International Journal of Agriculture and Forestry 2016, 6(5): 187-195
DOI: 10.5923/j.ijaf.20160605.03

Statistical Relationships and Variability of Selected Properties of Xanthic and Rhodic Ferralsols in a Humid Tropical Forest of Cameroon

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Abstract Soil quality is the most important factor in forest management decisions and is greatly influenced by soil physico-chemical properties. This study was carried out to enhance understanding of the relationships existing among selected properties of two ferralsols common in humid tropical forests (Xanthic and Rhodic ferralsols). In the field, thirty eight Xanthic ferralsols and sixteen Rhodic ferralsols were sampled from the upper 0 – 20 cm of mineral soil. Soil physical and chemical properties were analyzed following standard laboratory procedures. Descriptive statistics was performed on various soil properties and Student's t-test was used to compare properties of the two soil types. The relationship between soil properties was examined using correlation and regression analyses. Principal Component Analysis (PCA) was performed to identify sources of variations in soil properties and to group soil properties into units that could serve as a guide for soil quality monitoring and management. Results indicated that all soils were generally acidic (pH-H_2O < 4.8) and had high levels of exchangeable acidity (EA) (3.33 – 6.25 meq/100 g). Organic carbon (OC) ranged from 1.01 – 3.87%, base saturation (BS) ranged between 6.21 – 17.87%, cation exchange capacity (CEC) was low and ranged from 4.85 – 8.67 meq/100 g and the soils were rich in clay (24.6 – 54.6%). Between Xanthic and Rhodic ferralsols, there was a significant difference ($p < 0.05$) in OC, exchangeable Mg^{2+}, EA, CEC, effective CEC, % clay and % sand. Xanthic ferralsols showed less variability (CV% = 3.57 – 50.0%) compared to Rhodic ferralsols (CV% = 5.1 – 61.5%). There was a significant positive correlation between some soil properties (r = 0.32 – 0.88, $p < 0.05$, 0.01 for Xanthic ferralsols) and (r = 0.51 – 0.85, $p < 0.05$, 0.01 for Rhodic ferralsols). Simple linear regression analysis indicated that coefficients of determinations were low ($R^2 < 0.4$, $p < 0.05$) while multiple linear regressions among related soil properties yielded higher R^2 values ($R^2 = 0.57 – 0.96$). PCA yielded five principal components with Xanthic ferralsols which explained a total of 80.04% of the variation in soil properties. For Rhodic ferralsols, PCA yielded four principal components which explained a total of 79.42% of the variation observed. Grouping of soil properties within principal components showed that key indicators of soil quality to be considered in soil management are soil texture, soil acidity, base status and soil organic matter. We recommend detail soil characterization and the establishment of soil maps for better interpretation of soil analytical data and proper management of forest soil fertility, since our findings show that soil properties greatly vary even at the local scale.

Keywords Rhodic ferralsols, Xanthic ferralsols, Variability, Correlation analysis, Regression analysis, Principal Component Analysis

1. Introduction

Ferralsols form a broad category of soils, defined as having clay minerals with low cation exchange capacity (kaolinite, aluminum and iron oxides), moderate to strong acidity, and low exchangeable cation content. Internationally, Ferralsols are known as Oxisols (USA Soil Taxonomy), Latosols (Brazil), Sols Férrallitiques (French CPCS), Ferralitic soils (Russia) and Ferralsols (IUSS/FAO/ISRIC WRB). Rhodic ferralsols are defined as ferralsols having a B horizon with a Hue redder than 5YR (3.5YR or redder) and a moist colour value < 3.5, and a dry colour value > 1 unit higher than the moist value. On the other hand, Xanthic ferralsols are defined as ferralsols having a ferralic horizon with a yellow to pale yellow colour [1]. These colours are usually associated with the mineralogical composition of the soils. Reddish colours are usually associated with ferric oxides (hematite and magnetite) while the yellow colour of Xanthic ferralsols is as a result of iron oxyhydroxides (dominantly goethite) [2].

Ferralsols are the most common tropical soils which carry huge forest vegetation in the Amazon and Congo Basins. In

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Published online at http://journal.sapub.org/ijaf

Cameroon, ferrallitic soils cover more than 60% of the southern Cameroon plateau, where dense forests exist [3]. The ferralsols that occur in Cameroon include Rhodic and Haplic ferralsols, Humic ferralsols and Xanthic ferralsols [3]. The Humic ferralsols are dominant in the Western highlands of Cameroon, where low temperatures (mean annual temperature fluctuates around 18°C) delay organic matter decomposition [4, 5]. Rhodic, Haplic and Xanthic ferralsols are predominantly present in the humid forest zones where high temperatures (mean annual temperature > 23°C), high precipitations (mean annual rainfall is around 1500 mm) and low altitude (< 800 m above sea level) favour their formation [3]. These soils support huge forest cover, composed of many different hardwood species. Most of the forest species have been exploited for timber and this has led to soil degradation or extinction of some high value timber species.

In the management of forest resources within the Congo Basin in general, and Cameroon in particular, emphasis has always been made on the conservation of flora and fauna and water resources, meanwhile little attention has been given to the soil resource. The difficulty usually encountered during reforestation of degraded forest soils with particular tree species is in part due to lack of detailed knowledge about soil properties in forest milieu. Soils have been considered as a fundamental resource of tropical forests to predict the response of particular tree species to various soil types [6-8]. Another problem encountered is the lack of soil quality indicators which can serve as guide for sustainable management of forests [9]. These soil quality indicators have been established in the United States of America [10] and the United Kingdom [11]. In the Congo basin, information on soil quality indicators is lacking. A major difficulty encountered by forestry scientists is soil analysis and interpretatation of analytical results. Usually, analyses are carried out in forests as part of ad hoc studies, research projects and research thesis, or continuous monitoring studies and the results are not always recorded in databases. Some results remain on paper or in individual spreadsheets [9]. Using such data to produce reference values and indicators that can be used by foresters poses several questions. Furthermore, to decide on how forest stands should be managed, it is important to have a better knowledge of static and dynamic soil properties and their relationships in order to establish soil quality indicators.

The interrelationships that exist among soil physico-chemical properties can be used to evaluate the reliability and consistency of soil analytical data through statistical means [12]. However, little information exists for the use of such an approach, especially in forestry. Furthermore, the great diversity of soil encountered in tropical forests necessitates an understanding of soil properties and their relationships, even at the local scale. The objective of this study was therefore to inform on the statistical relationships among selected physico-chemical properties of Rhodic and Xanthic ferralsols in a humid tropical forest of East Cameroon, in order to enhance understanding of the soils, in view of their proper management in reforestation programs, and as a starting point for establishment of soil quality indicators. Specifically, the study was designed to compare the differences in soil properties of Rhodic and Xanthic ferralsols, to examine the relationship existing between soil properties, to assess the variability of soil properties and factors accounting for their variations, and to identify properties that can serve as proxies for soil quality indicators in humid tropical forests.

2. Materials and Methods

2.1. Description of Study Area and Collection of Soil Samples

The study was carried out in a forest management unit (FMU, 10 030) of PALLISCO Company in the East Region of Cameroon. The FMU is located between latitudes 3° 05’ N and 3° 30’ N and longitudes 14° 00’ E and 14° 30’ E. The climate is the Equatorial Guinea sub-type with two seasons; the main wet season (August to November) and main dry season (November to March), and two minor seasons designated as mini wet (March to May) and mini dry (June to July). Mean annual temperature is about 23.1°C and mean annual rainfall is 1566 mm [13]. Altitude varies between 600 and 760 m above sea level. The vegetation is the evergreen forest type, with Meliaceae, Sterculiaceae and Ulmaceae families dominating [14]. The dominant soils are Rhodic and Xanthic ferralsols, and are developed from various parent materials such as micaschists, gneisses and granites [3].

In the field, two distinct areas of about 100 ha each, dominated by Rhodic and Xanthic ferralsols, were sampled. In each area, soil samples were randomly collected from the upper 0 - 20 cm within 50 m x 50 m square plots and bulked to obtain composite soil samples. The plots were established following procedures described by Frontier Cambodia [15]. In all, thirty eight composite samples of Xanthic ferralsols and sixteen composite samples of Rhodic ferralsol were collected.

2.2. Laboratory Analysis

Soil samples from the field were air-dried at room temperature, crushed and sieved through a 2 mm sieve. The < 2 mm soil fraction was analyzed for both physical and chemical properties. Particle size analysis was done following the hydrometer method [16]. Soil pH was determined electrometrically with a 1:2.5 soil:H_2O and 1:2.5 soil:KCl ratio, using distilled deionised water and 1N KCl solution, respectively. Organic carbon (OC) was determined by the Walkley and Black wet combustion method as described by Pauwels et al, [17]. Soil organic matter (SOM) was estimated from OC by multiplying OC by 1.742 [17]. Exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) were determined following the Schollenberger’s method using a 1M ammonium acetate solution buffered at pH 7. The concentrations of Na^{+} and K^{+} ions in the extract were obtained by flame photometry, and those of Ca^{2+} and Mg^{2+} were determined by complexometric titration using a 0.002

M Na_2-EDTA solution. Cation exchange capacity (CEC) was determined as a direct continuation of the Schollenberger's method using a 1N KCl saturation solution. Exchangeable acidity (Al^{3+} + H^+) was determined using a 1N KCl solution for soil leaching following procedures outlined by Dipak and Abhijit, [18]. Effective CEC (ECEC) and base saturation (BS) were determined by the summation method [17].

2.3. Statistical Analysis

Descriptive statistics (minimum and maximum values, mean values, standard error of means, standard deviation, and coefficient of variation) was performed on soil properties. Coefficient of variation (CV %) was used to examine the variability of soil properties and was calculated using the formula;

$$CV \% = \frac{SD}{\bar{x}} \times 100$$

Where;
SD = standard deviation
$\bar{x}$ = arithmetic mean of soil properties

Soil properties having CV % values < 15% were grouped as least variable, those with CV % between 15 to 35% were grouped as moderately variable and those with CV % > 35% indicated high variability [19]. Principal Component Analysis was performed to identify factors accounting for the variation in soil properties. Differences in soil properties of the two soil types were compared using student's t-test. Relationships among soil properties were investigated using correlation and regression analyses. Soil parameters tested and fitted to regression models were based on prior established general relationships among variables as described by Yerima et al, [12]. Plots of the dependent versus independent variables were used to determine the fit of the models [20]. A general linear model was used based on visual observation of the shape of the relationship. Statistical analysis was facilitated using Microsoft Excel 2007 and SPSS (Version 19).

3. Results and Discussion

3.1. Physical and Chemical Properties of Soils

Descriptive statistics of soil properties are shown in Tables 1 and 2. In general, soil properties deviated from normality, as indicated by standard deviation values. There was a significant difference in some soil properties of Rhodic and Xanthic ferralsols, including OC, Mg^{2+}, exchangeable acidity, CEC, ECEC, % clay and % sand (Table 3). All soils were acidic in nature but Xanthic ferralsols were less acidic compared to Rhodic ferralsols and this difference in soil pH was concomitant to values of exchangeable acidity. Results of correlation analysis indicated that there was a non-significant negative correlation between soil pH and exchangeable acidity for both soil types. However, many studies have reported that soil pH and exchangeable acidity have an inverse relationship, i.e. as soil pH reduces below 5.5, exchangeable acidity increases [21]. At very low pH values (pH < 5.0), Al in clay minerals becomes soluble and exists as positively charged aluminum (Al^{3+}) or aluminum hydroxyl cations (e.g., $Al(OH)^{2+}$, $Al(OH)_2^{+}$). These cations can become adsorbed on negatively charged clay particles in a similar way to base cations. The presence of these acidic species in soil solution is the primary cause of P deficiency through fixation processes, and Al toxicity for particular tree species [22]. SOC was higher in Rhodic ferralsols compared to Xanthic ferralsols, and this difference in SOM is one of the factors accounting for the difference in their colours [2]. High SOM contents in soils are the result of slow decomposition rates, following the accumulation of large plant residue. The rate of organic matter decomposition varies depending on the type of organic material and its turnover [23]. Exchangeable bases (Ca^{2+} and Mg^{2+}) were low in all soils and these low values are generally associated with advanced weathering stages and leaching of humid tropical soils, influenced by high amounts of precipitation [2]. The low amounts of exchangeable cations are in accord with those reported in most soils of lowland humid tropical forests [24], [25]. CEC and ECEC were significantly higher in Rhodic ferralsols compared to Xanthic ferralsols. This was certainly due to the higher amounts of SOM and exchangeable cations. Rhodic ferralsols in this environment have a higher nutrient status compared to the Xanthic ferralsols, but could be toxic with respect to Al^{3+} content. SOM can therefore be used as a soil fertility indicator within humid tropical forests. BS was generally low in both soils (< 20%). It has been observed that highly weathered ferralsols in the Amazonian forest generally have low base status and this varies with weathering stages of the soils [22].

Table 1. Descriptive statistics of Xanthic ferralsols

Soil properties (n = 38)	Min.	Max.	Mean (±SE)	Std. Dev.	CV %
pH-H_2O	4.00	4.60	4.20 ± 0.02	0.15	3.57
pH-KCl	3.10	3.70	3.27 ± 0.03	0.15	4.59
OC (%)	1.01	3.19	2.08 ± 0.09	0.55	26.44
OM (%)	1.74	5.50	3.59 ± 0.15	0.94	26.18
Ca^{2+} (meq/100g)	0.32	0.88	0.51 ± 0.02	0.14	27.45
Mg^{2+} (meq/100g)	0.04	0.31	0.16 ± 0.01	0.08	50.00
Exch. Acidity (meq/100g)	3.33	4.67	4.02 ± 0.06	0.35	8.71
CEC (meq/100g)	4.85	8.64	6.46 ± 0.14	0.87	13.47
ECEC (meq/100g)	3.85	5.46	4.70 ± 0.07	0.41	8.72
BS (%)	6.21	17.87	10.58 ± 0.49	3.02	28.54
Clay (%)	24.60	48.60	37.07 ± 1.09	6.69	18.05
Silt (%)	8.00	34.00	16.84 ± 0.91	5.61	33.31
Sand (%)	33.40	57.40	46.08 ± 1.17	7.22	15.67

Std. Dev. = standard deviation, SE = standard error of means

Table 2. Descriptive statistics of Rhodic ferralsols

Soil properties (n = 16)	Min.	Max.	Mean (±SE)	Std. Dev.	CV %
pH-H_2O	3.80	4.70	4.07± 0.06	0.24	5.90
pH-KCl	3.10	3.70	3.33 ± 0.04	0.17	5.11
OC (%)	1.96	3.87	2.93 ± 0.12	0.49	16.72
OM (%)	3.38	6.67	5.06 ± 0.21	0.84	16.60
Ca^{2+} (meq/100g)	0.40	0.80	0.58 ± 0.03	0.14	24.14
Mg^{2+} (meq/100g)	0.04	0.56	0.26 ± 0.04	0.16	61.54
Exch. Acidity (meq/100g)	5.28	6.25	5.76 ± 0.07	0.28	4.86
CEC (meq/100g)	7.12	8.67	7.80 ± 0.12	0.48	6.15
ECEC (meq/100g)	5.97	7.17	6.62 ± 0.09	0.37	5.59
BS (%)	7.58	15.89	11.03 ± 0.72	2.86	25.93
Clay (%)	30.60	54.60	43.60 ± 1.41	5.66	12.98
Silt (%)	10.00	26.00	18.38 ± 1.07	4.27	23.23
Sand (%)	29.40	45.40	38.03 ± 1.15	4.60	12.10

Std. Dev. = standard deviation, SE = standard error of means

Table 3. Comparison of mean (±SE) soil properties of Xanthic and Rhodic ferralsols

Soil Properties	Xanthic ferralsol	Rhodic ferralsol	t-value	probability
pH-H_2O	4.20 ± 0.02	4.07 ± 0.06	1.99	0.06
OC (%)	2.08 ± 0.09	2.93 ± 0.12	-5.38	<0.001*
Ca^{2+} (meq/100g)	0.51 ± 0.02	0.58 ± 0.03	-1.77	0.083
Mg^{2+} (meq/100g)	0.16 ± 0.01	0.26 ± 0.04	-2.44	0.025*
Exch. acidity (meq/100g)	4.02 ± 0.06	5.76 ± 0.07	-17.45	<0.001*
CEC (meq/100g)	6.46 ± 0.14	7.79 ± 0.12	7.26	<0.001*
ECEC (meq/100g)	4.7 ± 0.07	6.62 ± 0.09	-16.29	<0.001*
BS (%)	10.58 ± 0.49	11.03 ± 2.71	-0.5	0.62
Clay (%)	37.07±1.09	43.6 ± 1.41	-3.42	0.001*
Silt (%)	16.84 ± 0.91	18.38 ± 1.0	-0.98	0.333
Sand (%)	46.08 ± 1.17	38.03 ± 1.15	-3.90	0.001*

* Mean values are significantly different at $p < 0.05$; SE = Standard error of means.

The percentage of clay was significantly higher in Rhodic ferralsols compared to Xanthic ferralsols. There was also a significant difference in % sand. Generally, soil texture plays an important role in soil nutrient availability as it influences the hydraulic properties of soil such as infiltration. Soil texture is an important property to consider in tree growth, since it influences root penetrability and physical stability and anchorage. According to O'Neill et al, [21] soil texture, alongside bulk density, are important parameters to consider in monitoring the compaction of forest soils, and this has significant implications for forest management. Additionally, soil texture plays a key role in belowground C storage in forest ecosystems and strongly influences nutrient availability and retention, particularly in highly weathered soils such as ferralsols [26].

3.2. Variability of Soil Properties

Coefficients of variation (CV %) indicated that for Xanthic ferralsols, least variable soil properties (CV % < 15%) were soil pH, exchangeable acidity ($Al^{3+} + H^+$), CEC and ECEC. Moderately variable soil properties (15% ≤ CV % ≤ 35%) were OC, BS, % sand, % silt and % clay. Mg^{2+} showed high variability (CV % > 35%). For Rhodic ferralsols, least variable soil properties were pH, exchangeable acidity, CEC, ECEC, % clay and % sand; moderately variable properties were OC, Ca^{2+}, BS and % silt; the most variable was Mg^{2+}. Comparatively, the results indicate that % clay and % sand are less variable in Rhodic ferralsols than in Xanthic ferralsols. In general, most soil properties ranged from least to moderately variable, and reflect the trend observed in most ferralsols due to the heterogeneity in soil properties [27].

Knowledge of soil variability is important for the evaluation of agricultural land management practices in the context of precision agriculture [19]. In natural ecosystems such as forests, soil variability is caused by soil forming factors, i.e., climate, parent material, time, topography, and vegetation [28]. Each of these factors may operate independently or in combination with other factors and over a wide range of spatial and/or temporal scales. Parent material plays a key role in maintaining the spatial variability of many physico-chemical properties [29]. The variability in soil properties observed in this study could therefore be a result of the heterogeneity in parent material in the study area (micaschists, gneisses and granites). The CV % for soil pH in both soils ranged from 3.57 to 5.9%. The pH values in our study show less variation compared to those reported in the Amazon rainforests, where CV % ranged from 6 to 8.5% [27]. These small variations (< 15%) indicate that soil pH can serve as a good indicator for soil quality monitoring in forest soils. Soil pH provides a good indication of the chemical status of the soil and can be used in part to determine potential plant growth in forest milieu [30]. However, it has been observed that even slight variations in soil pH could significantly affect nutrient availability and uptake [24], thus, the necessity to monitor soil pH variations in space and time.

In both soils, % sand, % silt and % clay were moderately variable (12.1 – 23.23%) and the trend is lower than that reported in a tropical forest of the Amazon, which was 32.5% [27]. The difference in soil SOM between both soils and the moderate variation in SOM (16.6 – 26.8%) could be a result of differences in soil litter type and decomposition rates of SOM. The variation could also be influenced by other soil properties and environmental factors that control losses and accumulation of organic matter, such as soil texture, mineralogy and soil moisture [31, 19]. The observed variation of SOM in this study is smaller, compared to that reported in Brazilian ferralsols, which was about 60% [27]. The marked difference is probably due to the larger spatial scale considered in their study (regional scale). According to Wilding and Drees [32], SOM is one of the most variable soil properties, with a magnitude of variability that generally increases with increasing scale factor from pedons (< 10%) to polypedons (20-30%) to mapping units (30-70%). Detailed appreciation of spatial and temporal variability of soil properties usually necessitates the collection of numerous soil samples and measurements need to be repeated as conditions change or to determine if they are changing. Knowledge on spatial variations in soil physical and chemical properties has been used within humid tropical forests to understand the spatial distribution patterns of various tree species [24, 33]. Although our study presents results obtained at local scale, information on the variation in soil properties is very important in forest management, since such variability at the local scale has been reported to influence the abundance and distribution patterns of tree species within tropical forests [34].

3.3. Relationship among Soil Properties

Results of correlation analysis for Xanthic and Rhodic ferralsols are shown in Tables 4 and 5, respectively. Correlation coefficients (r), linear regression equations and coefficients of determinations (R^2) are presented in Tables 6 and 7 for Xanthic and Rhodic ferralsols, respectively. In both soil groups, some soil properties showed significant positive and negative correlations between one another. It was observed that physical and chemical properties correlated among themselves, but correlations were more observed between chemical properties. In Xanthic ferralsols, there was a significant positive correlation between % clay and exchangeable acidity, and between % sand and soil pH. In both soils, physical properties that correlated between each other were % clay and % silt. The correlation was more negative for Rhodic ferralsols, probably due to the lower CV % observed for % clay and % silt. The low silt content and the negative relationship between % clay and % silt are explained by the increased susceptibility to weathering of primary minerals when their particle size is reduced [35].

Table 4. Correlation matrix of Xanthic ferralsols

	$pH-H_2O$	pH-KCl	OC (%)	Ca^{2+} (meq /100g)	Mg^{2+} (meq /100g)	Exch. Acidity (meq/100g)	CEC (meq/100g)	ECEC (meq /100g)	BS (%)	Clay (%)	Silt (%)	Sand (%)
$pH-H_2O$												
pH-KCl	.693**											
OC (%)	.253	.005										
Ca^{2+} (meq/100g)	.083	.081	-.004									
Mg^{2+} (meq/100g)	.094	.058	.042	.466**								
Exch. Acidity (meq/100g)	-.285	-.224	-.004	-.088	.252							
CEC (meq/100g)	.058	.042	.263	.123	.183	.409*						
ECEC (meq/100g)	-.200	-.155	.003	.362*	.573**	.883**	.432**					
BS (%)	.089	.086	-.087	.862**	.652**	-.148	-.255	.298				
Clay (%)	-.268	-.014	-.133	-.089	-.110	.406*	-.023	.299	-.105			
Silt (%)	-.142	-.221	.197	.183	.061	-.164	.051	-.066	.168	-.321*		
Sand (%)	.358*	.185	-.030	-.060	.055	-.249	-.019	-.226	-.033	-.677**	-.480**	

* Correlations are significant at P < 0.05, ** Correlations are significant at P < 0.01

Table 5. Correlation matrix of Rhodic ferralsols

	$pH-H_2O$	pH-KCl	OC (%)	Ca^{2+} (meq /100g)	Mg^{2+} (meq /100g)	Exch. Acidity (meq/100g)	CEC (meq/100g)	ECEC (meq /100g)	BS (%)	Clay (%)	Silt (%)	Sand (%)
$pH-H_2O$												
pH-KCl	.783**											
OC (%)	.253	.268										
Ca^{2+} (meq/100g)	.674**	.740**	.270									
Mg^{2+} (meq/100g)	.189	-.039	.101	.349								
Exch. Acidity (meq/100g)	-.097	-.266	-.074	-.350	.245							
CEC (meq/100g)	.603*	.481	.120	.512*	.294	.089						
ECEC (meq/100g)	.257	.052	.087	.251	.753**	.750**	.386					
BS (%)	.376	.304	.216	.740**	.852**	-.070	.272	.590*				
Clay (%)	-.360	-.333	-.068	-.300	-.208	.189	-.373	-.056	-.240			
Silt (%)	.392	.227	-.047	.198	.097	.128	.270	.215	.111	-.601*		
Sand (%)	.080	.199	.127	.186	.166	-.351	.207	-.131	.192	-.671**	-.189	

* Correlations are significant at P < 0.05, ** Correlations are significant at P < 0.01

Table 6. Regression equations and coefficients of determination for related soil parameters of Xanthic ferralsols

Related Soil Parameters	Regression equations and coefficients of determinations (R^2)
CEC - Exch. Acidity	CEC = 1.001* Exch. Acidity + 2.430 ($R^2 = 0.167$, $p < 0.05$)
ECEC - Ca^{2+}	ECEC = 1.039 * Ca^{2+} + 4.169 ($R^2 = 0.130$, $p < 0.05$)
Clay - Exch. Acidity	% Clay = 7.676 *Exch. Acidity + 6.225 ($R^2 = 0.165$, $p < 0.05$)
Clay – Silt	% Silt = -0.268 * % Clay + 26.81 ($R^2 = 0.102$)
Sand – pH-H_2O	% Sand = 16.86 * pH-H_2O - 24.70 ($R^2 = 0.128$, $p < 0.05$)
BS, ECEC, Ca^{2+}, Mg^{2+}	BS = 7.57 – 1.63 * ECEC + 15.84 * Ca^{2+} + 16.48* Mg^{2+} ($R^2 = 0.85$, $p < 0.05$)

Table 7. Regression equations and coefficients of determination for related soil parameters of Rhodic ferralsols

Related Soil Parameters	Regression equations and coefficients of determinations (R^2)
CEC - pH-H_2O	CEC = 1.211 * pH-H_2O + 2.866 ($R^2 = 0.364$, $p < 0.05$)
CEC - Ca^{2+}	CEC = 1.814 * Ca^{2+} + 6.742 ($R^2 = 0.262$, $p < 0.05$)
BS - ECEC	BS = 4.633 * ECEC - 19.65 ($R^2 = 0.348$, $p< 0.05$)
Clay – Silt	Silt = -0.454 * % Clay + 38.17 ($R^2 = 0.361$, $p < 0.05$)
CEC, Ca^{2+} pH-H_2O, %clay, %silt,	CEC = 5.96 + 0.6 * pH - H_2O – 0.01* % Clay – 0.04 * % Silt + 1.74* Ca^{2+} ($R^2 = 0.57$, $p < 0.05$)
Exch. Acidity, Mg^{2+}, ECEC, BS	Exch. Acidity = 0.21 + 0.08 * Mg^{2+} + 0.97 * ECEC – 0.08 * BS ($R^2 = 0.96$, $p < 0.05$)

Linear relationships between % clay and % silt had low R^2 values (R^2 = 0,102 for Xanthic ferralsols and R^2 = 0,361 for Rhodic ferralsols). For all other linear relationships, R^2 values were low ($R^2 < 0.4$). The low R^2 values coupled to the small correlation coefficients (r = 0.32 – 0.61) give evidence of the heterogeneity of soil properties in both areas. However, the smaller correlation coefficients of Xanthic ferralsols (r = 0.32 – 0.4, $p < 0.05$) indicated that soil properties were more heterogeneous than those of Rhodic ferralsols (r = 0.51 – 0.60, $p < 0.05$). Because of this heterogeneity, soil parameters cannot readily be estimated from one another using simple linear relationships. Some studies have observed that the analytical methods used for soil analysis could significantly influence the relationship between two soil parameters [12]. In this respect, quality control of soil analytical data is necessary, whereby different analytical methods should be used to check the reliability of methods and quality of data obtained. Notwithstanding, multiple linear regressions among related soil properties yielded high coefficients of determinations ($R^2 > 0.5$) (Tables 6 and 7). The results showed that in Xanthic ferralsols, Base saturation can be estimated from ECEC, exchangeable Ca^{2+} and exchangeable Mg^{2+} ($R^2 = 0.85$ $p< 0.05$), and in Rhodic ferralsols, Exch. Acidity can conveniently be estimated from exchangeable Mg^{2+}, ECEC and BS ($R^2 = 0.96$; $p< 0.05$).

3.4. Sources of Variation in Soil Properties

Principal Component Analysis (PCA) yielded five principal components (PC) for Xanthic ferralsols and four principal components for Rhodic ferralsols. In Xanthic ferralsols, the communalities for soil attributes indicated that the five components explained more than 90% of the variance in BS, ECEC, % Clay and % Sand; 70 – 80% of the variance in pH-H_2O, pH-KCl, Ca^{2+}, Mg^{2+}, Exch. Acidity, CEC and % Silt; and less than 60% of the variance in OC (Table 8). The five PCs could explain a total of 80.04% of the variation in the area dominated by Xanthic ferralsols (Table 9), with PC1, PC2, PC3, PC4 and PC5 contributing 20.16%, 16.06%, 15.04%, 14.96% and 13.29% respectively. For Rhodic ferralsols, the communalities for soil attributes showed that four components explained more than 90% of the variance in Mg^{2+} and ECEC; 60 - 80% of the variance in pH-H_2O, pH-KCl, Ca^{2+}, Exch Acidity, BS, % Clay, % Silt, % Sand, and less than 50% of the variance in OC (Table 10). The four components could explain a total of 79.42% of the variation observed, with PC1, PC2, PC3, and PC4 contributing 23.26%, 21.08%, 18.87% and 16.23% respectively (Table 11). The total variance of 80.04% for Xanthic ferralsols against 79.42% for Rhodic ferralsols provides more evidence for the heterogeneity of soil properties in the area covered by Xanthic ferralsols.

For Xanthic ferralsols, PC1 had high and positive loadings on Ca^{2+} (0.86), Mg^{2+} (0.81) and BS (0.98); and a moderate positive loading on ECEC (0.59). Because of the high loadings of PC1 on Ca^{2+}, Mg^{2+} and BS, this component was named the base status factor. PC2 was named Organic matter/CEC factor because of the high and moderate positive loadings on OC (0.57) and CEC (0.83). PC3 was named soil acidity factor as it showed high positive loadings on pH-H_2O (0.88) and pH-KCl (0.89). PC4 was named soil texture factor because of the high positive loadings on %clay (0.91) and high negative loading on % sand (-0.89), and PC5 as acidity/texture factor.

For Rhodic ferralsols, PC1 was rather named soil acidity/texture factor because of the similarity in loadings with PC5 of Xanthic ferralsols. PC2 was called base status factor; PC3, organic matter factor and PC4, soil texture factor. In both areas, the main factors accounting for variation in soil properties are base status, soil acidity, soil texture and soil organic matter. These factors serve as important key indicators of forest soil quality. For example, SOM is considered as a key index of soil quality because of its importance as a regulator of soil chemical, biological, and physical properties [36].

Table 8. Rotated component matrix of principal components and communalities (Xanthic ferralsols)

Soil properties	Principal Components					Communalities
	1	2	3	4	5	
pH-H_2O			0.882			0.839
pH-KCl			0.899			0.822
OC		0.573				0.566
Ca^{2+}	0.861					0.785
Mg^{2+}	0.813					0.737
Exch. Acidity		0.526			0.555	0.873
CEC		0.827				0.703
ECEC	0.591					0.946
BS	0.918					0.962
Clay				0.906		0.930
Silt					-0.845	0.831
Sand				-0.894		0.984

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Coefficients with absolute values < 0.5 are suppressed.

Table 9. Variance explained by principal components (Xanthic ferralsols)

Component	Rotation Sums of Squared Loadings		
	Total	Variance %	Cumulative Variance %
1	2.690	20.691	20.691
2	2.088	16.064	36.755
3	1.955	15.036	51.790
4	1.945	14.960	66.751
5	1.727	13.288	80.039

Table 10. Rotated component matrix of principal components and communalities (Rhodic ferralsols)

Soil properties	Component				Communalities
	1	2	3	4	
pH-H_2O	0.829				0.817
pH-KCl	0.734				0.823
OC			0.675		0.466
Ca^{2+}	0.574		0.586		0.827
Mg^{2+}		0.940			0.926
Exch. Acidity		0.512		-0.662	0.817
CEC	0.684				0.560
ECEC		0.893			0.960
BS		0.750			0.879
Clay	-0.594			-0.619	0.857
Silt	0.739				0.676
Sand				0.906	0.844

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Coefficients with absolute values < 0.5 are suppressed.

Table 11. Variance explained by principal components (Rhodic ferralsols)

Component	Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %
1	3.024	23.261	23.261
2	2.741	21.084	44.346
3	2.453	18.866	63.212
4	2.107	16.205	79.417

Forest ecosystems obtain most of their nutrients from the decomposition of litter, branches, and other organic materials near the soil surface. Additionally, SOM contains a large number of exchange sites that increase the capacity of the soil to adsorb these nutrients and prevent them from leaching below the rooting zone [21, 36, 37]. Soil acidity (pH) is a primary factor in determining the productivity of the soil through its regulation of soil nutrient availability and microbial activity. Maps of soil pH in relation to texture and forest type provide baseline indices of the weathering status and potential nutrient holding capacity of soils [21]. As concerns the base status factor, concentrations of plant nutrients (Ca, Mg, Al etc.) provide insight into questions about stand productivity, growth, survival and mortality, and even in the context of climate change and forest dynamics, emphasis is laid on these soil characteristics for adaptive management and sustainable production since soils act as reliable predictors of forest health [38].

4. Conclusions

Xanthic and Rhodic ferralsols have characteristic morphological properties (soil colour) which could easily give an impression of homogeneity in soil properties at a local scale. Our study showed that at the local level, soil properties showed variability ranging from least variable to highly variable (15% > CV % > 35%). The soils were generally acidic, low in exchangeable bases and organic matter, had high exchangeable acidity and low cation exchange capacity. Between Rhodic and Xanthic ferralsols, there were significant differences in some soil properties. Although many soil properties showed significant correlation between one another, correlation coefficients were generally low ($r < 0.5$, $p<0.05$) and linear regression equations yielded very low coefficients of determinations ($R^2 = 0.32 – 0.61$, $p < 0.05$), indicating the consideration to be given to detailed soil sampling and analysis for individual soil units. Also, the relatively small number of sampling points does not present a complete picture of the results obtained. Thus, detailed soil maps are imperative for a better understanding of soil properties and their spatial distributions within forest milieu. Principal component analysis (PCA) explained up to 80.0% of the variation in soil properties of Xanthic ferralsols and about 79% of the variation observed in Rhodic ferralsols. PCA provided some key indicators of soil quality that should be considered in soil management, which are: soil texture, soil acidity, base status and soil organic matter. We recommend the characterization and mapping of soil properties at larger spatial scales, including the use of different soil analytical techniques for the sake of quality control of soil data. Detailed soil maps will be of great use in site selection and reforestation of particular tree species.

ACKNOWLEDGEMENTS

This reseach was funded by the International Tropical Timber Organisation (ITTO/CITES) through the National Agency for Support to Forestry Development (ANAFOR), under project N°: 0737/CS/ANAFOR/DG/DT/CA Assamela-FP.

REFERENCES

[1] Soil Survey Staff, NRCS, USDA. 2010. Keys to Soil Taxonomy. 11th edition. Washington DC, USA.

[2] Beinroth, F.H., Eswaran, H., Palmieri, F., Reich, P.F. 1996. Properties, Classification, and Management of Oxisols. Soil Management Collaborative Research Support Program. Pp. 174. Washington DC, USA.

[3] Yerima, B.P.K., Van Ranst, E. 2005b. Major Soil Classification Systems used in the Tropics: Soils of Cameroon. Trafford Publishing, Canada.

[4] Tematio, P., Kengni, L., Bitom, D., Hodson, M., Fopoussi, J.C., Leumbe, O., Mpakam, H.G., Tsozué, D. 2004. Soils and their distribution in Bambouto volcanic mountain, West-Cameroon Highland, Central Africa. Journal of African Earth Sciences, 39,447-457.

[5] Yerima, B.P.K., Van Ranst, E. 2005a. Introduction to Soil Science: Soils of the Tropics. Trafford Publishing, Canada.

[6] Hahm, W. J., Riebe, C.S., Lukens, C.E., Araki, S. 2014. Bedrock composition regulates mountain ecosystems and landscape evolution. Environmental sciences, 111(9), 3338–3343. www.pnas.org/cgi/doi/10.1073/pnas.1315667111.

[7] Amani, A.C., Vleminckx, J., de la Thibauderie, T.D., Lejoly, J., Meerts, P., Hardy, O.J. 2013. Species Responses to Edaphic Heterogeneity in Semi-Deciduous Forests from the Congo Basin. Greener J. Bio. Sci., 3 (10): 365-374.

[8] Khairil, M., Wan Juliana, W.A., Nizam, M.S. 2014. Edaphic Influences on Tree Species Composition and Community Structure in a Tropical Watershed Forest in Peninsular Malaysia. Journal of Tropical Forest Science, 26(2), 284–294.

[9] Eglin, T., Manuel, M., Damien, M., Manuel, N., Perrier, C., Buitrago, M., Landmann, G. 2014. Collecting and using data on forestsoils. Revue forestière française. 4-2014. Available : http://documents.irevues.inist.fr/.

[10] Page-Dumroese, D., Jurgensen, M., Elliot, W., Rice T., Nesserc, J., Collins, T., Meurisse, R. 2000. Soil quality standards and guidelines for forest sustainability in northwestern North America. Forest Ecology and Management, 138, 445 - 462.

[11] Moffat, A.J. 2003. Indicators of soil quality for UK Forestry. Forestry, 76(5), 548-568.

[12] Yerima, B.P.K., Van Ranst, E., Verdoodt, A. 2009. Use of Correlation Relationships to Enhance Understanding of Pedogenic Processes and Use Potential of Vertisols and Vertic Inceptisols of the Bale Mountain Area of Ethiopia. TROPICULTURA, 27(4), 223-232.

[13] Hijmans, RJ., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A. 2005. Very high resolution interpolated climate surfaces for global land areas. Int. J. Climatol., 25, 1965–1978.

[14] Ouédraogo, D.Y., Fayolle, A., Daïnou, K., Demaret, C., Bourland, N., Lagoute, P., Doucet, J.L. 2014. Enrichment of Logging Gaps with a High Conservation Value Species (*Pericopsis elata*) in a Central African Moist Forest. Forests, 5(12), 3031-3047. doi:10.3390/f5123031.

[15] Frontier Cambodia. 2003. Forest Biodiversity Methodology Manual. Frontier Cambodia Environmental Research Report 2. Society for Environmental Exploration, UK.

[16] Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analysis of soil. Agronomy Journal, 54, 464 – 465.

[17] Pauwels, J.M., Van Ranst, E., Verloo, M., Mvondo Ze, A.D. 1992. Manuel de laboratoire de pédologie. Méthodes d'analyses des sols et des plantes, équipement, gestion de stocks de verrerie et de produits chimiques [Soil Science laboratory manual. Methods of soil and plant analysis, equipment, management of glassware and chemicals]. Publications Agricoles No. 28, AGCD: Bruxelles, Belgium.

[18] Dipak, S., Abhijit, H. 2005. Physical and Chemical Methods in Soil Analysis. New Age International Limited Publishers. Daryaganj, New Delhi, India.

[19] Rizwan, M., Siddique, M.T., Ahmed, H., Iqbal, M., Ziad, T. 2016. Spatial variability of selected physico-chemical properties and macronutrients in the shale and sandstone derived soils. Soil Environ., 35(1), 12-21.

[20] SPSS Statistics. 2010. IBM SPSS Advanced Statistics 19. Available: http://www.spss.com/worldwide.

[21] O'Neill, K.P., Amacher, M.C., Perry, C.H. 2005. Soils as an Indicator of Forest Health: A Guide to the Collection, Analysis, and Interpretation of Soil Indicator Data in the Forest Inventory and Analysis Program. Gen. Tech. Rep. NC-258. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station.

[22] Quesada, C.A., Lloyd, J., Schwarz, M., Patino, S., Baker, T.R., Czimczik, C., Fyllas, N.M., Martinelli, L., Nardoto, G.B., Schmerler, J., Santos, A.J.B., Hodnett, M.G. et al. 2010. Variations in chemical and physical properties of Amazon forest soils in relation to their genesis. Biogeo- sciences, 7, 1515–1541. doi:10.5194/bg-7-1515-2010.

[23] Anderson, J.M., Swift, M.J. 1983. Decomposition in tropical forests. In: Sutton, S.L., Whitmore, T.C., Chadwick, A.C. (editors). 1983. Tropical Rain Forest: Ecology and Management. Blackwell Science, Oxford, England.

[24] Silver, W.L., Scatena, F.N., Johnson, A.H., Siccama, T.G., Sanchez, M.J. 1994. Nutrient availability in a montane wet tropical forest: Spatial patterns and methodological

considerations. Plant and Soil, 164, 129 – 145.

[25] Sollins, P. 1998. Factors influencing species composition in tropical lowland forest: Does soil matter? Ecology, 79(1), 23-30.

[26] Silver, W.L., Neff, J., McGroddy, M., Veldkamp, E., Keller, M., Cosme, R. 2000. Effects of soil texture on belowground carbon and nutrient storage in a lowland Amazonian forest ecosystem. Ecosystems, 3, 193-209. doi: 10.1007/s100210000019.

[27] Bernoux, M., Arrouays, D., Cerri, C., Volkoff, B., Jolivet, C. 1998. Bulk Densities of Brazilian Amazon Soils Related to other Soil Properties. Soil Science Society of America Journal, 62 (3), 743-749.

[28] Jenny, H. 1980. The Soil Resource: Origin and behavior. 4th ed. Springer-Verlag, New York. USA.

[29] Cambardella, C.A., Moorman, T.B., Parkin, T.B., Karlen, D.L., Novak, J.M., Turco, R.F., Konopka, A.E. 1994. Field-scale variability of soil properties in Central Iowa soils. Soil Science Society of America Journal, 58, 1501-1511.

[30] Londo, A.J., Kushla, J.D., Carter, R.C. 2006. Soil pH and Tree Species Suitability in the South. Southern Regional Extension Forestry Bulletin, SREF-FM-002, January 2006.

[31] Lal, R. 2015. Restoring Soil Quality to Mitigate Soil Degradation. Sustainability, 7, 5875-5895. Doi:10.3390/su7055875.

[32] Wilding, L.P., Drees, L.R. 1983. Spatial variability in pedology. p. 83-116. In Wilding, L.P. et al. (ed.) Pedogenesis and soil taxonomy. I - Concepts and interactions. Elsevier, New York, USA.

[33] Toledo, M., Pena, C.M., Bongers, F., Alarcon, A., Balcazar, J., Chuvina, J., Leano, C., Licona, J.C., Poorter, L. 2012. Distribution patterns of tropical woody species in response to climatic and edaphic gradients. J. Ecology. 100, 253–263.

[34] Hall, J.S., McKenna, .J.J., Ashton, P.M., Gregoire, T.G. 2004. Habitat characterizations underestimate the role of edaphic factors controlling the distribution of *Endandrophragma*. Ecology, 85(8), 2171-2183.

[35] Van Wambeke, A., Eswaran, H., Herbillon, A.J., Comera, J. 1983. In: Wilding, L.P., Smeek, N.E., Hall, G.F. (editors), Pedogenesis and Soil Taxonotny. The Soil Orders, 11, 325-354. Elsevier, Amsterdam.

[36] Grigal, D.F., Vance, E.D. 2000. Influence of Soil Organic Matter on Forest Productivity. New Zealand J. For. Sci., 30 (1/2), 169-205.

[37] Lal, R. 1995. Forest soils and carbon sequestration. Forest Ecology and Management, 220, 242–258. doi:10.1016/j.foreco.2005.08.015.

[38] Peterman, W., Bachelet, D. 2012. Climate Change and Forest Dynamics: A Soils Perspective. In: Soils and Food Security. Hester, R.E., Harrison, R.M (editors). Issues in Environmental Science and Technology, 35, 158 – 182.