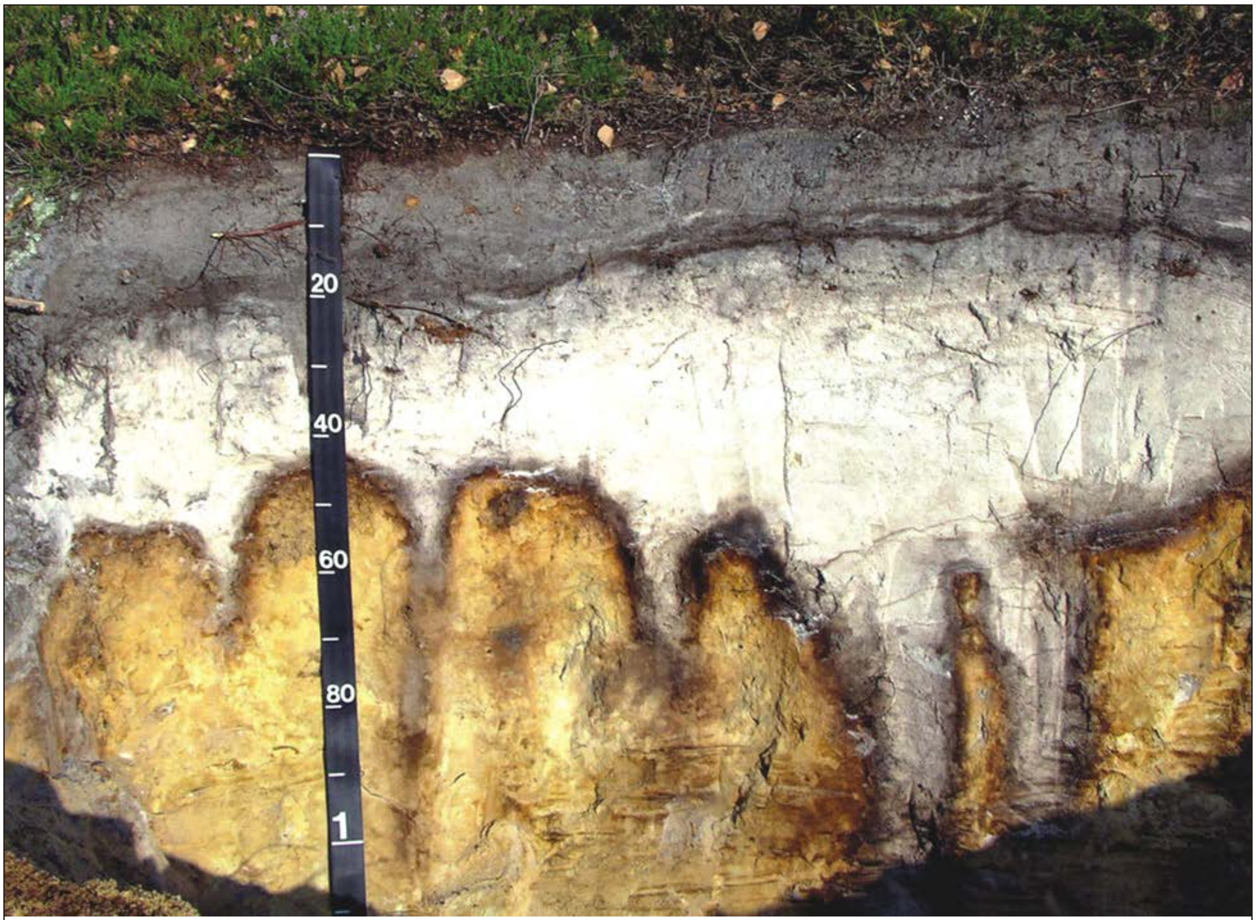

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Research Article

Relationship Between Soil Characteristics and Fertility Implications in Two Typical Dystrandept Soils of the Cameroon Western Highland

[1]D. Tsozué, [2]P. Tematio and [3,4]P. Azinwi Tamfuh

[1]Department of Earth Sciences, Faculty of Sciences, University of Maroua, P.O. Box 814, Maroua, Cameroon
[2]Department of Earth Sciences, Faculty of Sciences, University of Dschang, P.O. Box 67, Dschang, Cameroon
[3]Department of Earth Sciences, Faculty of Sciences, University of Yaoundé I, P.O. Box 812, Yaoundé, Cameroon
[4]Department of Geology, Higher Teacher Training College, University of Bamenda, P.O. Box 39, Bambili, Cameroon

Abstract

The study was undertaken to evaluate the relationships and fertility implications between Organic Carbon (OC), total nitrogen (N), exchangeable potassium (K) and available phosphorus (P) concentrations and sand, silt and clay contents in two dystrandept profiles in the Western Highland of Cameroon. The study was done in the field and completed by a battery of laboratory analyses. The results showed that the two weathering profiles developed on basalt and trachyte were 4 m thick. Among the different soil fractions, sand contents were the lowest, while silt and clay contents were high. There was no significant correlation between sand and the others soil fractions. A negative significant correlation between silt and clay fractions on contrary was noted. Total OC amounts were very high in the humiferous horizon. There was no significant relationship between OC and clay fractions, indicating that these two soil colloids responsible for the studied soil fertility acted independently. The presence of kaolinite as the unique clay mineral characterized by low surface area and Cation Exchange Capacity (CEC) compared to organic matter, implies that OC was the main source of soil fertility. There was a significant positive correlation between N and OC ($r = 0.99$, $p<0.0001$), N and sand fraction ($r = 0.93$, $p<0.02$) and between N and K ($r = 0.98$, $p<0.04$). Also, there was a significant negative correlation between C:N and K^+. Globally, amounts of K were below the critical levels. Available P exhibited a significant positive correlation with OC ($r = 0.87$, $p<0.05$) and total N ($r = 0.89$, $p<0.05$). Relationships existed among soil physicochemical properties, which positively or negatively interfered with nutrient availability.

Key words: Carbon, nitrogen, available phosphorus, potassium, texture, soil fertility

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Corresponding Author: D. Tsozué, Department of Earth Sciences, Faculty of Sciences, University of Maroua, P.O. Box 814, Maroua, Cameroon

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

INTRODUCTION

Crop production on a large scale is necessary in order to secure constant food supply for the sub-Saharan Africa population (Smaling *et al.*, 1997; Greenland and Nabhan, 2001; Nweke and Nnabude, 2014; Tsozue *et al.*, 2015). Most of this agricultural production, however is done in the rural areas by the rural population, presently growing rapidly, resulting to pressure on the available agricultural land (Verdoodt and van Ranst, 2003; Blay *et al.*, 2004; Nweke and Nnabude, 2014; Tsozue *et al.*, 2015). This has lead to a decrease in soil fertility status as the lands are not allowed to recover their fertility through natural fallows (Tematio *et al.*, 2011; Nweke and Nnabude, 2014; Tsozue *et al.*, 2015). The nutrient elements classified as chemical properties required for good growth and healthy conditions for the crops are mostly sourced from the soil (Hodges, 2010; Nweke and Nnabude, 2014; Tsozue *et al.*, 2015). From the twenty elements regarded as plant nutrients, carbon (C), nitrogen (N), phosphorus (P) and potassium (K) are the most important quantitatively (Lavelle, 2007) and are critical to the establishment, development, growth and productivity of crops (Nweke and Nnabude, 2014; Tsozue *et al.*, 2015). Malfunctioning of their cycles related to human activities also poses the most serious problems (Lavelle, 2007). Soil Organic Carbon (SOC) and N are the main nutrients used for vegetation growth and are also used as indexes of soil quality assessment and sustainable land use management (Sui *et al.*, 2005; Jiang *et al.*, 2007; Liu *et al.*, 2011). The SOC and N do not only reflect the soil fertility level, but can also explain the regional ecological systemic evolution (Ge *et al.*, 2013). The relationship between them can be represented as soil C:N ratio, a sensitive indicator of soil quality and for assessing C and N nutrient cycling of soils (Zhang *et al.*, 2011). The C cycle is strongly modified by the annual leakage to the atmosphere from 6-8 Pg (1 petagram = 10^{15} g) of C per year from burning fossil hydrocarbons and the release of the C which are in plant biomass and soil (Lavelle, 2007). The N cycle is affected by the addition of 200 Tg (1 teragram = 10^{12} g) per year of available N providing in the form of N fixed in agrosystems and chemical fertilizers; this contribution, which represents twice the contributions of the preindustrial era (estimated at 90-130 Tg year^{-1}) is only partly denitrified and available N accumulated in the terrestrial and aquatic ecosystems (Lal, 2004; Lavelle, 2007). Soil is one of the most important C and N pools and including approximately 75% Organic Carbon (OC) and 95% N (Schlesinger, 1997; Doetterl *et al.*, 2015). The maintenance of the SOC pool thus plays an important role not only in advancing food security in developing countries but also in relation to future net C budgets, where even small changes in the size of the SOC pool may alter the atmospheric CO_2 concentration (Schlesinger and Andrews, 2000; Bruun *et al.*, 2015). Plants that are present, which affects the ecosystem yield and the terrestrial C cycle, affect interaction between SOC and N (Sakin, 2012). Numerical models of C and N cycles include terms for the climate, the atmosphere and land use alternation (Pepper *et al.*, 2005; Sakin, 2012). Available P brought mainly as fertilizers in farmland also accumulates in the biosphere at a rate of 10.5-15.5 Tg year^{-1} compared to a 1-6 Tg of the preindustrial era (Lavelle, 2007). Accumulated in soils, this P is gradually transferred to the freshwaters and seas by erosion and deposition of atmospheric dust (Lavelle, 2007). According to Haby *et al.* (1990) from all alkali metals found in soils (K, Ca, Mg and Na), the most important in plant nutrition is K and it is occasionally found in plants in higher percentages than N. Most of agricultural plants, under optimal yield conditions, would take up between 100 and 300 kg of K per hectare from soils (Jakovljevic *et al.*, 2003). Soil texture protected Soil Organic Matter (SOM) from being decomposed by physical, chemical and biological mechanisms (Six *et al.*, 2002; Krull *et al.*, 2003; Sakin, 2012). It was suggested that chemical stabilization of organic molecules were well protected via mineral-organic matter bond from the beginning (Sakin, 2012). The clay content affects SOC accumulation in different ratios (Sakin, 2012). It was reported that maximum and medium SOC increased with increasing clay content in soil (Nichols, 1984; Bruke *et al.*, 1989; Sakin, 2012). However, it was expressed that this relationships was not global and SOC was sometimes much more strongly related to other factors in comparison to clay (Percival *et al.*, 2000; Krull *et al.*, 2003; Sakin, 2012). It was documented that, if other factors were fixed, as clay content increased, SOC accumulated faster (Jenkinson *et al.*, 1990). Many studies showed that soil texture affect soil aggregation (Chaney and Swift, 1984; Schlecht-Pietsch *et al.*, 1994; Sakin, 2012). As the clay content increases, they combine with SOC aggregate stability (Sakin, 2012). It affects the increase in soil aggregation and clay content and indirectly affects SOC stores by absorbing organic materials in soil (Sakin, 2012; Udom *et al.*, 2015). Soil texture also plays direct and indirect roles in chemical and physical protection mechanisms (Plante *et al.*, 2006; Sakin, 2012). The SOC is an index of sustainable land management (Woomer *et al.*, 1994; Nandwa, 2001) and is critical in determining response to N and P fertilization. There is however, no clear agreement on the level of SOC below

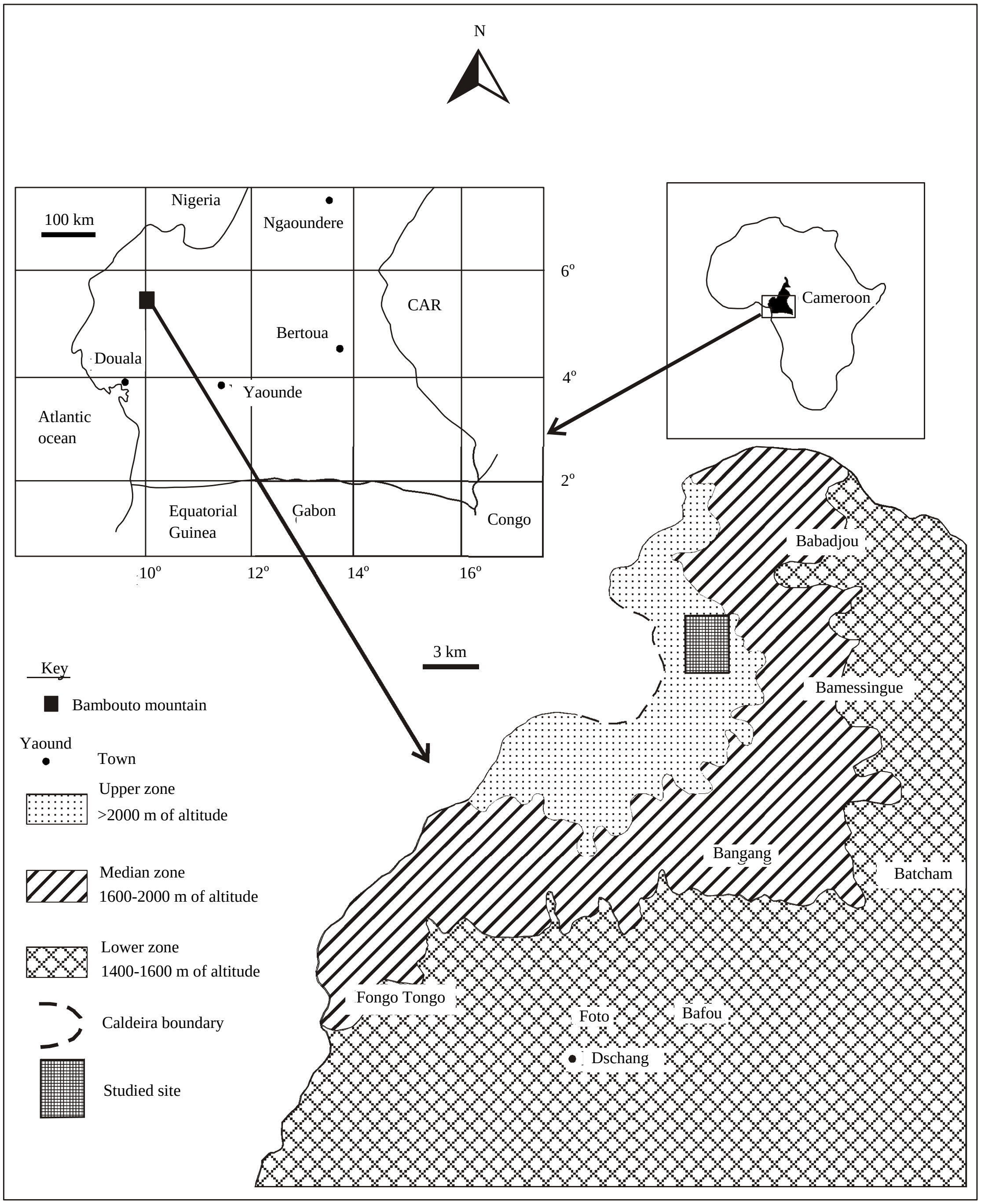

Fig. 1: Location of the studied site, modified after Tsozue *et al.* (2011)

which response to N and P fertilization does not occur (Bationo *et al*., 2007). Hence, this study was undertaken to evaluate OC, N, K and P concentrations, sand, silt and clay contents and the relationships between these soil parameters in two dystrandept profiles of the Western Highland of Cameroon in other to contribute to the restoration of soil fertility and improvement in crop productivity.

MATERIALS AND METHODS

Study site and sampling: The study site is located in the upper eastern part of Bambouto Mountains in the Western Highlands of Cameroon, above 2000 m a.s.l (5°40'-5°43' N and 10°05'-10°07' E) (Fig. 1). The climate is fresh and humid, with temperature range of 10-12°C and mean annual rainfall

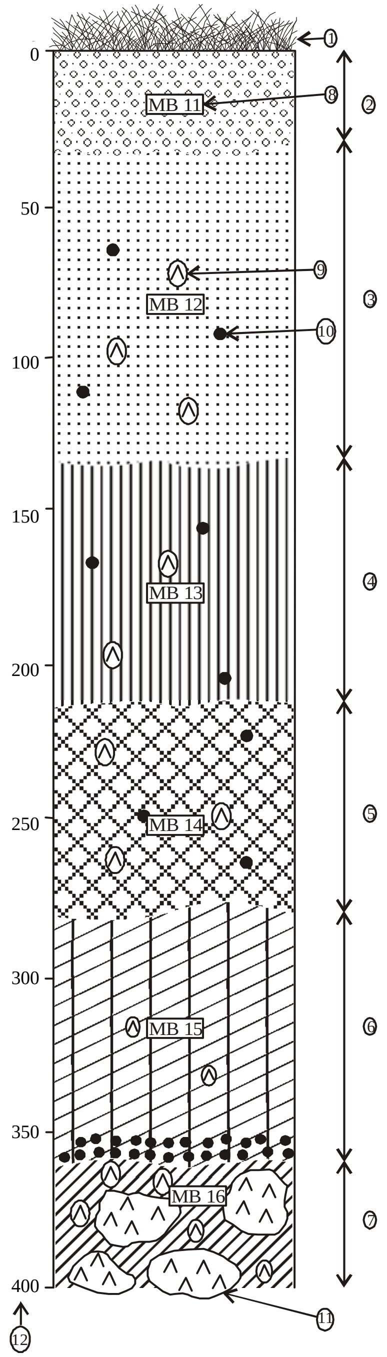

Fig. 2: Macroscopic organization of weathering profile on basalt, 1: Vegetation, 2: Humiferous black horizon, 3: Dark reddish brown horizon, 4: Dark red horizon, 5: Reddish brown horizon, 6: Dark red horizon, 7: Bluish gray horizon, 8: Sample locations, 9: Rock fragments, 10: Lithorelictuels nodules, 11: Blocks of basalt and 12: Depth (cm)

of 2507 mm. Natural vegetation consists of Sporobolus prairies typical of temperate environments. Most interfluves are rounded and have convex summits. The slopes are convexo-concave. The valleys are narrow and deep. Steep slopes (>20%) occupy more than 60% of the area. The bedrock consists mainly of basalt and trachyte of miocene age (Tchoua, 1974). The studied soils were typical dystrandept (Tematio *et al*., 2004), composed in addition to al-humus complexes of allophane, ferrihydrite, gibbsite, kaolinite, goethite, halloysite and opale (Tematio *et al*., 2009; Tsozue *et al*., 2009). Two soil profiles were dug in middle sequence position on two main rocks basalt and trachyte in March, 2014, described in detail and sampled for laboratory analyses.

Laboratory analyses: Soils were air dried and passed through a 2 mm sieve before laboratory analysis. For soil texture analysis, SOM and mineral cements were removed with hydrogen peroxide (30%) and diluted hydrochloric acid (10%), respectively. Then, soil samples were dispersed with sodium hexametaphosphate and particle size distribution was analysed by the Robinson's pipette method. Exchangeable K was determined using atomic absorption spectrophotometry in a solution of ammonium acetate at pH 7. Total N was obtained after heat treatment of each sample in a mixture of concentrated sulfuric acid and salicylic acid. The mineralization was accelerated by a catalyst consisting of iron sulfate, selenium and K sulfate. The mineralization was followed by distillation via conversion of N into steam in the form of ammonia (NH_3), after alkalinization of mineralized extract with NaOH. The distillate was fixed in boric acid (H_3BO_3) and then titrated with sulfuric acid or diluted hydrochloric acid (0.01 N). The OC was determined by the Walkley-Black method (Walkley and Black, 1934). Available P was determined by Bray-2 method (Bray and Kurtz, 1945).

Statistical analysis: The data collected were analyzed using descriptive statistics with the help of XLSTAT version 2008.6.03. Pearson correlation analysis was used to determine the relationship between soil parameters.

RESULTS

Morphological organization of the studied soils: Two weathering profiles developed on the two main rock types were described in detail. On basalt, the profile was 4 m thick and the following six horizons were noted from top to bottom (Fig. 2):

- A humiferous black (7.5YR2.5/1) horizon (35 cm), wet, highly porous, characterized by a loamy texture, fine lumpy structure and the presence of many rootlets, the bulk density was 0.55 g cm^{-3}, the pH was 4.7 and the boundary was gradual and regular
- A dark reddish brown (5YR3/3) horizon (100 cm), unctuous, characterized by very light and inconsistent aggregates, which gave a sponge-like appearance to the material and the presence of numerous cavities, rock fragments, lithorelictual millimetre-sized nodules (<1%) and rootlets, the bulk density was 0.61 g cm^{-3}, the pH was 4.9 and the boundary was gradual and regular
- A dark red (2.5YR3/6) horizon (75 cm). It was wet and dense, characterized by a clayey texture, a fine blunt blocky structure, a high cohesion and the presence of rock fragments, lithorelictual millimetre-sized nodules (1%), numerous cavities and little rootlets, the bulk density was 1.03 g cm^{-3}, the pH was 5.1 and the boundary was gradual and regular
- A reddish brown (5YR4/4) horizon (70 cm). It was very wet, unctuous, with very poorly developed structure. There were very light and inconsistent aggregates which gave a sponge-like appearance to the material, numerous cavities, rock fragments, lithorelitual millimetre-sized nodules (1 %) and very few fine rootlets, the bulk density was 0.89 g cm^{-3}, the pH was 5.6 and the boundary was gradual and regular
- A dark red (2.5YR3.5/6) horizon (85 cm), whose characteristics were similar to those of the upper dark red horizon. This horizon was limited at its base by a thin layer (5 cm thick) of lithorelictuels nodules with various forms, within which the basalt structure was recognizable, presence of rock fragments, the bulk density was 1.06 g cm^{-3}, the pH was 5.2 and the boundary was gradual and irregular
- A bluish gray horizon (more than 365 cm). It was massive, characterized by a loamy clay texture, the presence of rock fragments and blocks of basalt and the pH was 5.3.

On trachytic rocks, the profile was also 4 m thick. From top to bottom, the following five horizons were distinguished (Fig. 3):

- A humiferous black (7.5YR2.5/1) horizon (20 cm). Features were similar to those observed in humiferous horizon on basalt, the bulk density was 0.79 g cm^{-3}, the pH was 5.1 and the boundary was gradual and regular
- A dark brown (7.5YR3.5/4) horizon (70 cm). It was wet, unctuous, characterized by very fine blocky structure, light and inconsistent aggregates, little rootlets and numerous cavities, the bulk density was 0.74 g cm^{-3}, the pH was 5.2 and the boundary was gradual and regular

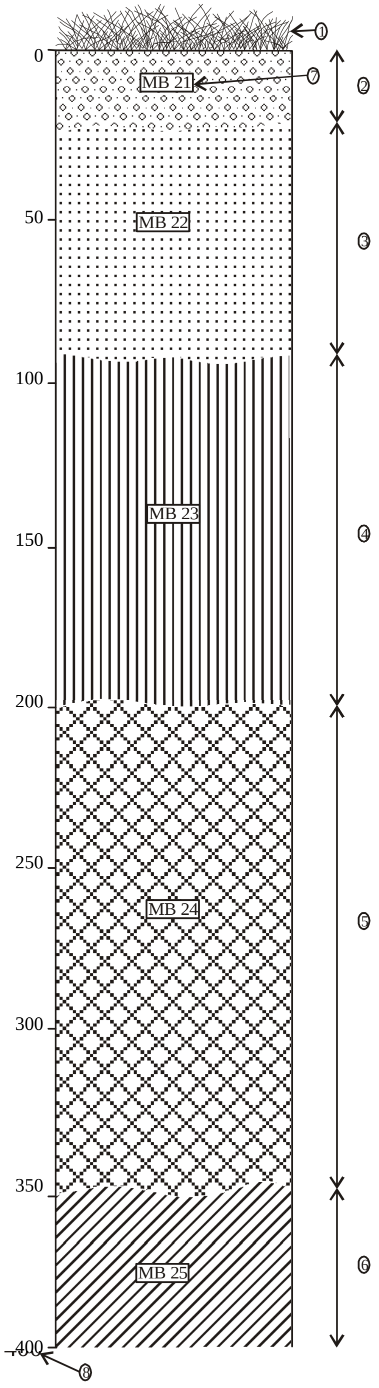

Fig. 3: Macroscopic organization of weathering profile on trachyte: 1: Vegetation, 2: Humiferous black horizon, 3: Dark brown horizon, 4: Dark red horizon, 5: Yellowish red horizon, 6: Weathered polychrome horizon, 7: Sample locations and 8: Depth (cm)

- A dark red (2.5YR3/6) horizon (110 cm). It was wet and dense, characterized by a clayey texture, a fine blocky structure, a high cohesion, little rootlets and numerous cavities with infillings, whose colour was similar to that of the two upper horizon, the bulk density was 1.09 g cm^{-3}, the pH was 5.6 and the boundary was gradual and regular
- A yellowish red (5YR5/8) horizon (150 cm), wet and less dense than the upper horizon. It was characterized by a clayey texture, a very poorly developed fine blocky structure, weak consistent and the presence of rare rootlets, the bulk density was 0.94 g cm^{-3}, the pH was 5.3 and the boundary was gradual and regular
- A weathered polychrome (white, gray and pink colours) (more than 350 cm) horizon with loamy texture and massive structure, the bulk density was 1.10 g cm^{-3}, the pH was 4.9

Particle size distribution: Among the different soil fractions, sand content were lowest in the two profiles. They ranged globally from 1-13% and were highly variable (CV>35%) (Table 1 and 2, Fig. 4 and 5). Their contents varied little along the profiles (Fig. 6 and 7). Silt and clay contents were the highest, ranging, respectively from 23-76% and from 12-74% on basalt, from 20-64% and from 30-77% on trachyte (Table 1 and 2, Fig. 4 and 5). They were moderately (15%<CV<35%) to highly variable (CV>35%) (Table 1 and 2). These two soil fractions evolved in opposite trends along the profile, with a zigzag highly pronounced for soil on basalt (Fig. 6 and 7). There was no significant correlation between sand and the other soil fractions. However, there was a negative significant correlation between silt and clay fractions in the soil profile (r = -0.99, p<0.0001) (Table 3 and 4).

Soil organic carbon, total nitrogen stocks and carbon/nitrogen ratio: Total OC amounts were high in the humiferous horizon (10% on trachyte and 15% on basalt) (Table 1 and 2, Fig. 4 and 5). These amounts decreased gradually with depth, reaching 0.30 and 0.23% in the

Table 1: Physicochemical characteristics of the soil developed on basalt

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	K^+ (cmol kg^{-1})	OC (%)	N (%)	C:N	Available P (ppm)
10-20	8.0	73.0	19.0	0.23	15.80	0.778	20.31	12.60
75-85	5.0	65.0	30.0	0.16	5.40	0.190	28.42	5.60
170-180	6.0	35.0	59.0	0.23	1.40	0.057	24.56	4.20
240-250	13.0	76.0	12.0	0.09	0.20	0.007	30.00	3.50
315-325	3.0	23.0	74.0	0.32	0.40	0.019	20.00	5.60
370-380	4.0	49.0	47.0	0.00	0.30	0.009	34.40	17.50
Minimum	3.0	23.0	12.0	0.00	0.20	0.007	20.00	3.50
Maximum	13.0	76.0	74.0	0.32	15.80	0.778	34.40	17.50
Mean	6.50	53.50	40.17	0.17	3.92	0.180	26.28	8.17
Coefficient of variation (%)	50.80	36.70	54.60	60.70	143.30	156.40	19.80	62.70

OC: Organic carbon, N: Nitrogen and P: Phosphorus

Table 2: Physicochemical characteristics of the soil developed on trachyte

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	K^+ (cmol kg^{-1})	OC (%)	N (%)	C:N	Available P (ppm)
5-15	7.0	64.0	30.0	0.81	10.00	0.80	21.50	16.80
50-60	3.0	47.0	49.0	0.32	2.69	0.21	21.90	1.40
150-160	3.0	20.0	77.0	0.00	0.31	0.07	7.01	4.20
270-280	3.0	38.0	59.0	0.00	0.23	0.04	6.40	5.50
370-380	1.0	61.0	37.0	0.00	0.23	0.03	6.60	4.20
Minimum	1.0	20.0	30.0	0.00	0.23	0.03	6.40	1.40
Maximum	7.0	64.0	77.0	0.81	10.00	0.80	21.90	16.80
Mean	3.4	46.0	50.4	0.23	2.69	0.23	12.68	6.42
Coefficient of variation (%)	57.60	34.90	33.00	140.40	140.20	127.10	58.10	83.50

OC: Organic carbon, N: Nitrogen and P: Phosphorus

Table 3: Pearson correlation matrix for linear relationships between parameters for the soil on basalt

Variables	Sand	Silt	Clay	K^+	OC	N	C:N	Available P
Sand	1							
Silt	0.734	1						
Clay	-0.792	-0.996*	1					
K^+	-0.264	-0.462	0.447	1				
OC	0.126	0.507	-0.478	0.266	1			
N	0.148	0.487	-0.462	0.273	0.995*	1		
C:N	0.141	0.292	-0.277	-0.954*	-0.483	-0.505	1	
Available P	-0.317	0.102	-0.050	-0.483	0.298	0.322	0.309	1

*Significant at p<0.05, OC: Organic carbon, N: Nitrogen, K: Potassium and P: Phosphorus

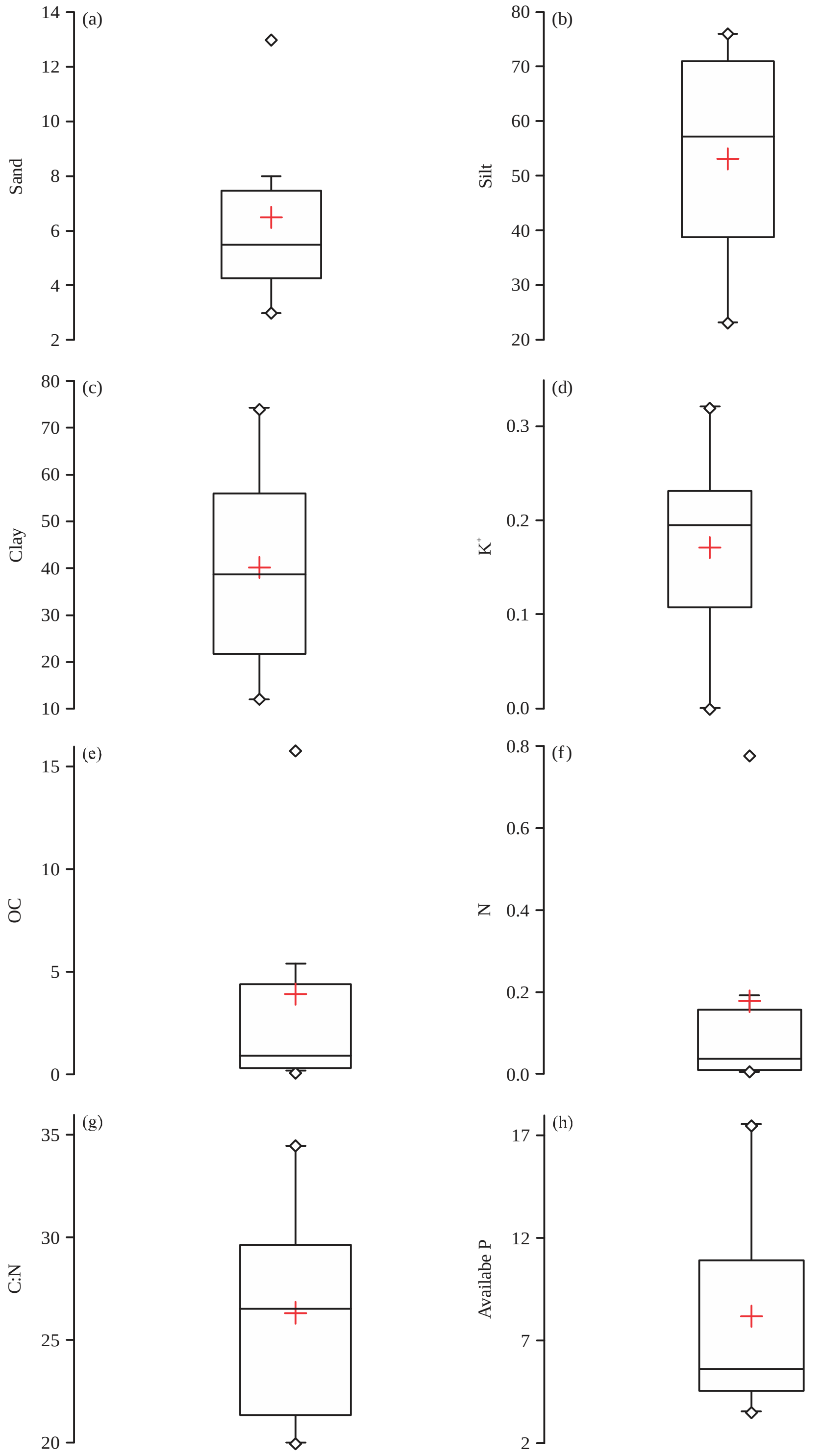

Fig. 4(a-h): Box plots showing a summary of laboratory measured parameters of soil on basalt,(a): Sand, (b): Silt, (c): Clay, (d): K^+, (e): OC, (f): N, (g): C:N and (h): Available P

weathering horizons, respectively, on basalt and trachyte (Table 1 and 2, Fig. 6 and 7). They were very highly variable along the soil profiles. There was a significant positive correlation between OC and sand fraction, only on trachyte ($r = 0.92$, $p<0.03$) (Table 4). This significant correlation was confirmed by their similar evolution with depth observed in

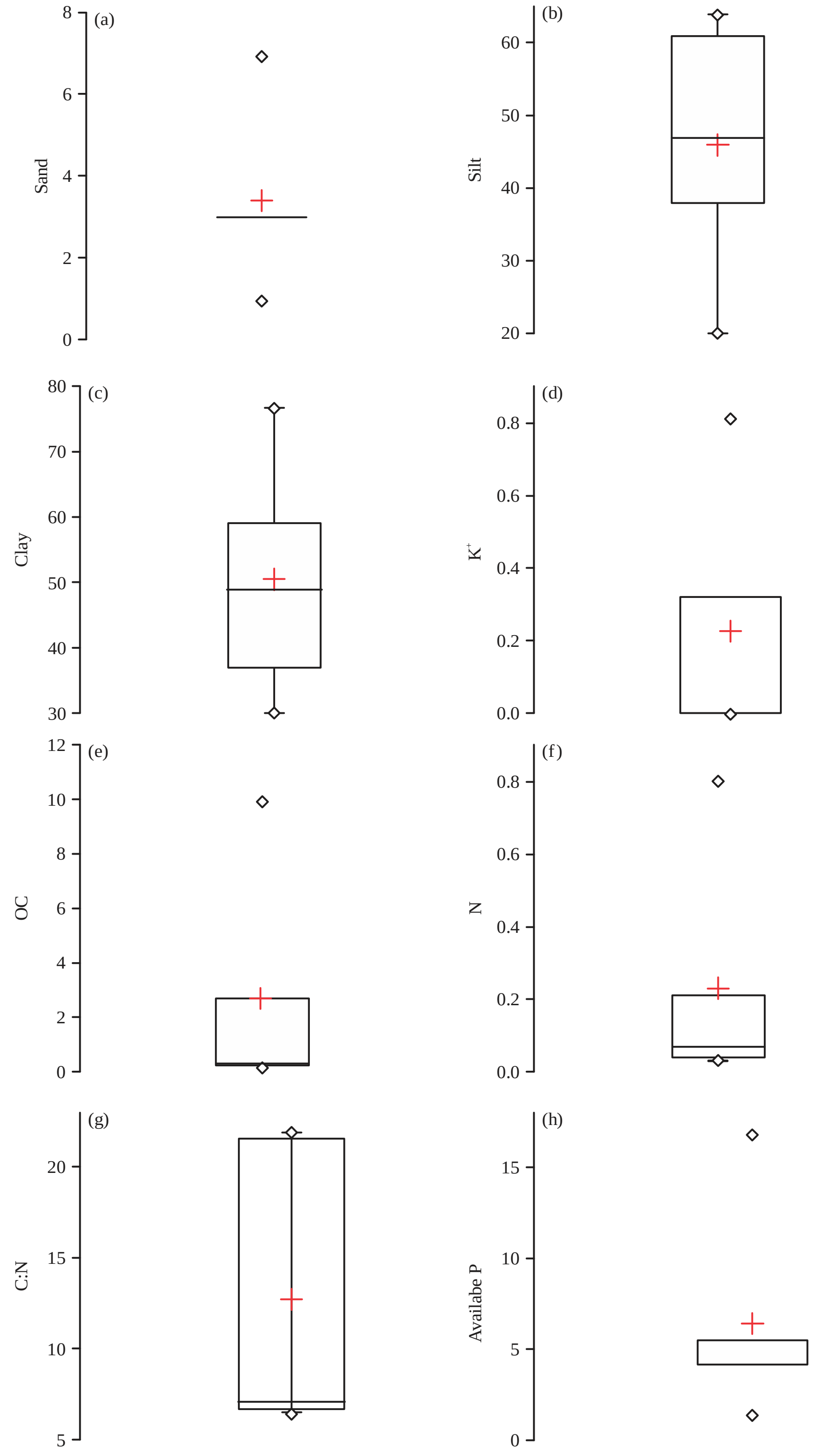

Fig. 5(a-h): Box plots showing a summary of laboratory measured parameters of soil on basalt,(a): Sand, (b): Silt, (c): Clay, (d): K$^+$, (e): OC, (f): N, (g): C:N and (h): Available P

Fig. 7. Total N stocks were also high in the humiferous horizon (0.80%). They decreased gradually with depth and were also very highly variable along the profiles (Table 1 and 2). There was a significant positive correlation between N and OC on basalt (r = 0.99, p<0.0001) (Table 3). On trachyte, there was a significant positive correlation between N and sand fraction

Table 4: Pearson correlation matrix for linear relationships between parameters for the soil on trachyte

Variables	Sand	Silt	Clay	K^+	OC	N	C:N	Available P
Sand	1							
Silt	0.267	1						
Clay	-0.337	-0.997*	1					
K^+	0.897*	0.585	-0.644	1				
OC	0.924*	0.582	-0.640	0.989*	1			
N	0.936*	0.550	-0.610	0.982*	0.999*	1		
C:N	0.657	0.464	-0.517	0.864	0.780	0.758	1	
Available P	0.875	0.496	-0.544	0.800	0.879*	0.893*	0.391	1

*Significant at $p<0.05$, OC: Organic carbon, N: Nitrogen, K: Potassium and P: Phosphorus

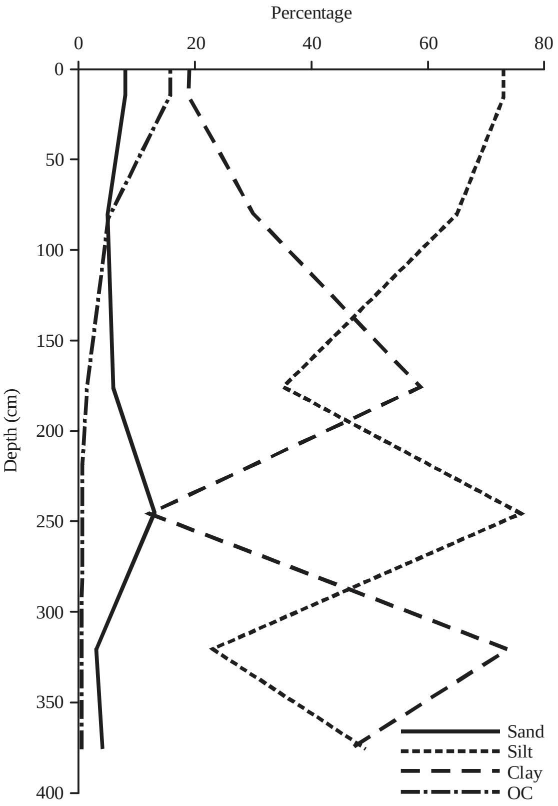

Fig. 6: Distribution of particle size distribution fractions and organic carbon with depth for soil on basalt

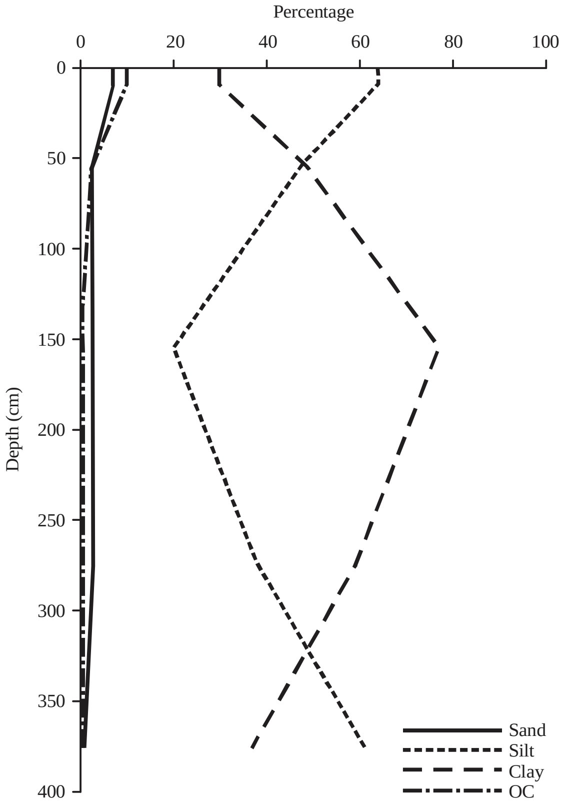

Fig. 7: Distribution of particle size distribution fractions and organic carbon with depth for soil on trachyte

($r = 0.93$, $p<0.02$), N and OC ($r = 0.99$, $p<0.0001$) and between N and K ($r = 0.98$, $p<0.04$) (Table 4). The C:N ratios were globally high along the soil profile developed on basalt, ranging between 20 and 34.4, with a mean value of 26.28 (Table 1 and Fig. 4). These ratios were moderately variable ($15\%<CV<35\%$) (Table 1). On trachyte, similar ratios were observed only in the two upper horizons. They varied between 6.40 and 7.01 in the horizons below (Table 2 and Fig. 5). Globally, C:N ratios along the soil profile on trachyte were highly variable ($CV>35\%$). There was a significant negative correlation between this soil parameter and K on basalt ($r = 0.95$, $p<0.003$) (Table 3).

Phosphorus and potassium stocks: Except in the humiferous horizon on trachyte, the amounts of K were below the critical levels in the studied soils (Table 1 and 2, Fig. 4 and 5). They were highly variable. The only significant correlation was noted with C:N ratio. Available P contents were low to very low. Medium values were noted in the weathering horizon on basalt and the humiferous horizon on trachyte (Table 1 and 2, Fig. 4 and 5). These contents were highly variable ($CV>35\%$) (Table 1 and 2). Available P exhibited a significant positive correlation with OC ($r = 0.87$, $p<0.05$) and total N ($r = 0.89$, $p<0.05$) but only in soil profile develop on trachyte (Table 4).

DISCUSSION

Except for the significant positive correlation between OC and sand fraction on trachyte, there was no significant correlation between SOC and texture. This implied that SOC would be mostly retained in sand fractions on trachyte. Similar findings were reported by Udom *et al.* (2015). In addition, McLauchlan (2006) observed a very slight relationship between SOC and texture. Six *et al.* (2000) documented that clay concentrations had a very slight effect on SOC accumulation rate and soil aggregate dynamics. Texture thus has a lesser effect on SOC storage in comparison to other soil parameters (Sakin, 2012). Mineral and organic colloids account for essentially all of the charge and chemical reactivity of soils greatly affect the availability of nutrients (Hodges, 2010). Because of the highly variable and often intermingled nature of sources in soils, the charges are sometimes referred to as the colloidal complex (Hodges, 2010). The absence of significant correlation between SOC and clay could imply that these two soil colloids responsible for the studied soil fertility acted independently. This was confirmed by the presence of kaolinite as the only clay mineral in the studied soil, characterized by low surface area and CEC (10-20 g m^{-2} and 1-10 cmol kg^{-1}, respectively) compared to Organic Matter (OM) (800-900 g m^{-2} and 100-300 cmol kg^{-1}, respectively), which means that OC was the main source of soil fertility in this tropical mountainous ecosystem. It was well recognized that SOM increased structural stability, resistance to rainfall impact, rate of infiltration and faunal activities (Roose and Barthes, 2001; Tematio *et al.*, 2011) and its amount in a system is a good measure of sustainability (Bationo *et al.*, 2007). There was a significant correlation between N and OC. Generally, concentrations of N are high in areas, where the SOC is high (Sakin, 2012). This indicates that the N nutrition of crops largely depends on the maintenance of SOC levels (Manu *et al.*, 1991). Nitrogen is an essential nutrient used in relatively large amounts by all living things (Hodges, 2010). It is critically important to plants because it forms a fundamental part of the chlorophyll molecule and formation of amino acids and proteins (Hodges, 2010). On trachyte, the C:N ratio in the surface soil was higher than that in lower portions of the subsurface soil horizons. This indicates high resolution and separation rates (Sakin, 2012). Contrary on basalt, the C:N ratio was globally high, but exhibited a zigzag evolution along the soil profile. This might be related to the variation of rainfall over the time in agreement with Miller *et al.* (2004) who reported that C:N ratio increased with precipitation and decreased with higher temperatures. According to Callesen *et al.* (2007) there is a positive relationship between C:N ratios, precipitation and temperature. High soil C:N ratio could slow down the decomposition rate of OM and organic N by limiting the soil microbial activity's ability with lower mobilization of N (Wu *et al.*, 2001; Prusty *et al.*, 2009). Low soil C:N ratio on contrary, could accelerate the process of microbial decomposition of OM and N, which was not conducive for C sequestration (Wu *et al.*, 2001; Prusty *et al.*, 2009). The C:N ratios exhibited significant negative correlation with K on basalt. On trachyte, there was a significant positive correlation between OC and K as well as between N and K. Plant use K in photosynthesis, in carbohydrate transport, in water regulation and in protein synthesis (Krauss and Johnston, 2002; Hodges, 2010). The benefits of proper K nutrition are improved disease resistance, vigorous plant growth, increased drought tolerance, improved winter hardiness of forages and decreased lodging (Hodges, 2010). As a result, K fertilization is frequently associated with improved crop quality as well as better handling and storage properties (Krauss and Johnston, 2002; Hodges, 2010). Phosphorus exhibited a significant positive correlation with N and OC, but only on trachyte. It was one of the nutrients that limit tree growth, especially in tropical areas (Zas and Serrada, 2003). It is essential in several biochemical that control photosynthesis, respiration, cell division and many other plant growth and development processes (Hodges, 2010). The dependence of P fertility on OM led to feedback mechanisms that further confound the assessment of P availability in tropical soils by chemical tests (Oberson *et al.*, 2006). The significant correlation between OC, N, P and K means that the depletion of SOM would lead to a corresponding depletion of N, P and K. Soil fertility determines plant growth and depends on the concentration of N, P, K organic and inorganic materials, micronutrients and water (Tale and Ingole, 2015). Generally, soil chemical fertility and in particular lack of nutrient inputs is a major factor in soil degradation (Hartemink, 2010). Nutrients deficiency has become major constraint to productivity, stability and sustainability of soils (Bell and Dell, 2008). The increasing trends of biomass C, N and P in the soils are attributed to OM inputs as compliment fertilizer materials and would improve the quality of soils for sustainable crop production (Odunze *et al.*, 2012). Relationship existed among soil physicochemical properties which positively or negatively, interfered with nutrient availability (Onwudike, 2015).

CONCLUSION

In the studied soil, sand contents were low, while silt and clay contents were high. There was no significant correlation between sand and the others soil fractions, but a negative significant correlation exists between silt and clay. Total OC contents were high in the humiferous horizon. There was a significant positive correlation between OC and sand fraction only on trachyte, confirmed by their similar evolution with depth. Total N stocks were also high in the humiferous horizon. There was a significant positive correlation between N and OC, indicating that N nutrition of crops largely depends on the maintenance of SOC levels. The C:N ratios were high along the soil profile developed on basalt and in the two upper horizons on trachyte. There was a significant negative correlation between C:N and K on basalt. Except the humiferous horizon on trachyte, the amounts of exchangeable K were below the critical levels. It was only significantly correlated with C:N ratio. Phosphorus contents were low to very low, exhibiting a significant positive correlation with OC and total N, but only in soil profile developed on trachyte. Relationship existed among soil physicochemical properties, which positively or negatively, interfered with nutrient availability.

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