Colour matrix (moist)	Soil structure	Soil consistence	Roots
Mixed vegetation (5°31′ 23.97″ N; 7°41′ 21.00″ E)					
Oa	2-0	-	-	-	-
A	0-10	Dark brown (7.3 YR $^3/_2$)	3 far	Friable	3 vf
AB	10-40	Brown (7.5 YR) $^3/_2$	2 msbk	Friable	2 vf-m
Bt	40-80	Strong Brown 7.5 YR ^{4}/6	M	Firm	1 vf
Btz	80^+	Reddish brown 5 YR $^4/_3$	M	Firm	1 vf-.co
Pine forest					
A	0-11	Brown 7.5 YR$^4/_3$	1 msbk	Loose	3 vf
AB	11-35	Reddish Brown 5 YR $^4/_4$	M	Friable	2 vf
Bt	35-90	Reddish Brown 5 YR $^5/_3$	M	Firm	1 vf-co
BC	90-120	Light cum 5 YR $^7/_1$	M	Firm	1 vf-co

Structure;1: Weak, 2: Moderate,3: Strong, gr: Granular, m: Massive, sbk: Subangular blocky, f: Fine , Roots;1:Few, 2: Common, 3: Many, co: Coarse, m: Medium, vf: Very fine

Table 2: Physical properties of soils

Horizons	Depth (cm)	Sand	Silt (g kg^{-1})	Clay	Silt/clay	Bulk density (mg m^{-3})	Total porosity (%)
Mixed vegetation							
Oa	2-0	-	-	-	-	-	-
A	0-10	880	30	90	0.3	1.26	52
AB	10-40	850	60	90	0.2	1.33	50
Bt_1	40-80	830	20	150	0.1	1.39	47
Bt_2	80^+	900	10	90	0.1	1.66	37
Pine forest							
A	0-11	890	10	100	0.1	1.39	47
AB	11-35	880	10	110	0.9	1.61	39
Bt	35-90	800	80	120	0.7	1.77	33
BC	90-120	920	30	50	0.6	1.82	31

Table 3: Chemical properties of soils

Horizons	Depth (cm)	pH water	OC (g kg^{-1})	TN	C/N	TEB (emol kg^{-1})	Bsat (%)	ECEC (emol kg^{-1})	Ca/Mg
Mixed Vegetation									
Oa	2-0	-	-	-	-	-	-	-	-
A	0-10	5.7	20.0	1.6	12.5	6.0	51	11.8	3.3
AB	10-40	5.1	12.0	1.0	12.0	3.5	38	9.2	2.6
Bt	40-80	4.9	8.0	0.6	13.0	2.9	29	9.8	2.7
Bt_2	80^+	4.7	4.0	0.4	10.0	3.0	34	8.8	2.9
Pine Forest									
A	0.11	4.8	11.0	0.9	12.0	3.2	44	7.2	2.8
AB	11-35	4.6	9.0	0.8	11.0	2.9	43	6.6	2.2
Bt	35-90	4.5	2.0	0.3	10.0	1.5	45	3.3	2.5
BC	90-120	4.3	1.0	0.1	10.0	1.6	43	3.7	1.2

OC: Organic carbon, TN: Total nitrogen, C/N: Carbon-nitrogen ratio, TEB: Total exchangeable bases, Bsat: Base saturation, ECEC: Effective cation exchange capacity, Ca/Mg: Calcium-magnesium ratio

Table 4: Mean annual soil temperature and mean annual soil moisture content for 5 years at each depth under mixed and pine forests

	Mixed vegetation		Pine forest	
Depth (cm)	Temperature (°C)	Moisture (w/w%)	Temperature (°C)	Moisture (w/w%)
10	13.8	15.0	14.9	10.2
40	13.3	17.6	14.5	10.6
50	13.0	20.0	14.3	12.4
80	12.9	18.0	14.4	8.8
80^+	12.8	18.0	14.2	8.8

environment coupled with heterogeneity in foliage could be attributed to variation in carbon - nitrogen ratio since both sites are geographically related.

Basic cation accumulation was higher 6.0 cmol kg^{-1} in epipedons under mixed forest when compared to 3.2 cmol kg^{-1} in soils under pine forest. Despite the higher total porosity of soils of the mixed forest, these basic actions accumulated in greater proportion in mixed forest, indicating in impact of trees (biosequence) on studied soils. However, if basic cations are sourced from vegetation, results showed that translocatory process of leaching though minimal may have caused slight movement from Bt (2.9 cmol kg^{-1}) horizon to Bt_2 horizon 3.0 cmol kg^{-1} in mixed forest. The same pedogenic process would be responsible for the slight differences in TEB between Bt horizon at 35-90 cm depth (1.5 cmol kg^{-1}) and BC horizon at 90-120 cm depth (1.6 cmol kg^{-1}) (Table 3).

Edaphic properties: Both soils are deep ensuring a good foothold for arable crops. Soils are sandy, ranging from 830-900 g kg^{-1} (mixed vegetation) and 800-920 g kg^{-1} (pine forest). Bulk density increased with depth but higher in pine forest. Organic carbon and total nitrogen values decreased with depth in all pedons: Soils of the mixed vegetation had more OC and TN than soils under pine forest. There were more concentration of basic cautions in soils of the mixed vegetation (TEB = 2.9-6.0 cmol kg^{-1}) compared to 1.5-3.2 cmol kg^{-1} (Pine forest). At the epipedon, Ca:Mg of 3.3 (mixed vegetation) was obtained compared to 2.8 in soils of the pine forest. Ealier Landon (1991) posited that soils with Ca: Mg ratio greater than 3.0 are fertile.

Soil temperature and soil moisture: Generally, changes in soil temperature with depth tended to be similar in both soils (Table 4). However, mean annual temperatures for 5 years of measurements at 5 cm depths ranged from 13.8-12.8°C (mixed vegetation) and 14.2-14.9°C (pine forest). There were wider temperature variations at depths between 10-40 cm indicating a difference of 0.5°C in mixed vegetation and 0.4°C in pine forest as compared with 0.3 °C (mixed vegetation) and 0.2°C (pine forest) at depths between 40 and 50 cm. Soil taxonomy recognizes 50 cm as the depth where diurnal temperature fluctuations are hardly noticeable and measurable and 10 m as a depth at which annual temperature cycles are eliminated (USDA., 1993). Higher temperatures as indicated could quicken activity of soil organisms hence accelerate transformation of organic materials by these decomposers.

Higher fluctuations in values of mean annual soil temperature at the surface horizon could be due to its closeness to the atmospheric temperature which was not measured in this study. Differences in soil temperature among horizons were generally lower under pine forest indicating greater effectiveness of pines in moderating soil temperatures. In mixed forest the difference between surface horizon and deepest horizon (80^+ cm) was 1.0°C while it was 0.6°C in soils under pine (Table 4).

Soil moisture content with depth in both microclimates are shown in Table 4. Horizons under mixed forest stored more soil moisture with values ranging from 15.0- 20.0% w/w when compared with a range of 8.8-12.4 % w/w. In both soils, highest soil moisture contents stored were recorded in Bt horizon with large values of clay content. Differences in soil moisture content in epipedons of the two pedons could be attributed to the degree of canopy cover in relation to evapo-transpiration as well as changes in clay content (Foth, 1990). Field observations indicate greater canopy cover and litter biomass in soils of mixed regulation over soils under the pine forest. With higher values of soil temperature in soils under pine forest, it is expected that evaporative force will be higher in the soils, leading to lower values of soil moisture under pine forest. This is consistent with the findings of Schaufler *et al.* (2010) that soil temperature influences soil moisture and greenhouse gas emissions in European soils.

CONCLUSION

The study revealed that major pedogenic processes in the two microclimate were littering, melanization, leaching, eluviation, illuviation and decomposition and these differed among the two soil groups. Soil temperature and soil moisture content differed in the two soil groups and these influenced the degree of pedogenesis in studied soils.

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