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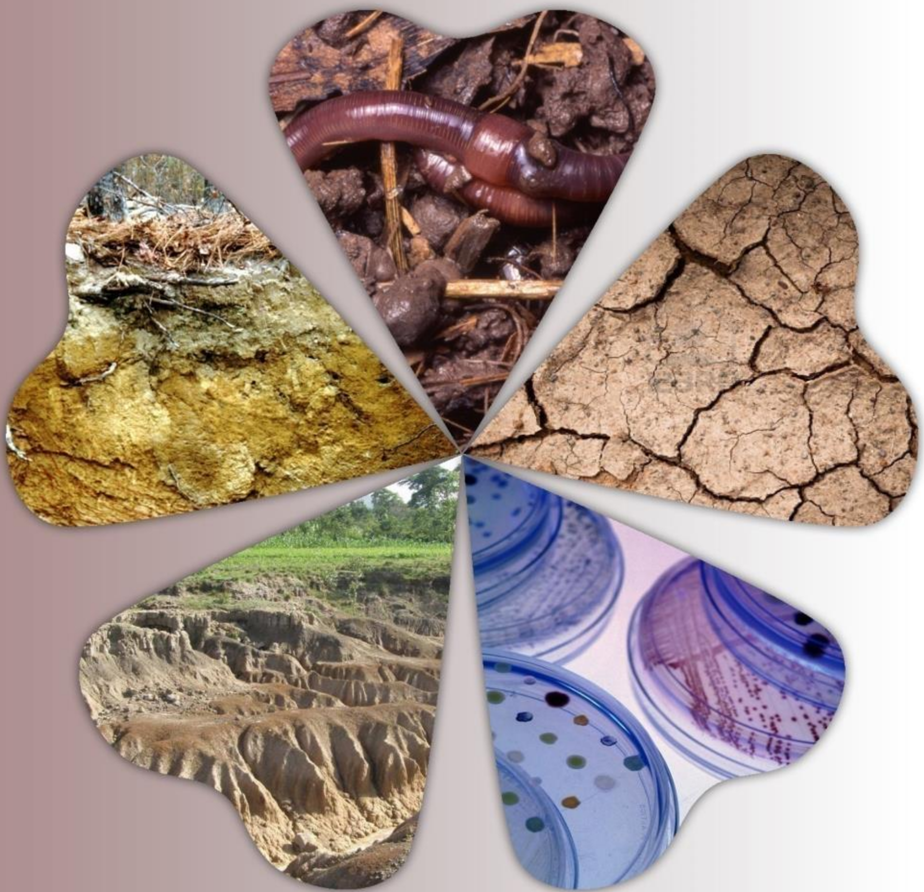

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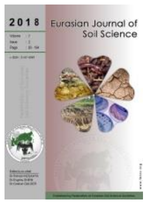

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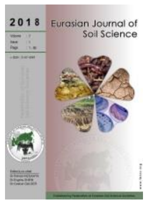

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Spatial and fractal characterization of soil properties across soil depth in an agricultural field, Northeast Iran

Ali Keshavarzi [a,*], Henry Oppong Tuffour [b], Ali Bagherzadeh [c], Duraisamy Vasu [d]

[a] Laboratory of Remote Sensing and GIS, Department of Soil Science, University of Tehran, Karaj, Iran
[b] Department of Crop and Soil Sciences, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana
[c] Department of Agriculture, Islamic Azad University, Mashhad Branch, Mashhad, Iran
[d] Division of Soil Resource Studies, ICAR-National Bureau of Soil Survey and Land Use Planning, Nagpur, Maharashtra, India

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Abstract

The present study was conducted to explore the fractal behavior and establish fractal dimensions of soil physical and chemical properties (i.e., sand, silt, and clay contents, bulk density, degree of moisture saturation, pH, organic carbon content, total nitrogen, available phosphorus, and available potassium) to characterize their spatial patterns. Soil samples were collected from 0-30 (surface) and 30-60 cm (subsurface) depths from an agricultural field, Mashhad Plain, Northeast Iran. Descriptive statistics and fractal analysis were used to describe the extent and form of variability. Spatial patterns of the soil properties were estimated using GS+ 10.0 software. Soil properties showed low to high variations in both surface and subsurface layers across the field, where bulk density and pH being the most reliable soil physical and chemical properties in the study area. The variability was high (CV > 35%) for total N, available P, available K and organic carbon in both surface and subsurface soils and it could be attributed to management practices and micro-topographical variations as these are the dynamic properties of soil. The fractal dimension (D) values of soil physical properties ranged from 1.398 to 1.913 at the surface, and from 1.874 to 1.934 at the subsurface indicating both short and long range variations. The D values for the chemical properties ranged from 1.331 to 1.975, and 1.148 to 1.990 in the surface and subsurface layers, respectively. The results showed that fractal analysis could be employed to effectively describe the structure of soil heterogeneity in spatial scale for effective agricultural and environmental management of soil.

Keywords: Fractal dimension, Hurst exponent, Spatial variability, Self-similarity, Semivariogram.

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Introduction

Soil covers land as a continuum having properties that vary enormously and continuously with depth and horizontal distances (Gessler et al., 2000). This variability is reflected in soil test results and variations in crop yields (Tuffour, 2015). These variations are largely the results of various factors and processes of soil formation, and management, functioning independently or in combination over broad spatial and temporal scales with different intensities (Beckett and Webster 1971; Burrough, 1983a,b; Tuffour, 2015). The spatial variation of soil properties such as organic matter, clay content, pH and water retention capacity is caused by pedogenic processes which are influenced by hydrological and temperature regimes modified by topography (Pilesjő et al., 2005; Florinsky, 2012; Vasu et al., 2017a). The source of these variations, which

* Corresponding author.
Laboratory of Remote Sensing and GIS, Department of Soil Science, University of Tehran, Karaj 31587-77871, Iran
Tel.: +98 26 32231787 E-mail address: alikeshavarzi@ut.ac.ir
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hitherto recognized as a nuisance, has received widespread recognition among researchers in recent times (Bengough et al., 2000; Linsenmeier et al., 2011; Tuffour, 2015; Miloš and Bensa, 2017; Vasu et al., 2017a).

Knowledge on the spatial distribution of soil properties at different scales is a prerequisite for site specific soil management and minimizes the negative effects of management practices on environmental quality (Cambardella et al., 1994; Bogunovic et al., 2014). In recent past, GPS (Global Positioning System), GIS (Geographical Information System) and geostatistics have played a very significant role in the study of spatial variability of soil properties (Vasu et al., 2017b). Geostatistical tools incorporate the spatial coordinates of soil observations in data processing, facilitate description and modelling of spatial patterns, predict values for unsampled locations and validates these predictions (Goovaerts, 1998). Because of these advantages, geostatistical techniques have been widely employed by researchers to address the heterogeneity in soil properties and processes in space under different environmental conditions (Wang and Shao, 2011; Tuffour et al., 2013, 2016; Kooch et al., 2014). The structure of spatial variation is vital to decide the magnitude of variability and that can be assessed by semivariograms which indicate the spatial correlation in values measured at sample locations (Vasu et al., 2017b). The spatial patterns are described in terms of dissimilarity between samples as a function of separation distance (Goovaerts, 1998). The average dissimilarity between data is separated by a vector and is measured by the semivariogram. However, anomalies in soil data and their deviation from normal (Gaussian) or log-normal distribution need to recognized for identification, accurate delineation, and modeling of soil properties for site specific soil management and precision agriculture (Fu et al., 2010; Bogunovic et al., 2014; Vasu et al., 2017a).

Soil particles were assumed to have "self-similar" features, and fractal theories were employed to investigate their characteristics in several studies (e.g., Oleschko et al., 2008; Tuffour, 2015; Li et al., 2016; Miloš and Bensa, 2017). For example, fractal dimensions of particle size distribution (PSD) were found to be influenced by land use and management practices (Wang et al., 2008). For newly formed wetlands in Yellow river delta, the fractal dimension values (D) of PSD varied from 1.82 to 1.90 indicating coarse texture (Yu et al. 2015). Therefore, the objective of this study was to investigate the fractal behavior and establish fractal dimensions of soil physical and chemical properties to characterize their spatial patterns.

Material and Methods

Study area

The study site is located in Mashhad Plain, Khorasan-e-Razavi Province, Northeast Iran with an area of 6131 km^2 (Figure 1). The region is located between latitudes 35° 59′ N to 37° 04′ N and longitudes 58° 22′ E to 60° 07′ E. The elevation of the study area ranges from 900 to 1500 m a.s.l., while the elevation of surrounding areas is up to ~1200 m a.s.l. The study area is characterized by semi-arid climate with mean annual precipitation of 222.1 mm and mean annual temperature of 15.8°C (Keshavarzi et al., 2016). The major soil types include Calcaric Cambisols, Gypsic Regosols, Calcaric Regosols and Calcaric Fluvisols occurring in pediment plains, plateau, upper terraces and gravelly colluvial fans, respectively. Soil texture varied from loam, to sandy loam to sandy clay loam. The main land use in the study area is irrigated farming.

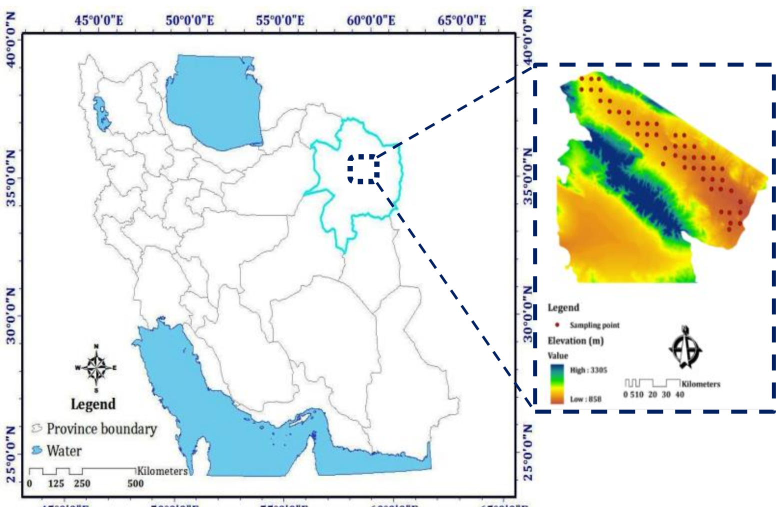

Figure 1. Location and geographical position of the study area

Soil sampling and laboratory analyses

A Digital Elevation Model (DEM) with 10×10 m grid size was extracted from a paper-based topographic map (1:25000 scale) using GIS platform and 10-meter contour lines interval. Vasu et al. (2016) established the importance of subsurface soil properties in evaluation of soil quality, spatial variability and their management. Disturbed and undisturbed samples were collected from surface (0-30 cm) and subsurface (30-60 cm) of 48 representative soil profiles (96 samples) by stratified random sampling technique. The sampling points were designed to represent all the major soil and land use types. Large plant materials and pebbles in the samples were separated by hand and discarded. Collected soil samples were air dried, crushed and sieved by using 2 mm sieve size before laboratory analysis. Soil organic carbon (SOC) content was determined by the Walkley and Black method (Walkley and Black, 1934) with dichromate extraction and titrimetric quantization (Nelson and Sommers, 1986). Percentages of clay (< 0.002 mm), silt (0.002–0.05 mm), and sand (0.05–2 mm) particles were measured by hydrometer method (Gee and Bauder, 1986). Soil moisture content based on the degree of saturation (DS) and bulk density (BD) (Blake and Hartge, 1986; Gardner, 1986) were also determined. Soil reaction (pH) was measured in saturated paste extract using a digital pH-meter (Thomas, 1996). Total N, Olsen P (available phosphorus) and available potassium were measured using standard procedures (Sparks et al., 1996).

Data analyses

Descriptive statistics

Measured variables in the data set were analyzed using descriptive statistics including the minimum, maximum, mean, coefficient of variation (CV), skewness and kurtosis. The CV values were classified according to Wilding (1985). Due to the presence of small variations that could result in chance fluctuations in the skewness and kurtosis (Tuffour et al., 2013, 2016), the frequency distribution was validated using the Watson normality test.

Fractal analysis

Fractal dimension (D) was estimated from the slope of log-log semivariogram. Semivariogram analysis was conducted to ascertain the spatial structure of the soil properties using GS+ (Geostatistics for environmental science; Gamma Design, Plainwell, Mich.) 10.0 software. Isotropy and anisotropy of the semivariograms were determined in four directions (i.e., 0°, 45°, 90° and 135°) with a tolerance of 22.5°, and the structure of spatial variance between observations was calculated from the semivariogram defined by the equation (Gupta et al., 2003; Tuffour, 2015):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i - Z(x_i + h)]^2 \qquad (1)$$

where,

$\gamma(h)$ is the semi-variance for separate distance class h, $N(h)$ is the number of sample pairs at each distance interval h, $Z(x_i)$ is the value of the variable Z at sampled location x_i and $Z(x_i + h)$ is the value of the variable Z at a distance h away from x_i (Lark, 2000).

The fractal dimensions (D) were estimated from the slopes of log-log semivariograms as (Tuffour, 2015):

$$D = 2 - \frac{m}{2} \qquad (2)$$

where:
D = Fractal dimension (Hausdorff-Besicovitch statistic), between 1 and 2
m = Slope of the log-log semivariogram plot
To measure the smoothness of the measured data sets, the Hurst exponent (H) was estimated from D as follows (Tuffour, 2015):

$$H = 2 - D \qquad (3)$$

where:
$0 \leq H \leq 1$; The closer the value of H to 0, the more random will be the distribution of the property.

Results and Discussion

Descriptive statistics for soil properties

Soils in the study area were predominantly Aridisols, with a few patches of Entisols. The descriptive statistics of the analyzed soil properties are presented in Tables 1.1 and 1.2. The variability was interpreted using the coefficient of variation (CV). The results indicate that the CVs varied from 1.47 to 91.49%. The criteria proposed by Wilding (1985) was used to classify the parameters into most (CV >35%), moderate (CV 15-35%) and least (CV <15%) variable classes. Accordingly, the variability was high (CV >35%) for total N, available P, available K and organic carbon in both surface and subsurface soils and it could be attributed to management practices and micro-topographical variations as these are the dynamic properties of soil (Vasu et al., 2016). Clay is an intrinsic soil property whose depth distribution is influenced by parent material, topography and hydraulic conductivity. In the present study, clay varied moderately in surface soils (CV=33.43%) but found to be high in variability in subsurface soils (CV=41.02%). Bulk density and pH were low in variability in both surface and subsurface soils (Tables 1.1, 1.2). Similarly, Tuffour et al. (2016) observed low variability for BD in the 0-20 and 20-40 cm depth of an Acrisol.

Table 1.1. Descriptive statistics for soil physical features in study site

Soil property	Depth	Descriptive statistics						
	(cm)	Min.	Max.	Mean	CV (%)	Skew.	Kurt.	Normality
Sand (%)	0-30	14.00	64.00	32.12	32.14[b]	0.85	1.29	0.14
	30-60	13.00	73.00	32.92	34.55[b]	1.35	3.050	NS
Silt (%)	0-30	26.00	64.00	49.60	16.30[b]	-0.84	0.71	0.14
	30-60	19.00	66.00	47.17	18.96[b]	-0.67	1.22	NS
Clay (%)	0-30	4.00	32.00	18.27	33.43[b]	0.21	-0.49	NS
	30-60	4.00	41.00	19.92	41.02[a]	0.45	-0.051	NS
BD (g/cm^3)	0-30	1.28	1.47	1.39	3.55[c]	-0.44	-0.49	NS
	30-60	1.43	1.65	1.55	3.66[c]	-0.34	-0.44	NS
DS (%)	0-30	21.80	50.40	36.21	17.20[b]	0.20	0.15	NS
	30-60	18.30	56.10	37.83	19.86[b]	-0.025	0.47	NS

Kurt. = Kurtosis; Skew. = Skewness Min. = Minimum parameter value; Max. = Maximum parameter value;
CV = Coefficient of Variation (a, b, c = very high, moderate and weak variations, respectively); BD = Bulk Density;
DS = Degree of Saturation; NS = Not Significant.

The moderate variability observed for DS in both layers was due to the influence of both static (topography and soil properties) and dynamic (precipitation and soil moisture content) properties of the study area, which causes variation in soil moisture patterns (Western et al., 2004; Mapfumo et al., 2006; Tuffour et al., 2016). The observed variability in the soil physical properties considered in this study, viz., BD, DS and particle size distribution have important implications on infiltration rate, and runoff/erosion processes. They could have severe impacts on the variability soil-plant-water relationships, and on crop growth (Tuffour et al., 2016).

Table 1.2. Descriptive statistics for soil chemical properties in study site

Soil property	Depth	Descriptive statistics						
	(cm)	Min.	Max.	Mean	CV (%)	Skew.	Kurt.	Normality
Total N (%)	0-30	0.006	0.20	0.089	44.49[a]	0.69	0.93	NS
	30-60	0.004	0.203	0.0679	65.50[a]	1.083	1.093	0.1286
Olsen P (mg/kg)	0-30	1.60	30.40	10.16	73.55a	1.32	0.79	NS
	30-60	1.20	32.80	5.63	91.79[a]	3.56	14.90	NS
Available K (mg/kg)	0-30	92.62	525.50	239.60	38.11[a]	0.66	0.69	NS
	30-60	53.98	525.50	194.30	46.14[a]	0.88	2.079	NS
OC (%)	0-30	0.13	1.61	0.55	51.14[a]	1.72	3.56	NS
	30-60	0.11	1.58	0.43	57.35[a]	2.34	7.94	NS
pH	0-30	7.70	8.30	8.085	1.59[c]	-0.93	0.72	NS
	30-60	7.90	8.40	8.11	1.47[c]	0.36	0.050	NS

NS = Not significant; Kurt. = Kurtosis; Skew. = Skewness; Min. = Minimum parameter value; Max. = Maximum parameter value; CV = Coefficient of Variation (a, b, c = very high, moderate and weak variations, respectively).

The mean values of sand, clay, BD and DS were higher in the subsurface layers than the surface layers but mean silt content was higher in the surface layer than in the subsurface layer. The high heterogeneity observed for the primary soil particles (i.e., from moderate to high) in both depths could be attributed to land use and soil management in the study area (Tuffour et al., 2016).

Skewness, kurtosis and the Watson normality test results indicated that only sand and silt contents in the surface layer and total N in subsurface layer followed normal distribution. The mean values show high contents of N, P, and K in the surface layer than the subsurface layer. However, OC was higher in the surface than the subsurface layer. The high N, P and K contents observed in the subsurface layer can be attributed to leaching as evidenced by the high degree of moisture saturation in the subsurface layer than the surface layer (Table 1.1), which suggests high water transmission and infiltration rate of the soils studied. The high OC content in the surface layer, however, could have resulted from the accumulation of organic residues from different sources with different compositions and rates of decomposition, and the differential growth behavior of crops in the field (Santra et al., 2008; Tuffour et al., 2013). Similarly, studies by Camacho-Tamayo et al. (2008), Balasundram et al. (2009) and Tuffour et al. (2013) also reported high OC content in the soil surface than the subsurface layer.

Soil pH was not significantly different among the soil layers, however, it was slightly higher in the subsurface than the surface layer. Soil pH in both soil layers showed a more consistent pattern than other properties which was evident from the low CVs (Table 1.2). This low variation in pH could be attributed to the sampling distance adopted in this study, since soil pH has been reported to show higher variations at scales of centimeters than at meters (Göttlein and Stanjek, 1996; Tuffour et al., 2013). However, relatively higher variability of pH in the surface layer than the subsurface layer could be the result of soil management practices, such as tillage and fertilizer application (Huang et al., 1999), seasonal fluctuations in soil moisture, temperature, microbial activity, plant growth and parent materials of the soil in the study area (Tuffour et al., 2013).

Fractal characterization of soil physical and chemical properties

The fractal dimensions (D) determined from the slope obtained by plotting the semivariance against the sample spacing (distance) (Figures 2.1–2.10) were used to describe the spatial variability of the soil properties. The Hurst exponents (H) estimated from Equation (3) are presented for various depths in Table 2. The values of D ranged from 1.398 to 1.934 for the physical properties, and 1.148 to 1.990 for the chemical properties. The range of H for the physical properties was between 0.066 and 0.602, and 0.01 and 0.852 for the chemical properties.

Table 2. Summary of fractal analysis of soil physical and chemical properties in the field

Soil property	Depth (cm)	Fractal parameter	
		D	H
Sand (%)	0-30	1.913	0.087
	30-60	1.934	0.066
Silt (%)	0-30	1.878	0.122
	30-60	1.899	0.101
Clay (%)	0-30	1.841	0.159
	30-60	1.881	0.119
Bulk Density (g/cm^3)	0-30	1.870	0.13
	30-60	1.874	0.126
Degree of Saturation (%)	0-30	1.398	0.602
	30-60	1.876	0.124
Total Nitrogen (%)	0-30	1.947	0.053
	30-60	1.584	0.416
Olsen Phosphorus (mg/kg)	0-30	1.524	0.476
	30-60	1.746	0.254
Available Potassium (mg/kg)	0-30	1.914	0.086
	30-60	1.990	0.01
Organic Carbon (%)	0-30	1.331	0.669
	30-60	1.148	0.852
pH	0-30	1.975	0.025
	30-60	1.858	0.142

D = Fractal dimension; H = Hurst exponent

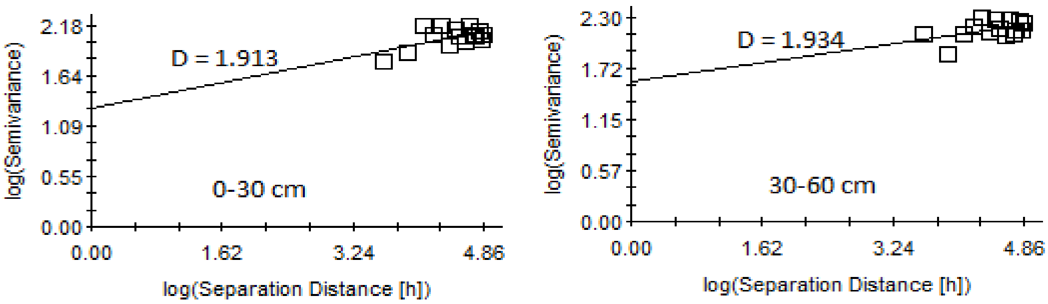

Figure 2.1. Log-log plot of isotropic variograms with fractal dimension (D) for sand content

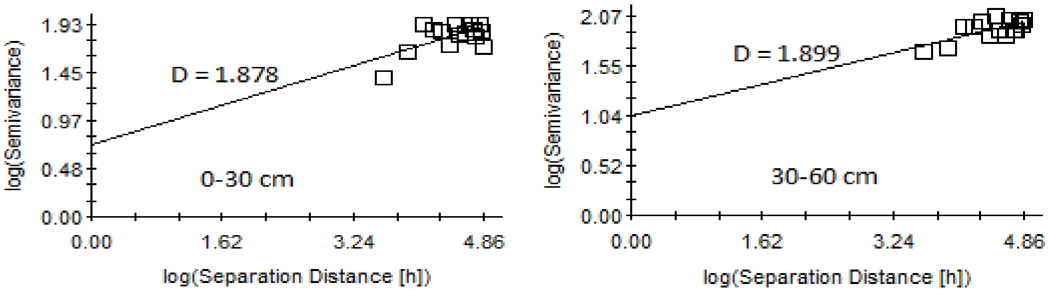

Figure 2.2. Log-log plot of isotropic variograms with fractal dimension (D) for silt content

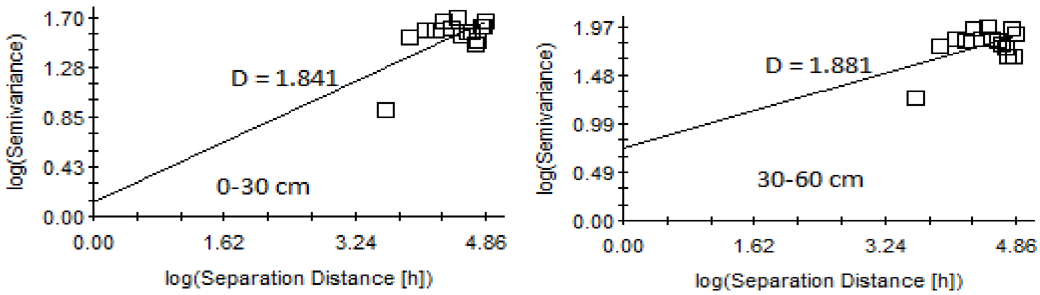

Figure 2.3. Log-log plot of isotropic variograms with fractal dimension (D) for clay content

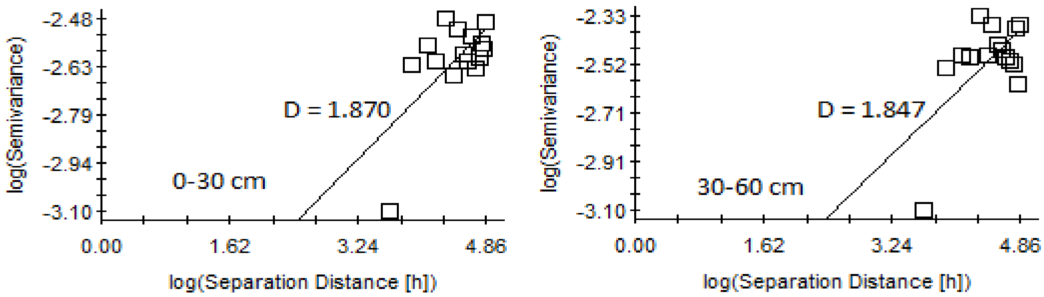

Figure 2.4. Log-log plot of isotropic variograms with fractal dimension (D) for bulk density

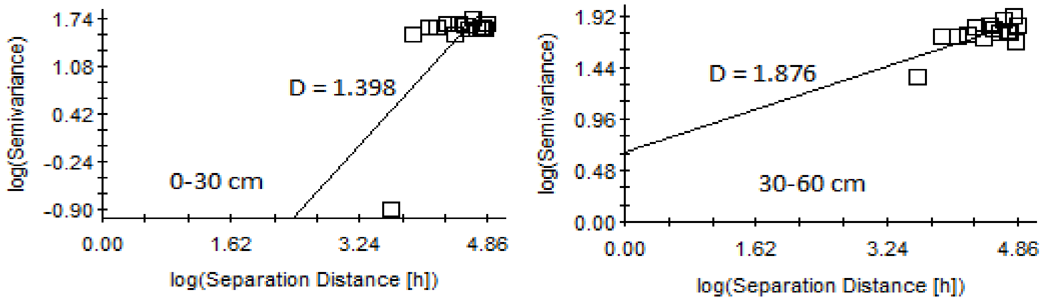

Figure 2.5. Log-log plot of isotropic variograms with fractal dimension (D) for degree of saturation

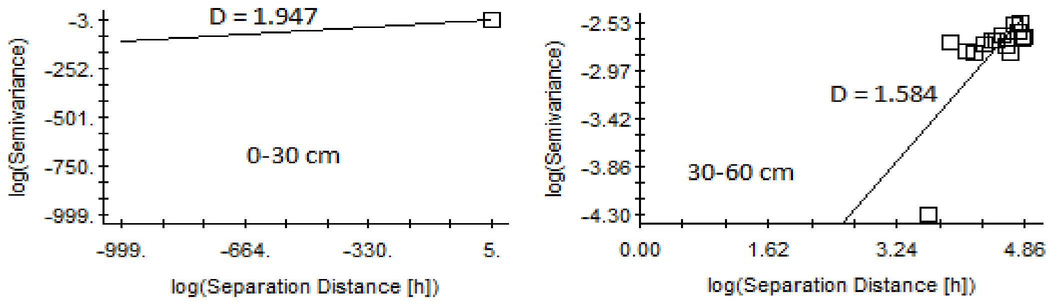

Figure 2.6. Log-log plot of isotropic variograms with fractal dimension (D) for total nitrogen

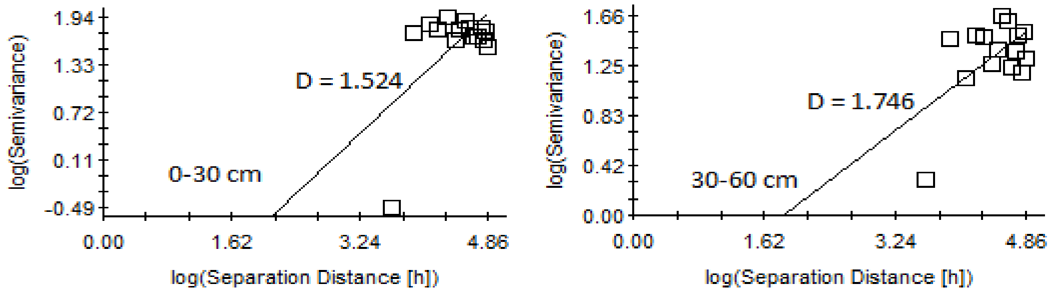

Figure 2.7. Log-log plot of isotropic variograms with fractal dimension (D) for Olsen phosphorus

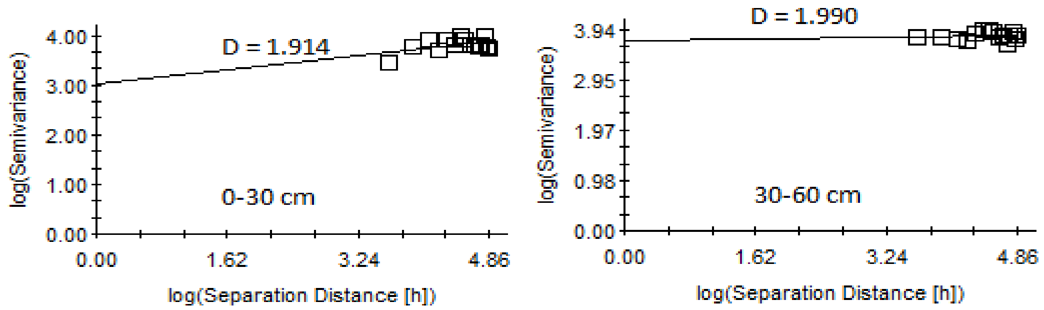

Figure 2.8. Log-log plot of isotropic variograms with fractal dimension (D) for available potassium

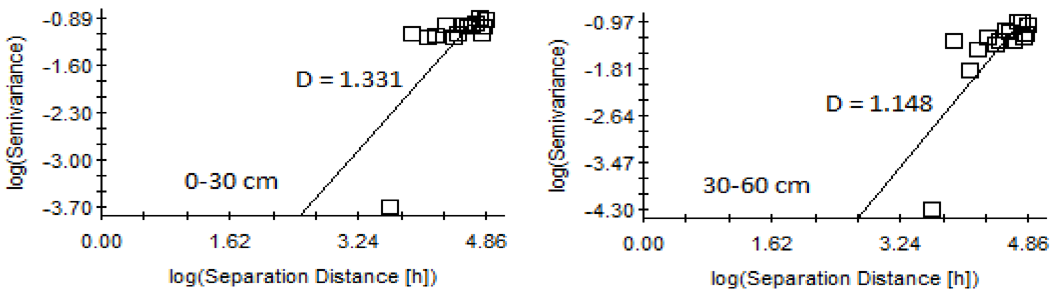

Figure 2.9. Log-log plot of isotropic variograms with fractal dimension (D) for soil organic carbon

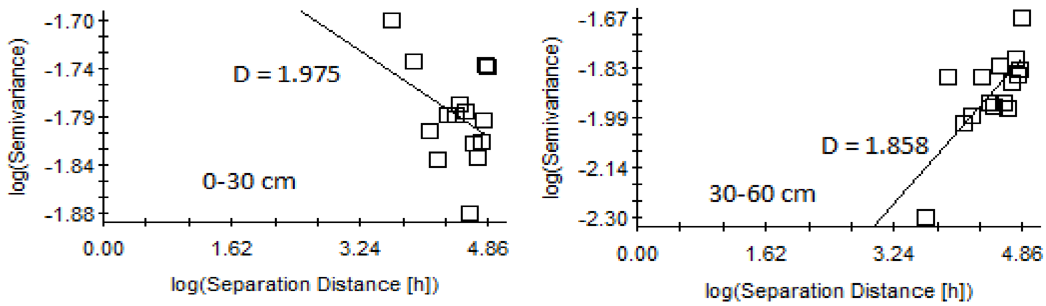

Figure 2.10. Log-log plot of isotropic variograms with fractal dimension (D) for soil pH

The results obtained for D revealed that the soil properties show fractal behavior, wherein, lower the value of D, longer the range of variation, and vice versa (Vieira et al., 2010; Tuffour, 2015). Based on the scaling properties of fractional Brownian motion reported by Sugihara and May (1990) and Tuffour (2015), H values > 0.5 represent smooth or persistent nature of the soil property, whereas, H < 0.5 represents anti-persistent nature. Liao et al. (2017) successfully employed fractal analysis to investigate the spatio-temporal variability of soil moisture content in contrasting land uses. The above studies showed that fractal dimension can be used for assessing the spatial distribution of soil properties at different scales. Mohammadi et al. (2017) analyzed spatial variability of soil textural fractions and fractal parameters derived from Particle Size Distributions (PSD). In this research, fractal features of particle size distribution of soil samples were studied using fractal geometry and then the geostatistics approach was applied to characterize the spatial variability of fractal and soil textural parameters. According to the semivariogram models and validation parameters applied to the models, it was found that the fractal parameters had powerful spatial structure and could better describe the spatial variability of soil texture. The results of the present study (Table 2) showed that the nature of the distribution of the soil properties ranged from smooth (persistent) to rough (anti-persistent). For instance, DS in the surface layer with D and H values of 1.398 and 0.602, respectively implies a long range variation and a more persistent nature than in the subsurface layer (D = 1.876 and H = 0.124), wherein it would exhibit a short range variation and an anti-persistent nature. Furthermore, with the exception of DS in the surface layer (H = 0.602), and OC in both the surface and subsurface layers (H = 0.669 and 0.852, respectively), all the soil properties were anti-persistent in nature across the study area.

Conclusion

In this study, classical and fractal methods were applied to reveal and describe the spatial variability of soil properties (i.e., sand, silt, and clay contents, bulk density, degree of moisture saturation, pH, organic carbon content, total nitrogen, available phosphorus, and available potassium) in an agricultural field, Northeast Iran using fractal parameters (fractal dimension and Hurst exponent). Comparing the results of the descriptive statistics and fractal analysis, revealed that the selected soil properties in the study area exhibit short to long range variations at the local scale. The results also showed that fractal characterization is an applicable technique for describing the spatial patterns of soil properties.

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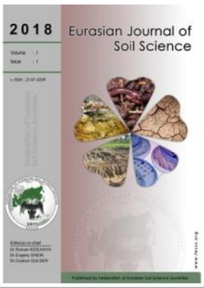

Soil carbon, nitrogen and texture dynamics at root zone and between plants in Riverine plantation of *Acacia catechu, Dalbergia sissoo, Phyllanthus emblica* and *Eucalyptus camaldulensis*

Ram Asheshwar Mandal [a,*], Ishwar Chandra Dutta [b], Pramod Kumar Jha [a]

[a] Central Department of Botany, Tribhuvan University, Kirtipur, Nepal
[b] Tribhuvan University Service Commission, Kirtipur, Nepal

Abstract

This research was objectively carried out to assess the dynamic of carbon, nitrogen and texture at root zone and location between plants. The plantation of *Acacia catechu, Dalbergia sissoo, Phyllanthus emblica* and *Eucalyptus camaldulensis* of Pragati community forest, Mahottari district, Nepal was selected for this study which was done in 2011. The stratified random sampling was applied to collect soil samples. Altogether 320 soil samples were collected from 0-10, 10-30, 30-60 and 60-90 cm depths. The result showed that soil carbon was about 8.16 t ha^{-1} at root zone which was only 7.56 t ha^{-1} at location between plants at 0-10cm depth in *Phyllanthus emblica* stratum. The soil carbon was the least nearly 2.08 t ha^{-1} at root zone which was 1.59 t ha^{-1} at location between plants in *Eucalyptus camaldulensis* stratum. The carbon percentage was the highest about 1.35% at root zone of *Phyllanthus emblica* stratum. However, the C/N ratio was the highest about 69:1 at location between plants of *Dalbergia sissoo* stratum. The texture of soil was loamy sand at root zone in *Phyllanthus emblica*, *Acacia catechu* and *Dalbergia sissoo* plantations while it was sandy at both root zone and between plants of *Eucalyptus* plantation. Plantations have significant effect on soil carbon and nitrogen at 95% confidence level.

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Introduction

The plant is the most capable living component to conserve and restore the soil, reduce the erosion and retain the fertility (Durán Zuazo and Rodríguez Pleguezuelo, 2008; Stokes et al., 2009). The canopy and crown of plants slow down the speed of the rainfall to reach the land surface (Holder and Gibbes, 2017). Plants like grass, ground covers, shrubs, and trees can help to stabilize river embankments through root system to hold the soil minerals (Preti and Giadrossich, 2009). The vegetations absorb rain water to reduce the surface runoff rate. In addition, the plants importantly stop to wash out the soil particles (Doran and Zeiss, 2000; Karlen et al., 2001). So, the plantations play a vital role to reduce hazards due to flood, land slide and bank cutting due to river (De Baets et al., 2007; Karoshi and Nadagoudar, 2012). Meanwhile plants play a key role to sequestrate the carbon and maintain soil fertility enhancing Nitrogen. Especially the natural hazardous is severe at exposed land area in comparison to vegetated land. Therefore, plantation especially at the bank of the river and surrounding has great importance to conserve the soil.

Globally, climate change is serious issue and one of the extreme effects is river flood (van den Honert and McAneney, 2011; Kundzewicz et al., 2013). The evidences are the severe flood in 2000 in Mozambique that

* Corresponding author.
Central Department of Botany, Tribhuvan University, Kirtipur, PO Box 44618, Nepal
Tel.: :+ 977 1 9841450564
E-mail address: ram.mandal@gmail.com
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killed thousands of citizens (Aderogba et al., 2012). One of the most devastating floods occurred in southern Alberta, Canada in 2004 (Buttle et al., 2016) which damaged many health and wealth. The heavy torrential rains caused floods in Kyushu, Japan, killed 32 people (Takezawa et al., 2014). The Cyclone Ita flood killed 21 people in Solomon Islands (Davidson, 2014). The heavy rainfall in Visakhapatnam, India in 2014 destroyed many things and made thousands more homeless (Ramuje and Rao, 2014). The mass slide killed two dozen citizens in Sindhupalchok, Nepal in 2014 (MoI, 2014; MoHA, 2015). The best option is restoration of soil through plantation and river training to protect the land and lives (Aston, 1979) on the earth.

The plantation of Acacia *catechu, Dalbergia sissoo, Eucalyptus camaldulensis* and *Phyllanthus emblica* was carried out targeting to control the soil erosion and minimize the effects of flood at Pragati community forest, Mahottary district Nepal. On the other hand, the plantation has high positive effect on soil carbon (C), nitrogen (N) and texture formation (Hofstede et al., 2002; Kooch and Zoghi, 2015; Li et al., 2017) but the research regarding the contribution of plantation was not done yet. Moreover, it is more interesting fact that the soil carbon, nitrogen and texture are so sensitive to the vegetation that these were differed even at "root zone" and "location between the plants (about 1-1.25m away from root zone)" as well. Therefore, this study was objectively carried to assess the soil carbon, nitrogen and texture dynamics at root zone and location between plants of riverine plantation of *Acacia catechu, Dalbergia sissoo, Phyllanthus emblica* and *Eucalyptus camaldulensis*.

Material and Methods

Pragati community forest of Mahottary district, Nepal was selected for this study because the community forest was established at bank of the Ratu river where plantation of four species specifically *Acacia catechu, Dalbergia sissoo, Phyllanthus emblica* and *Eucalyptus camaldulensis* were done in 2011. The plantation is about five years old. The purpose of the plantation was to control soil erosion and bank cutting caused by Ratu river. Geographically, Mahottary district is located at 26° 36' to 28° 10' N and 85° 41' to 85° 57' E (Figure 1). The temperature of this district ranges between 20-45 °C and average annual rainfall has been recorded between1100-3500 mm.

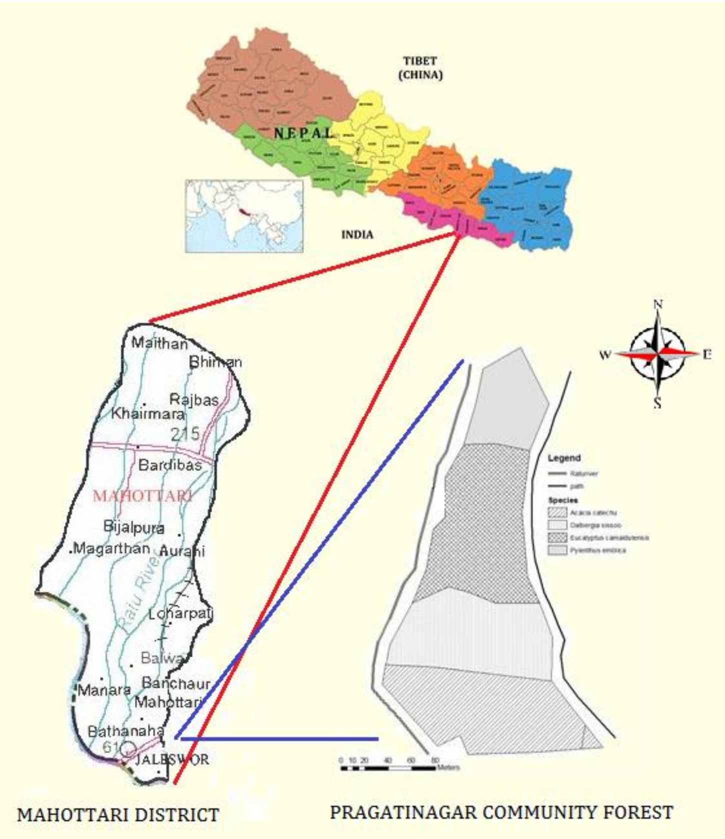

Figure 1. Experimental site

Experimental design and sampling method

The whole plantation area was considered as one block. The block was categorized into four strata according to species. Hence stratified random sampling was applied setting randomized block design (Kothari, 2004). The map of whole plantation area was prepared and stratified. Altogether 320 points for soil samples were marked on the map in such way that 160 points laid close to the root of the plant called "root zone" and same number of points were laid at the midpoint of two plants named as "location between plants". The spacing was maintained 2-2.5m between plants. In fact, 20 samples were collected from each species strata specifically 10 samples from root zone and same number of samples from location between plants (Winner, 2009).

The soil samples were collected from four soil depths particularly from 0-10, 10-30, 30-60 and 60-90cm using soil corer (IPCC, 2006).

Soil Analyses

Collected soil samples were analyzed in the lab. Soil carbon, nitrogen, and C/N were analyzed. The soil texture (sand, silt and clay) was estimated using feel analysis (Thien, 1979). Field-moist samples from both sampling batches were gently and manually crumbled and sieved (<8 mm) in order to remove the root material. Each sample was thoroughly mixed and stored at field humidity in polyethylene bags until analyses. Soil analyses were conducted on air-dried samples from which crop residues, root fragments and rock larger than 2 mm had been removed and stored at room temperature. Some soil analyses were determined by the following methods: soil texture by the Bouyousoc hydrometer method (Anderson and Ingram, 1993), total Nitrojen by digestion and subsequent measurement conducted by the Kjeldahl method (Kjeldahl, 1883). All soil samples were sieved through a 150 µm mesh to determine the total organic carbon content by the wet oxidation method (Walkley-Black) with $K_2Cr_2O_7$ (Walkley and Black, 1958). C/N ratio in soils were calculated as total organic carbon / total nitrogen.

Statistical Analysis

The descriptive analysis was carried out to find the mean, standard deviation and standard error of the soil carbon of different stratum. At the same time, distributions of data were examined using Kolmogorov-Smirnov and Shapiro-Wilk tests to evaluate the normality of the data. Next, the t-test was applied to compare the carbon in total and at different depth at the location root zone and between the plants (Kothari, 2004).

Results and Discussion

Soil carbon dynamics at root zone and between plants

The soil carbon was differed at root zone and location between plants according to species. In case of *Phyllanthus emblica*, this was more about 8.16 t ha^{-1} at root zone which was 7.56 t ha^{-1} at location between plants at 0-10cm depth. This was decreased according to increasing soil depths. In addition, soil carbon was the least nearly 2.08 t ha^{-1} at the root zone which was 1.59 t ha^{-1} at location between plants in *Eucalyptus camaldulensis* stratum. This indicates that the capacity of soil carbon formation was the highest of *Phyllanthus emblica* while it was the least of *Eucalyptus camaldulensis*. The reason behind this was leaf decomposition of leaf litter of *Phyllanthus emblica* was faster than the leaves of *Eucalyptus camaldulensis*. At the same time values of soil carbon were also high about 7.85 and 5.83 t ha^{-1} at root zone of *Acacia catechu* and *Dalbergia sissoo*. The study importantly showed that *Phyllanthus emblica*, *Acacia catechu* and *Dalbergia sissoo* are favorable species for soil formation in comparison to *Eucalyptus camaldulensis.* Moreover, there were significant differences in soil carbon between the location root zone and between plants at 95% confidence interval at different soil depth. This showed that the soil carbon formation in riverine areas was higher at the root zone than other place, since the microbial activities are high in soil near the root (Table 1).

Table 1. Status of soil carbon

Species	Details	Soil carbon t ha^{-1} according to soil depth			
		0 -10 cm	10-30 cm	30-60 cm	60-90 cm
Phyllanthus emblica	Root zone	8.16	6.84	4.93	3.69
	Between Plant	7.56	6.43	3.28	3.02
	Difference/p-value (t-test)	0.50/0.01	0.41/0.02	1.65/0.00	0.67/0.01
Acacia catechu	Root zone	7.85	6.35	3.04	3.02
	Between Plant	3.69	3.02	2.9	2.64
	Difference/p-value (t-test)	4.16/0.00	3.33/0.00	0.14/0.00	0.38/0.00
Dalbergia sissoo	Root zone	5.83	4.58	4.29	1.89
	Between Plant	2.64	1.84	1.84	1.78
	Difference/p-value (t-test)	3.19/0.01	2.74/0.00	2.45/0.00	0.11/0.40
Eucalyptus camaldulensis	Root zone	2.08	1.62	1.22	0.72
	Between Plant	1.59	1.12	0.74	0.25
	Difference/p-value (t-test)	0.49/0.00	0.5/0.01	0.48/0.00	0.47/0.00

The mean carbon of soil was the highest nearly 23.62 t ha^{-1} at root zone of *Phyllanthus emblica* stratum while this was the lowest 3.7 t ha^{-1} at location between plants of *Eucalyptus camaldulensis*. There were significant differences in soil carbon at the root zone and location between plants in different plantation strata at 95% confidence level. The maximum and minimum records of soil carbon were 25.86 and 22.21 t ha^{-1} respectively at the root zone of *Phyllanthus emblica* stratum (Table 2). The soil carbon in *Eucalyptus camaldulensis* stand was about 9.2 t ha^{-1} in Southern China (Du et al., 2015) which value was about to similar with this study.

Carbon and nitrogen ratio at root zone and between plants

The carbon percentage was the highest about 1.35% at the root zone of *Phyllanthus emblica* stratum but this was the least only 0.47% at location between plants in *Eucalyptus camaldulensis* stratum. However, the C/N ratio was the highest about 69:1 at location between plants of *Dalbergia sissoo* stratum.

Table 2. Summary statistics of carbon at root zone and location between plants

Species	Location	Mean C t ha-1	C difference t ha-1	p-value (t-test)	Min.	Max.	Standard deviation	Standard error
Phyllanthus emblica	Root zone	23.62	3.33	0.01	22.21	25.86	1.03	1.06
	Between Plants	20.29			18.92	21.60	0.94	0.88
Acacia catechu	Root zone	20.26	8.01	0.00	20.26	20.51	0.08	0.03
	Between Plants	12.25			11.22	13.32	0.66	0.43
Dalbergia sissoo	Root zone	16.59	8.49	0.00	14.26	19.71	1.99	0.63
	Between Plants	8.10			5.90	10.77	1.25	0.39
Eucalyptus camaldulensis	Root zone	5.64	1.94	0.00	3.34	4.11	0.08	0.25
	Between Plants	3.70			4.64	7.69	0.25	0.80

The soil fertility is improving high at root zone of *Acacia catechu* stratum since the C/N ratio was found to be the lowest here while it was the lowest rate of soil improving at location between plants of *Eucalyptus camaldulensis* stratum because C/N ratio was nearly 61.00:1 (Table 3). High C/N ratio can slow down the decomposition rate of organic matter and nitrogen depends up on the C/N ratio (Swangjang, 2015). The higher the soil C/N ratio the lower the decomposition process of organic matter and nitrogen because it can limit the ability of soil microbial activity (Wu et al., 2001). The C/N ratio ranges 0.2:1 to 27.4:1 in plantation area in Northeastern United States Watersheds (Ross et al., 2011) and the highest ratio of this research was about similar to the C/N ratio of at the location between plants in *Acacia catechu* stratum. Soil materials are affected due to C/N ratio (Swangjang, 2015). The soil having very less N % is considered as the very low fertile soil (Dawud et al., 2017).

Table 3. C/N ratio in soil

Species	Zone	C %	C difference	N%	N difference	C/N ratio	Soil Fertility Improvement
Phyllanthus emblica	Root zone	1.35	0.03	0.04	0.01	33.75:1	High
	Between Plants	1.32		0.03		44.00:1	
Acacia catechu	Root zone	1.06	0.17	0.04	0.01	26.50:1	High
	Between Plants	0.89		0.03		29.67:1	
Dalbergia sissoo	Root zone	0.89	0.2	0.02	0.01	44.5:1	Low
	Between Plants	0.69		0.01		69:1	
Eucalyptus camaldulensis	Root zone	0.61	0.14	0.01	0.00	61.00:1	Low
	Between Plants	0.47		0.01		47.00:1	

Soil texture dynamics at root zone and location between plants

The soil texture consists of proportion of sand, clay and silt. These were differed at root zone and location between plants. The texture of soil was loamy sand at root zone in *Phyllanthus emblica*, *Acacia catechu* and *Dalbergia sissoo* plantations while it was sandy at both root zone and between plants in *Eucalytus camaldulensis*. The finding showed that the *Eucalytus camaldulensis* has very poor capacity to form the soil in riverine site (Table 4). The percentage of sand, silt and clay was significantly differed at root zone and between plants at 95% level of confidence. The soil texture at the bank of the river and ocean is dominated by sandy soil (Matsui et al., 2015).

Table 4. Soil Texture Dynamics at Root zone and Location between plants in different stratum

Species	Sites	Sand %	Clay %	Silt %	Texture
Phyllanthus emblica	Root zone	82.50	5.50	12.00	Loamy sand
	Between Plants	89.00	4.25	6.75	Loamy sand
	Difference/p-value	6.50/0.00	1.25/0.00	5.25/0.00	
Acacia catechu	Root zone	89.00	4.25	6.75	Loamy sand
	Between Plants	96.50	2.25	1.25	Sandy
	Difference/p-value	7.50/0.00	2.00/0.00	5. 50/0.00	
Dalbergia sissoo	Root zone	89.80	3.5	6.70	Loamy sand
	Between Plants	95.25	3	1.75	Sandy
	Difference/p-value	5.45/0.00	0.50/0.00	4. 95/0.00	
Eucalyptus camaldulensis	Root zone	93.50	4.00	2.50	Sandy
	Between Plants	95.50	3.50	1.00	Sandy
	Difference/p-value	2.00/0.00	1.00/0.00	1.50/0.03	

Conclusion

The carbon and nitrogen were significantly varied at root zone and location between plants according to soil depths and species. The carbon and nitrogen were higher at root zone in comparison to between plants. The soil texture was recorded sandy loam in *Phyllanthus emblica, Acacia catechu* and *Dalbergia sissoo* strata but it was sandy in *Eucalyptus camaldulensi* stratum. The C/N ratio was higher at location between plants than root zone. Mean soil carbon was the highest at root zone of *Phyllanthus emblica* but this was the lowest at the location between plants of *Eucalyptus camaldulensis* stratum. The research can be applied to choose the appropriate species for plantation in river reclaimed area. Further studies are essential to examine soil carbon formation in different sites according to the plants species.

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Chemical and microbiological properties in soil cultivated with sugarcane (*Saccharum officinarum*)

Rosana Faria Vieira *, Nilza Patrícia Ramos

Embrapa Meio Ambiente, CP 69, CEP 13820-000, Jaguariúna, São Paulo, Brazil

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Abstract

The aim of this study was to evaluate the response of chemical parameters and microbiological processes related to the nitrogen (N) cycling in an area cultivated with sugarcane (SC), as compared to the native forest area (NF), considered as the reference. The pH value, the total C (C_{tot}), N (N_{tot}) contents, the P, K, Ca, Mg, Zn, Mn, B and Cu contents, the labile carbon (LC) content, cation exchange capacity (CEC), microbial biomass N (N_{mic}), potentially mineralizable nitrogen (PMN) and the urease activity (UA) were determined in soil samples taken at depths of 0-10 and 10-20 cm. Most of the chemical properties were higher in the NF soil at both depths, except for C_{tot}, N_{tot} and the total K content, which did not present significant differences between the areas at the deeper level. All microbiological processes were higher in the NF soil and showed positive correlations with the total Cu and B contents, demonstrating the importance of these nutrients in the biological N cycling. The higher values obtained for almost all parameters in the NF soil attest to the need for constant monitoring of areas cultivated with sugarcane in order to avoid the adverse effects of soil degradation. The results obtained between the areas, in relation to N cycling processes also demonstrated the suitability of using them as reliable indicators of soil quality.

Keywords: N cycling, urease activity, N immobilization, mineralizable nitrogen.

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Introduction

Biofuels are considered to be one of the most promising alternatives to the use of fossil fuels, and in Brazil they are practically all sugarcane derivatives. Currently, Brazil is the world's largest producer of sugarcane. The cultivation area covers about 9.1 million hectares. Although Brazilian sugarcane production is significant, an additional of 6.4 million hectares would be required to meet the internal demand for ethanol projected for 2021. This is considered to be one of the main causes of land use changes in the south central region of Brazil (Goldemberg et al., 2014). However, the destruction of complex ecosystems to cultivate sugarcane can result in modifications of various soil properties, influencing the sustainability of the production systems (Walter et al., 2014).

It is thought that some biological properties of the soil are sensitive to changes when the soil is subjected to any type of anthropogenic activities. Quantifying the changes in those properties has been a key tool for monitoring soil quality (Neves et al., 2007). According to Marinari et al. (2006), microorganisms can show the changes caused by soil cultivation more quickly, since they are more susceptible to changes imposed by the environment. Of the microbiological parameters used to study the effects of agricultural soil use, the following stand out: microbial biomass since it represents the most active reservoir of organic matter (Roscoe et al., 2006), enzyme activities since they are essential for soil element cycles (Silva et al., 2012) and

* Corresponding author.
Embrapa Meio Ambiente, CP 69, CEP 13820-000, Jaguariúna, São Paulo, Brazil
Tel.: +551933112616
E-mail address: rosana.vieira@embrapa.br
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the potentially mineralizable nitrogen, which provides information about the ability of the soil to make N available to the cultures (Dilly et al., 2003).

The aim of this study was to evaluate the impact of long-term sugarcane cultivation on some chemical soil parameters and processes related to the nitrogen cycle.

Material and Methods

The study was carried out in a commercially cultivated sugarcane area (SC) and in a native forest (NF) area with no history of agricultural interference, which could therefore serve as the reference for the initial soil condition. Historically, the sugarcane area has been cultivated with sugarcane for more than 15 years. The two areas were located in adjacent positions in the municipality of Guaira, State of São Paulo, Brazil (latitude 20⁰19'06" S, longitude 48⁰18'38" W). The regional climate is of the Aw type according to the Köppen classification system. The minimum and maximum mean annual temperatures in the region are between 12 and 20⁰C and between 28 and 33⁰C, respectively. The rainfall varies from 12.3 mm to 267.3 mm (http://www.cpa.unicamp.br), concentrated in the hot months from November to March.

The soil samples were taken on October 24th 2012 from an area of approximately 2000 m^2 cultivated with sugarcane, subdivided into 500 m^2 quadrants from where six subsamples were randomly taken at depths of 0-10 cm and 10-20 cm. Homogenization of the subsamples resulted in four compound samples per depth. The samples were taken 20 cm from the plantation line, and those from the forest area were taken following the same system.

Table 1 shows the chemical attributes of the soils (Red Acriferric Latosol with 65% clay). The macronutrient (P, K, Ca e Mg) and micronutrient (Zn, Mn, B e Cu) contents and the cation exchange capacity (CEC) were determined according to Camargo et al. (2009). The pH was measured in an aqueous extract in a 1:2.5 soil:water proportion. The total C (C_{tot}) and N (N_{tot}) contents were determined using an N and C element analyzer (Truspec-Leco) and the labile carbon (LC) was extracted using 0.5 M K_2SO_4 and quantified in a total organic C analyzer (TOC – 500 Shimadzu). The microbial biomass N content (N_{mic}) was determined using the fumigation-extraction method described by Brookes et al. (1985) with a k_{EC} factor of 0.54.The total N content of the extracts was determined by the Kjeldahl digestion method (Bremner, 1996). The potentially mineralizable nitrogen (PMN) and urease activity were estimated using the anaerobic incubation method described by Kandeler (1996) and the method described by Tabatabai and Bremner (1972), respectively.

Table 1. Chemical characteristics of the soils

	Depths of soil sample collection			
	0-10 cm		10-20 cm	
	Soil Cultivated with sugarcane (SC)	Native Forest Soil (NF)	Soil Cultivated with sugarcane (SC)	Native Forest Soil (NF)
pH (H_2O)	6.11 a	4.55 b	5.38 a	4.25 b
Total N (N_{tot}), %	0.17 b	0.29 a	0.15 b	0.19 b
Total C (C_{tot}),%	2.10 b	3.50 a	1.91 b	2.13 b
Labile C (LC), μg g^{-1} soil	65.71 b	88.53 ab	44.07 c	118.80 a
C/N	12.00 a	12.00 a	13 a	11:00 AM
P, mg dm^{-3}	21.50 a	18.25 b	25.25 a	15.00 b
K, $mmol_c dm^{-3}$	8.58 a	5.03 b	5.40 b	5.40 b
Ca, $mmol_c dm^{-3}$	72.38 a	35.00 b	44.25 b	7.00 c
Mg, $mmol_c dm^{-3}$	19.88 a	18.75 a	9.00 b	4.50 c
CTC, $mmol_c dm^{-3}$	120.01 a	126.78 a	83,65 b	88.90 b
Mn, mg dm^{-3}	35.23 b	42.05 a	19.77 c	23.70 bc
Cu, mg dm^{-3}	4.50 b	5.78 a	3.85 bc	6.00 a
Zn, mg dm^{-3}	1.96 a	0.75 b	2.70 a	0.35 b
B, mg dm^{-3}	0.22 b	0.39 a	0.17 b	0.30 a

Means followed by the same letters in the same line are not significantly different (t test, $p \leq 0,05$)

All analyses were carried out with the natural soil moisture content and the results expressed per gram of dry soil. The data were discussed considering the results within each soil depth.

For the purposes of the statistical analysis, each quadrant was considered as a plot, used as the replicates during sampling and analysis. The dataset was subjected to a one-way ANOVA according to an entirely randomized design, followed by a means comparison using the t test ($p \leq 0.05$). A correlation matrix of the different properties was based on the Pearson correlation coefficients.

Results and Discussion

As compared to the NF soil, the pH of the soil in the SC area was higher at both depths (Table 1). These results corroborate those obtained by Corrêa et al. (2001). The lower pH values in the NF area could be due to a greater accumulation of humus as compared to the soil cultivated with sugarcane.

The C_{tot} content was 71% higher in the native forest soil at a depth of 0-10 cm, but at 10-20 cm there was no significant difference for this parameter between the two areas (Table 1). Marchiori Junior and Melo (2000) found smaller amounts of organic carbon in soil cultivated with sugarcane at depths of both 0-10 cm and 10-20 cm, as compared to those found in natural forest soil. The smaller value found for C_{tot} in the surface layer of SC soil could be related to the increase in the mineralization rate of the organic matter (OM), when NF is turned over to agriculture. In native forest soil the processes of adding and losing organic C are in a state of equilibrium, which can rapidly be undone when the forest is cut down for agricultural purposes. This occurs as a function of soil disturbance, which breaks up the aggregates that provide physical protection to the organic matter of the soil, thus exposing it to greater microbial degradation.

The results obtained for LC showed significant differences between the treatments at both depths, and were higher in the NF soil, the differences being 35% and 170% for the depths of 0-10 cm and 10-20 cm, respectively (Table 1). These results were to the contrary of those obtained for C_{tot}, showing that this last parameter is not always adequate to verify the sustainability of different types of soil management. This could also be observed from the lack of correlation between the C_{tot} and LC contents (Table 2).

Table 2. Pearson's correlation analysis between the variables measured

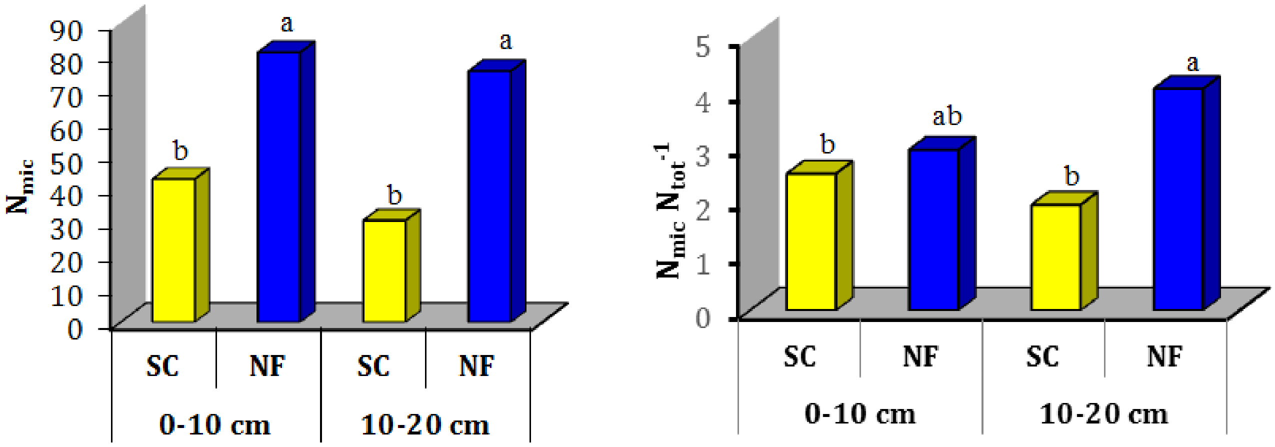
	C_{tot}	N_{tot}	LC	N_{mic}	MPN	UA
C_{tot}	1.00					
N_{tot}	0.94***	1.00				
LC	NS	NS	1.00			
N_{mic}	0.65**	0.56*	0.78**	1.00		
PMN	0.90***	0.97***	0.54*	0.70**	1.00	
UA	0.73**	0.77**	0.81*	0.88***	0.87***	1.00
pH	NS	NS	-0.73**	-0.75**	-0.57*	-0.79**
P	NS	NS	-0.74**	-0.71**	NS	-0.65**
Cu	0.55*	0.59**	0.75**	0.79**	0.69**	0.84***
Zn	NS	NS	-0.69**	-0.71**	-0.55*	-0.73**
B	0.84***	0.82***	0.64**	0.86***	0.89***	0.91***

$p \leq 0.001$***; $p \leq 0.01$**; $p \leq 0.05$*

The soil N_{tot} contents were higher in the NF soil, but only in the surface layer. Souza et al. (2012) verified higher N_{tot} contents in native forest soil at a depth of 0-20 cm, when compared to soil cultivated with sugarcane, harvested without burning. Despite the differences between the values obtained for C_{tot} and N_{tot}, the C/N ratios were similar for the two soils at the two depths, demonstrating differences in the compositions of degradable humic compounds between the two areas (Dilly et al., 2003). In the same way as that occurring with the C_{tot}, the N_{tot} did not present correlation with the contents of LC (Table 2).

The values for P, Ca and Zn were higher in the soil cultivated with sugarcane. Corrêa et al. (2001) also reported increases in the P and Ca contents in an area cultivated with sugarcane, as compared to a forest area. The Mg contents showed no differences between the two areas at a depth of 0-10 cm, but were higher in the NF soil at the depth of 10-20 cm. The soil K contents were higher in the area cultivated with sugarcane at the lower depth. The greater concentrations of some elements in the area cultivated with sugarcane could be related to the chemical fertilizations performed on this soil. For example, this fact could be observed from the absence of correlation between the P and Zn contents and the soil C_{tot} and N_{tot} contents (Table 2). The Mn contents showed tendencies to be higher in the NF soil at both depths, while the Cu and B contents were higher in the NF soil. No significant differences were found between the soils with respect to the CEC value.

The soil N_{mic} values were about 89% and 147% higher in the NF area, at the lower and greater depths, respectively (Figure 1a). These results demonstrate that the NF soil has a greater N immobilization capacity by the microorganisms, suggesting a reduced loss of this element to the environment. The microbial biomass is an important factor responsible for the liberation of nutrients during the turnover of organic matter, and reductions in this parameter have been associated with decreases in the transformation rates and availability of N in the soil (Tan et al., 2008). The positive correlations between the N_{mic} and the soil Cu ($r = 0.79$, $p \leq 0.01$) and B contents ($r = 0.86$, $p \leq 0.01$) demonstrate the importance of these elements in the incorporation of N by the soil microbiota (Table 2).



(a) (b)

Figure 1. (a) N_{mic}, N immobilized by microorganisms, (μg g^{-1} soil); (b) N_{mic} N_{tot}^{-1}, ratio between the N immobilized by microorganisms and the total N content of the soil, (%). SC, soil cultivated with sugarcane. NF, native forest soil. 0-10 and 10-20 cm, depths of soil sample collection. Means followed by the same letters are not significantly different (t test, $p \leq 0.05$)

The specific efficiency of the conversion of organic N into N_{mic} can be calculated from the N_{mic} N_{tot}^{-1} ratio and can be interpreted as the availability of substrate and the portion of total N immobilized on the microbial cells. There were no significant differences between the treatments for this parameter at a depth of 0-10 cm, but at the greater depth the ratio was 110% greater in the NF soil, despite there were no differences between treatments in relation to the soil N_{tot} (Figure 1b). This fact could be related to the greater amount of readily available organic N in the NF soil at the greater depth, or the occurrence of different microbial communities in the two soils

The PMN was greater in the NF soil at both depths (Figure 2), the percent differences being 217% and 248% at the lower and greater depths, respectively. This parameter refers to the soil´s ability to transform organic nitrogen compounds into ammonium/nitrate under optimal conditions of humidity and temperature, for a given period of time. Soil microorganisms are the primary agents responsible for the mineralization of organic N. They enzymatically degrade those compounds in simpler constituents such as amino acids, glucosamines and ammonium and immobilize them via cellular uptake to synthesize polymers used for growth (Paul and Clark, 1996). According to Dilly et al. (2003) the N mineralization rate is an indicator of the amount of biologically active N in the soil, and can provide indicatives concerning the potential of the soil to provide N to the cultures. The greater PMN values in the forest soil at both depths, suggests the occurrence of a greater organic matter turnover rate, and consequently a greater nutrient availability. This can be confirmed by the high correlation obtained between the PMN and the N_{tot} (r = 0.97, $p \leq 0.001$), C_{tot} (r = 0.90, $p \leq 0.001$) contents and the N_{mic} (r = 0.70, $p \leq 0.01$) (Table 2).

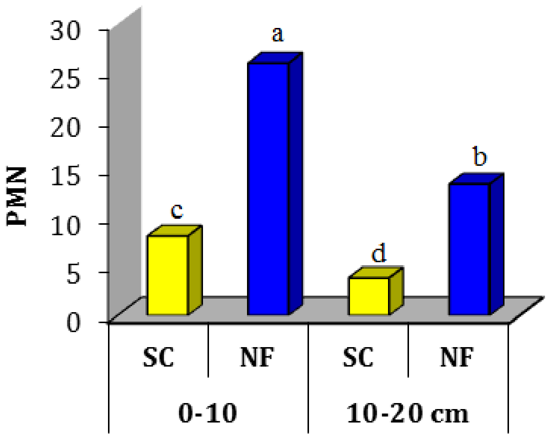


Figure 2. PMN, potentially mineralizable nitrogen, (μg NH_4^+ g^{-1} soil day^{-1}). SC, soil cultivated with sugarcane. NF, native forest soil. 0-10 and 10-20 cm, depths of soil sample collection. Means followed by the same letters are not significantly different (t test, $p \leq 0.05$)

The enzyme urease is one of the most frequently evaluated enzymes, since it has a great influence on the transformation and destiny of an important fertilizer that is the urea. This enzyme catalyzes the hydrolysis of organic N into inorganic forms, using substrates like urea. The UA values were different between the two soils at both depths (Figure 3). At the depths of 0-10 cm and 10-20 cm the values obtained in the forest soil were respectively 159% and 259% higher than those obtained in the soil cultivated with sugarcane. Kuwano et al. (2014) also found lower urease activity in an area cultivated with sugarcane as compared to the forest area. The lower activity in the soil cultivated with sugarcane could have been due to a greater number of final products containing compounds like urea, which repress synthesis of the enzyme (Tscherko et al., 2003), or to a smaller concentration of available substrates for urease. However, the positive correlations between urease activity (UA) and N_{tot} ($r = 0.77$, $p \leq 0.01$) and between UA and C_{tot} ($r = 0.73$, $p \leq 0.01$) suggest that this feedback may not have occurred. The negative correlations between UA, the soil pH ($r = -0.79$, $p \leq 0.01$), the P ($r = -0.65$, $p \leq 0.01$) and Zn ($r = -0.73$, $p \leq 0.01$) contents, demonstrate the importance of these factors in determining a greater or lesser activity of this enzyme. The strong positive correlation between N_{mic} and UA ($r = 0.88$, $p \leq 0.001$) supports the hypothesis that in the soil this enzyme is principally of microbial origin (Klose and Tabatabai, 2000). Roscoe et al. (2000) also obtained positive correlation between urease activity and N_{mic}. In this last study, the N microbial biomass accounted for 97% of the variance of soil urease activity. The positive correlation between UA and PMN ($r = 0.87$, $p \leq 0.001$) could suggest that the supply of N to the soil was amply regulated by this enzyme.

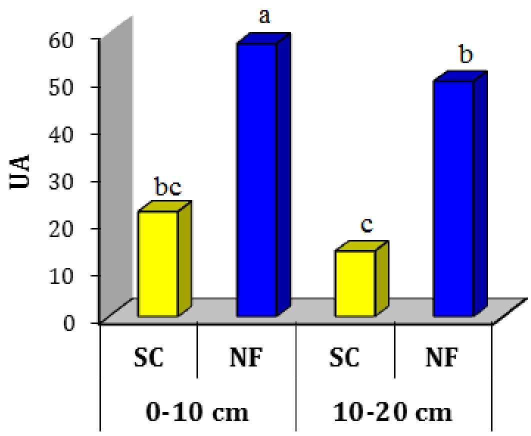


Figure 3. UA, urease activity, (µg NH_3 g^{-1} soil h^{-1}). SC, soil cultivated with sugarcane. NF, native forest soil. 0-10 and 10-20 cm, depths of soil sample collection. Means followed by the same letters are not significantly different (t test, $p \leq 0.05$)

Conclusion

The nitrogen cycling processes and chemical soil characteristics successfully discriminated the area cultivated with sugarcane from the native forest area. All the microbiological parameters evaluated were smaller in the soil cultivated with sugarcane demonstrating that is still possible to improve soil quality in comparison to the conditions of soil native forest. The results obtained with those parameters also showed that the soil C_{tot} and N_{tot} contents are not always adequate to show differences between areas with different types of soil management. The results also showed the need for constant monitoring of areas cultivated with sugarcane so as to prevent further soil degradation. Since the microbiological parameters vary with the climatic conditions, further studies should be carried out with soil samples taken at different times during the sugarcane growth cycle.

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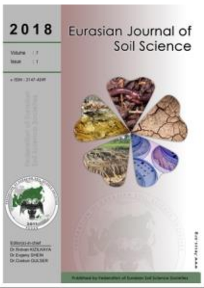

Relationships between soil properties, topography and land use in the Van Lake Basin, Turkey

Siyami Karaca [a,*], Füsun Gülser [a], Ramazan Selçuk [b]

[a] Van Yüzüncü Yıl University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, Van, Turkey
[b] GAP International Agricultural Reseach and Training Center, Diyarbakır, Turkey

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Abstract

The objective of this study was to determine the relationship between soil properties and different topography and land uses in the Van Lake Basin, Turkey. It has sharp and sheer slopes, and the big differences on altitude generally occur from the mountainous formations. Surface soil samples (0–20 cm) were taken from 40 different points with three different topography (backslope, footslope and terrace) and three different landuses (wheat, clover and pasture). Some of the studied soil properties (soil texture, electrical conductivity [EC], pH, lime content, organic matter content, macro and micro nutrients) changed in response to land use and topography. The clay, boron content, pH and EC values increased from the backslope to the terrace. Soil organic matter and EC values were lower in cultivated wheat and clover fields than in uncultivated pasture. The EC values had significant positive correlations with $CaCO_3$, organic matter, K, B, Cu contents at 5% level and with Mg at 1% level statistically. The soil nutrient contents of cultivated wheat and clover fields were generally lower than the uncultivated pasture. The nutrient contents of soils in cultivated fields decreased due to nutrient uptake by crops. Soil texture, EC, pH, lime, organic matter and nutrient contents significantly varied in different topographic positions due to leaching, transporting and accumulation.

Keywords: Land use, nutrient, soil properties, topography.

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Introduction

Parent material, climate and geological history strongly affect soil properties at the regional and continental scale. However, both topography and land use can influence the soil physical and chemical properties. The availability of the essential elements of soil for plant growth can change depending on the land use and topography. These factors also affect water infiltration and degree of evapotranspiration by modifying the soil moisture content and consequently influencing the yield, plant litter production and decomposition (Birkeland, 1999).

Topography influence drainage, runoff, soil temperature, soil erosion and soil formation (Aandahl, 1948). Differences in soil formation along a hillslope result from the differences in soil properties (Brubaker et al.,1993). Ovalles and Collins (1986) reported that soil physical properties such as clay content distribution with depth, sand content and pH were highly correlated with landscape position. Several researchers (Miller et al., 1988; Bhatti et al., 1991) reported that organic matter content varies by slope position. In contrast, organic carbon content, clay content, and surface thickness increases from the backslope to the footslope (Young and Hammer, 2000; Garten and Ashwood, 2002; Yoo et al., 2006).

* Corresponding author.
Van Yüzüncü Yıl University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, 65080 Van, Turkey
Tel.: +904322251104 E-mail address: s.karaca@yyu.edu.tr
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Land use practices also influence the soil properties. Barreto et al. (2000) reported that three types of land use (forest, abandoned pasture and active pasture) had significant effects on the soil physical and chemical properties. Van lake basin in Turkey is 1797643 ha including the lake surface area. It is generally mountainous and has sharp and sheer slopes. The mean altitude of the basin is around 1600-2500 m. Water erosion and soil loss are common in the basin. The natural vegetation is meadow and the climate is continental climate in the region. The objective of the current study was to determine the effects of different topography and land use on soil physical and chemical properties in the basin.

Material and Methods

The study was conducted in the Van Lake Basin, Turkey (39° 14' – 38° 18' N; 43° 59' – 43° 11' E). Fourty soil samples were collected from 0–20 cm soil depth. Each soil sample was separately air-dried, ground and passed through a 2-mm sieve prior to determining the chemical and physical properties. Some soil physical and chemical properties of soil were determined as follows; texture by Bouyoucos hydrometer method (Black, 1965), organic matter by modified Walkley-Black method, available phosphorus by Olsen method, pH in 1:1 soil: water suspension by pH meter, salt content in the same suspension by EC meter, lime content by Scheiblercalcimeter, potasium, calcium and magnesium by the extraction with 1 N neutral ammonium acetate, micro nutrients by the extraction with DTPA extraction solution by using atomic absorption spectrophotometers (Thermo ICE 3000 Series) according to Kacar (1994).

Variance analyses of the experimental data were done using SPSS statistic program and significantly different means were shown with LSD test. Significant levels of data among the soil properties were shown with * at $P<0.05$ and ** at $P<0.01$ (Steel and Tore, 1996).

Results

Changes in clay, pH, EC, lime, organic matter, exchangeable cations and micronutrient contents according to the different topography are given in Table 1. The clay content ($P < 0.05$), boron content and pH value ($P < 0.05$) were significantly influenced by the different topography. These parameters increased from the backslope to the terrace. The clay content means were 17.00%, 20.36% and 25.76% in the backslope, footslope and terrace, respectively (Figure1).

Table 1. The effects of different physiographic units on soil properties in the Van Lake basin

	Phy. †	Min.	Max.	Mean	St. Dv.		Phy. †	Min.	Max.	Mean	St. Dv.
Clay, %	1	4.00	38.00	17.00 a*	11.62	Exc. Ca, %	1	0.08	0.93	0.52	0.28
	2	12.00	28.00	20.36 a	5.39		2	0.29	1.00	0.66	0.25
	3	10.00	40.00	25.76 b	8.85		3	0.19	0.81	0.62	0.16
Silt, %	1	18.00	58.00	34.42	12.16	Exc. Mg,%	1	0.02	0.07	0.04	0.02
	2	24.00	56.00	33.55	10.79		2	0.02	0.05	0.04	0.01
	3	10.00	46.00	30.53	8.25		3	0.02	0.10	0.05	0.02
Sand, %	1	28.00	72.00	48.58	13.27	Exc. K,%	1	0.02	0.17	0.06	0.04
	2	24.00	64.00	46.09	10.79		2	0.02	0.10	0.05	0.02
	3	25.00	76.00	43.71	15.09		3	0.03	0.13	0.05	0.02
pH	1	6.57	8.24	7.68 b*	0.61	B,mg kg^{-1}	1	0.18	1.23	0.51a*	0.32
	2	6.17	8.30	7.89 ab	0.61		2	0.16	1.14	0.64 ab	0.32
	3	6.87	9.13	8.15 a	0.49		3	0.21	2.47	0.90 a	0.63
EC,µS cm^{-1}	1	84.50	574.50	251.76	136.73	Cu,mg kg^{-1}	1	0.48	2.25	1.31	0.66
	2	126.80	488.00	263.24	108.24		2	0.44	2.50	1.17	0.70
	3	134.55	518.50	276.97	101.09		3	0.37	3.25	1.25	0.78
OM, %	1	0.72	6.17	2.33	1.89	Fe,mg kg^{-1}	1	1.98	157.10	25.21	44.09
	2	0.50	3.08	1.55	0.79		2	2.02	230.40	27.17	67.57
	3	0.58	5.65	2.01	1.34		3	0.98	29.06	9.05	6.97
$CaCO_3$, %	1	1.42	44.39	14.63	17.49	Mn,mg kg^{-1}	1	4.00	66.49	16.58	17.43
	2	1.01	49.45	12.20	13.60		2	6.33	39.00	11.85	9.33
	3	1.62	58.37	21.28	16.51		3	1.05	31.03	9.63	6.93
						Zn,mg kg^{-1}	1	0.30	9.70	2.55	3.30
							2	0.39	5.73	1.11	1.54
							3	0.41	5.56	1.16	1.39

†Physiographic units: 1-Backslope, 2-Footslope, 3-Terrace
*significant at 0.05 level.

It was shown in Figure 2 the pH value was significantly ($P<0.05$) lower in the backslope (7.68) than in the terrace (8.15). Soil pH showed a significant positive correlations with $CaCO_3$ (0.391*), Ca (0.381*), B (0.479**), and negative correlations with organic matter (−0.363*), Fe (−0.725**), Mn (−0.808**) and Zn (−0.550**) contents.

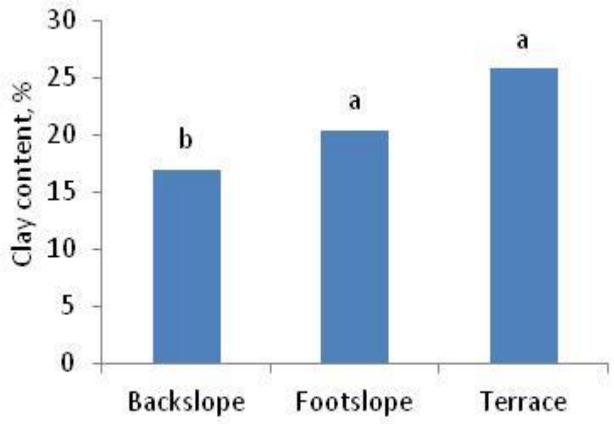

Figure 1. Effect of physiographic units on clay content ($P<0.05$)

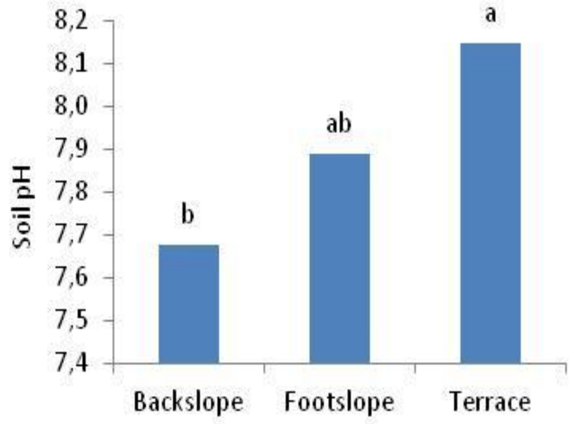

Figure 2. Effect of physiographic units on soil pH ($P<0.10$)

The EC values increased from the backslope to the terrace; however, these increments were not found to be significant. The EC values were 251.7, 263.2 and 279.9 µS cm^{-1} in the backslope, footslope and terrace positions, respectively. EC values showed significant positive correlations with $CaCO_3$ (0.361*), organic matter (0.598**), K (0.620**), Mg (0.420**), B (0.375*) and Cu (0.321*) contents.

There were no significant differences in soil nutrient contents, except boron, among the topographic units in this study. Boron content was significantly ($P<0.05$) higher in the terrace position than in the footslope. The boron contents were determined as 0.507 mg kg^{-1}, 0.644 mg kg^{-1} and 0.899 mg kg^{-1} in backslope, footslope and terrace, respectively (Figure 3).

The mean values of clay content and EC values increased from the shoulder to the terrace position (Figure 4). It was thought that these increments occurred by leaching and moving soil particles throughout slope. Also, lime content and pH values in terrace position were higher than that in shoulder position. Iron, manganese and zinc contents in surface soil samples decreased from the shoulder to the terrace position due to nutrient uptake by crops in cultivated fields located at terrace positions. The high soil pH, clay, and $CaCO_3$ contents in terrace positions might cause these decreases in micronutrient contents (Table 1).

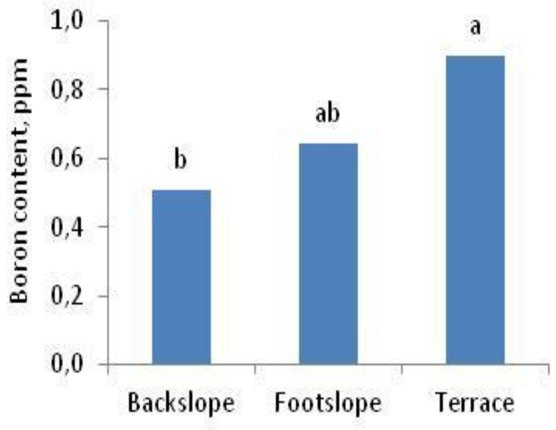

Figure 3. Effect of physiographic units on boron content ($P<0.10$)

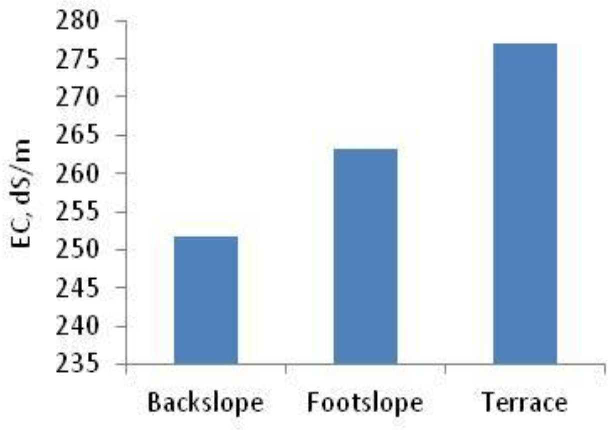

Figure 4. Effect of physiographic units on EC

Changes in clay, pH, EC, lime, organic matter, exchangeable cations and micronutrient contents according to the different land use are given in Table 2. There were significant effects of land use on soil organic matter (P

< 0.05), Mg content (P < 0.01), and EC (P < 0.05). The mean soil organic matter was 1.32%, 1.7% and 2.47% in cultivated wheat, clover fields and pasture, respectively (Table 2). There was a significant difference in soil organic matter content between wheat fields and pasture. Soil organic matter decreased in cultivated wheat and clover fields relative to the uncultivated pasture (Figure 5). The organic matter content had significant positive correlations with K (0.547**), Mg (0.374*), Cu (0.542**), Fe (0.417**), Mn (0.537**) and Zn (0.538**) contents.

Table 2. The effects of different land use on soil properties in the Van Lake basin

	L use†	Min.	Max.	Mean	St. Dv.		L use†	Min.	Max.	Mean	St. Dv.
Clay, %	1	10.00	32.00	20.29	6.88	Exch. Ca,%	1	0.08	1.00	0.57	0.28
	2	10.00	40.00	23.50	9.45		2	0.19	0.95	0.62	0.24
	3	6.00	40.00	22.43	11.63		3	0.30	0.81	0.59	0.17
Silt, %	1	20.00	56.00	34.07	9.43	Exch. Mg,%	1	0.02	0.06	0.03	0.01
	2	18.00	52.00	34.00	9.63		2	0.02	0.10	0.05	0.02
	3	10.00	54.00	31.21	10.64		3	0.02	0.07	0.04	0.01
Sand, %	1	24.00	64.00	45.64	11.71	Exch. K,%	1	0.02	0.10	0.05	0.02
	2	25.00	72.00	42.50	14.17		2	0.03	0.07	0.05	0.01
	3	26.00	76.00	46.36	15.56		3	0.02	0.17	0.06	0.04
pH	1	6.60	8.35	7.89	0.49	B, mg kg^{-1}	1	0.22	1.14	0.58	0.35
	2	6.87	8.33	7.98	0.42		2	0.21	1.07	0.64	0.23
	3	6.17	9.13	7.95	0.80		3	0.16	2.47	0.85	0.72
EC, µS cm^{-1}	1	84.50	355.00	219.9 b*	79.19	Cu,mg kg^{-1}	1	0.37	2.20	0.96	0.59
	2	134.55	488.00	256.2 ab	93.94		2	0.44	3.25	1.25	0.90
	3	139.55	574.50	303.7 a	135.41		3	0.65	2.50	1.46	0.62
OM, %	1	0.50	4.73	1.32 b*	1.12	Fe,mg kg^{-1}	1	0.98	53.02	8.32	13.14
	2	0.94	2.35	1.71 ab	0.45		2	4.64	29.06	11.05	7.92
	3	0.99	6.17	2.47 a	1.58		3	3.74	230.40	36.23	68.70
$CaCO_3$, %	1	1.01	39.72	13.38	12.77	Mn,mg kg^{-1}	1	2.60	29.18	9.13	6.77
	2	1.42	58.37	16.25	20.98		2	9.07	31.03	13.42	6.65
	3	1.82	39.97	16.77	13.96		3	1.05	66.49	14.72	17.53
						Zn, mg kg^{-1}	1	0.30	4.02	0.92	1.07
							2	0.52	3.31	0.92	0.85
							3	0.42	9.70	2.18	2.86

†Land use: 1-Wheat, 2-Clover, 3-Pasture
*significant at 0.05 level.

The soil nutrient contents of cultivated wheat and clover fields were generally lower than the uncultivated pasture. The change in magnesium content was significant (P < 0.01) and the mean EC significantly decreased (P < 0.05) in cultivated land. The EC values were 219, 256 and 303 µS cm^{-1} in wheat fields, clover fields and pasture, respectively (Figure 6).

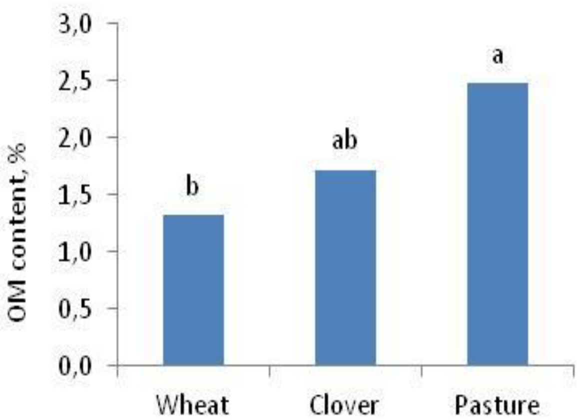

Figure 5. Effect of land use on organic matter content (P<0.05)

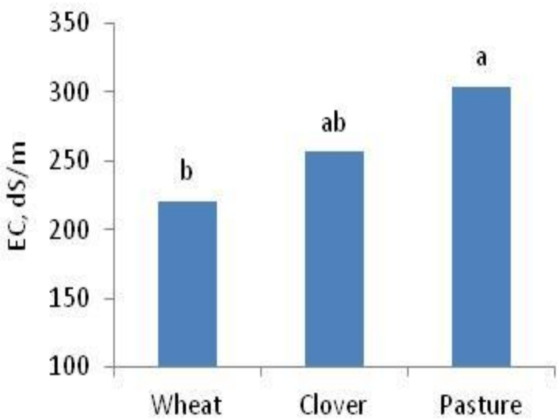

Figure 6. Effect of land use on EC (P<0.10).

Discussion

Previous researches have also shown that the soil physical properties, such as clay content and pH, were strongly correlated with landscape position (Ovalles and Collins, 1986; Gregorich and Andersen, 1985). Similarly, Wang et al. (2001) reported that there were no significant differences in soil nutrients between different landscape positions. Smilarly Malo et al. (1974) also reported that clay content increased from the backslope to the footslope.

Aandahl (1948) reported that the topography affect runoff, drainage, soil temperature and soil erosion and consequently influence soil formation. In the current study, the clay, boron content and EC values increased from the backslope to the terrace positions, which is likely to be in response to surface runoff and leaching processes.

The results reveal that cultivation decreases soil nutrient levels, which has been reported by many researchers (Lepsch et al., 1994; Zheng et al., 1996). Gülser (2004) reported that the different cropping treatments increased soil organic matter, total N, EC and exchangeable K contents in different levels when compared with the bare soil. Wang et al. (2001) found higher soil organic matter contents in uncultivated land than in cultivated land. Fu et al. (1999) and Hontoria et al. (1999) reported that land use and soil management practices influence the soil processes related to soil nutrients, such as erosion, oxidation, mineralization and leaching, and consequently modify the processes of transport and redistribution of nutrients. In this study, EC values, organic matter and magnesium contents also varied between different land uses.

Conclusion

This study provides the current status of soil environment in term of topographic position and land use types in the basin. Topography and land use had significant effects on clay, pH, EC, soil organic matter and nutrient contents in the Van Lake Basin, Turkey. The results of this study may help to better understanding of the effects of environmental components of soils on sustainable crop production and soil management.

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Amending triple superphosphate with chicken litter biochar improves phosphorus availability

Audrey Asap [a], Ahmed Osumanu Haruna [a,b,c,*], Nik Muhamad Ab. Majid [c], Maru Ali [a]

[a] Department of Crop Science, Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia Bintulu Sarawak Campus, Bintulu, Sarawak, Malaysia

[b] Borneo Eco-Science Research Centre, Universiti Putra Malaysia Bintulu Sarawak Campus, Bintulu, arawak, Malaysia

[c] Institute of Tropical Agriculture and Food Security, Universiti Putra Malaysia, Serdang, Selangor, Malaysia

Abstract

The reaction of $H_2PO_4^{2-}$ and HPO_4^{-} with Al and Fe in acid soils to form a precipitate reduces P availability. Chicken litter biochar has been used to improve soil P availability for maize production but with limited information on optimum rates of biochar and Triple Superphosphate (TSP) to increase P availability. This study determined the optimum amount of chicken litter biochar and TSP that could increase P availability. Different rates of chicken litter biochar and TSP were evaluated in an incubation study for 30, 60, and 90 days. Selected soil chemical properties before and after incubation were determined using standard procedures. Soil pH, total P, available P, and water soluble P increased in treatments with 75% and 50% biochar. Total acidity, exchangeable Al^{3+}, and Fe^{2+} were significantly reduced by the chicken litter biochar. The chicken litter biochar also increased soil CEC and exchangeable cations (K, Ca, Mg and Na). The use of 75% and 50% of 5 t ha^{-1} biochar with 25% TSP of the existing recommendation can be used to increase P availability whilst minimizing soil Al and Fe content. This rates can be used to optimize chicken litter biochar and TSP use in acid soils for crop production especially maize and short term vegetables.

Keywords: Incubation period, interaction, optimization, phosphorus fertilizers, phosphorus fixation, tropical acid soils.

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Introduction

Orthophosphates are essential macronutrients which when taken up by plants as soluble inorganic P regulate protein synthesis (Mkhabela and Warman, 2005). Phosphate availability and use efficiency is poor in acid soils (Oxisols and Utisols) because of Al and Fe ions. Aluminium and Fe ions have been implicated in P fixation (Adnan et al. 2003; Ch'ng et al. 2014a,b, 2016a,b,c). The reaction of $H_2PO_4^{2-}$ and HPO_4^{-} with Al and Fe ions to form a precipitate reduces diffusion of P into plant roots (Adnan et al., 2003) and conventionally, large amounts of lime and P fertilizers such as triple super phosphate (TSP) and rock phosphates are applied to acid soils to saturate Al and Fe ions (Ch'ng et al. 2014a; Rahman et al. 2014). Although this approach is to maintain sufficient supply of plant-available P (Myers and De Pauw, 1995; Ch'ng et al. 2014a; Rahman et al., 2014) it is uneconomical and environmental unfriendly. Moreover, it leads to wastage of the limited P resources and the Ca from liming may also fix P in the soil thereby compounding the problem of P fixation. Hence there is a need for more sustainable and environmentally friendly methods for improving tropical acid soil P availability.

* Corresponding author.
Department of Crop Science, Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia Bintulu Sarawak Campus, Bintulu, 97008 Sarawak, Malaysia
Tel.: +6086855406
E-mail address: osumanuharuna@gmail.com
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In recent times, attempts have been made to increase soil available P using organic amendments (Ch'ng et al. 2014a,b, 2016a,b,c). Ch'ng et al. (2014a) reported that amending tropical acid soils with biochar does not only improve soil total P, available P, organic P, and inorganic fractions of P (soluble-P, Al-P, Fe-P, redundant soluble-P, and Ca-P) but it also reduces soil exchangeable acidity, Fe, and Al. This is possible because biochar fixes Al and Fe ions instead of P. Although Ch'ng et al. (2014a) used chicken litter biochar to improve P availability of TSP, their study did not optimize the use of both biochar and TSP as these materials were not varied. Therefore, this present study was focused on optimizing biochar and TSP to increase P availability by understanding the reaction between biochar and TSP. Hence, an incubation study was conducted over a period of 90 days in a controlled environment to determine the optimum rates of biochar and TSP *vis a vis* reduction of P fixation by Al and Fe ions. It was hypothesized that the use of the right amounts of chicken litter biochar and TSP will significantly increase soil available P by reducing P-fixation by Al and Fe ions. The objectives of this study were to determine: (i) the optimum amounts of biochar and TSP that will not only increase P availability in an acid soil but will also reduce P-fixation by Al and Fe ions and (ii) how time affects P availability following application of chicken litter biochar and TSP.

Material and Methods

Soil sampling and preparation

The soil (Nyalau Series, *Typic Paleudults*) used in this study was taken from an uncultivated secondary forest at Universiti Putra Malaysia, Bintulu Sarawak Campus. Although this soil is high in Al and Fe, it is one of the most cultivated soils in Sarawak, Malaysia. The soil samples were taken at 0-20 cm using a shovel. The soil samples were air dried, ground, and sieved to pass through 2 mm afterwhich they were bulked. A 300 g of soil was taken for each treatment with nine replications based on the bulk density.

Incubation set up

The percentages of chicken litter biochar and phosphorus fertilizer rates are summarized in Table 1. The soil, chicken litter biochar, and TSP were thoroughly mixed afterwhich the mixture was incubated in a transparent polypropylene container of 800 cm^3 volume. The treatments were arranged in a Complete Randomized Design (CRD) with 3 replicates at the Research Centre, Universiti Putra Malaysia Bintulu Sarawak Campus, Malaysia. The mixture was moistened to 60% of moisture content based on the soil field capacity afterwhich the TSP rates in Table 1 were surface applied. The lids of the polypropylene containers were perforated to allow good aeration. When necessary, the soil moisture content was maintained using distilled water. The incubated soil was sampled using destructive sampling at 30, 60, and 90 days of incubation. The recommended rate of P fertilizer used was 60 kg P_2O_5 ha^{-1} (130 kg ha^{-1} TSP) for maize production and this was scaled down to per plant basis (Table 2) from the standard fertilizer recommendation by Malaysian Agriculture Research and Development Institute (1993). The chicken litter biochar rate was 5 t ha^{-1} and but it was scaled down to per plant basis (Table 2).

Table 1. Percentages of chicken litter biochar and phosphorus fertilizer rates

Treatment code	Treatment		
	Soil	Biochar (5 t h^{-1})	TSP (60 kg h^{-1})
T1	Soil	0%	0%
T2	Soil	0%	100%
T3	Soil	100%	0%
T4	Soil	75%	25%
T5	Soil	50%	25%
T6	Soil	25%	25%
T7	Soil	75%	50%
T8	Soil	50%	50%
T9	Soil	25%	50%
T10	Soil	75%	75%
T11	Soil	50%	75%
T12	Soil	25%	75%

Soil chemical analysis before and after incubation

Soil samples were characterized for physical and chemical properties before and after the incubation study. Soil pH in water and KCl were determined in a 1:2.5 (soil: distilled water / KCl) using a digital pH meter (Peech, 1965). Soil texture was determined using the hydrometer method (Bouyoucus, 1962). Soil total carbon was calculated as 58% of the organic matter determined using loss of weight on ignition method

(Cheftez et al. 1996). The amount of the soil used in this study was based on soil bulk density method (Dixon and Wisniewski, 1995). The cation exchange capacity (CEC) was determined using leaching method (FAO, 1980) followed by steam distillation (Bremner, 1965). Exchangeable cations were extracted with 1 M NH_4OAc, pH 7.0 using the leaching method (FAO, 1980). Afterwards, the cations were determined using Atomic Absorption Spectrometer (AAnalyst 800, Perkin Elmer Instruments, Norwalk, CT). Total N was determined using Kjeldhal method (Tan, 2005). Soil total P was extracted using aqua regia method (Bernas, 1968) whereas soil available P was extracted using Mehlich No.1 Double Acid method (Mehlich, 1953).Water soluble P was extracted using deionized water. Total P, available P, water soluble P were determined using Spectrophotometer after blue colour was developed (Murphy and Riley, 1962). Soil exchangeable acidity, H^+, and Al^{3+} were determined using acid-base titration method (Rowell, 1994).

Table 2. Scale down of chicken litter biochar and phosphorus fertilizer rates in incubation study

Treatments	Soil	Biochar rate	TSP rate
	……………………. g container^{-1} …………………….		
T1	300	0	0
T2	300	0	4.8
T3	300	7.7	0
T4	300	5.8	3.6
T5	300	3.9	3.6
T6	300	1.9	3.6
T7	300	5.8	2.4
T8	300	3.9	2.4
T9	300	1.9	2.4
T10	300	5.8	1.2
T11	300	3.9	1.2
T12	300	1.9	1.2

Statistical analysis

Analysis of variance (ANOVA) was used to test treatment effects whereas treatments means were compared using Tukey's Test. Statistical Analysis Software version 9.3 was used for the statistical analysis (SAS, 2011).

Results and Discussion

Initial soil chemical properties

The physico-chemical properties of the soil used in this study (Table 3) were within the range reported by Soil Survey Staff (2014) for Bekenu series (*Typic Paleudult*). The pH values, and C, N, P, K, Ca, Al, Fe, Mg and Na contents of the chicken litter biochar were also within the range reported by the Black Earth Company in North of Bendigo Victoria, Australia (Table 4).

Table 3. Selected physico-chemical properties of Nyalau Series

Properties		Value Obtained
Bulk density (g cm^{-3})		1.12
Soil texture		Sand: 67.5%, Silt: 15.5%, Clay: 17%, Sandy Loam
pH in water		4.44
pH in KCl		3.83
Total Carbon (%)		1.20
Total N (%)		0.08
Total P (%)		0.005
Available P (ppm)		4.50
CEC	(cmol kg^{-1}soil)	5.22
Exchangeable acidity	(cmol kg^{-1}soil)	0.51
Exchangeable Al	(cmol kg^{-1}soil)	0.32
Exchangeable H	(cmol kg^{-1}soil)	0.19
Exchangeable K	(cmol kg^{-1}soil)	0.22
Exchangeable Ca	(cmol kg^{-1}soil)	0.25
Exchangeable Mg	(cmol kg^{-1}soil)	0.34
Exchangeable Na	(cmol kg^{-1}soil)	0.22
Extractable Fe	(cmol kg^{-1}soil)	0.19

Table 4. Selected chemical properties of chicken litter biochar

Properties	Chicken little biochar
pH in water	8.5
pH in KCl	7.83
Total Carbon	63.7
Total N (%)	2.8
Total P (%)	2.6
Total K (%)	3.9
Total Ca (%)	5.9
CEC (cmol kg^{-1} biochar)	80.5
Total Mg (g kg^{-1} biochar)	15.2
Total Na (g kg^{-1} biochar)	19.5
Total Fe (g kg^{-1} biochar)	2.7
Total Al (g kg^{-1} biochar)	0.0006

Effects of different amounts of chicken litter biochar and phosphorus on soil total C and pH

The interaction between treatments and incubation time significantly affected soil total carbon (TC) (Table 5). At 30 days of incubation, the effect of T3 on TC was higher than those of T1, T2, T4, T5, T6, T7, T8, T9, T10, T11, and T12 (Figure 1). Soil TC at 30 days of incubation of T4, T7, and T10 were not significantly different but higher than those of T1, T2, T5, T6, T8, T9, T11, and T12 (Figure 1). Among the treatments amended with chicken litter biochar, T6, T9, and T12 showed lower soil TC at 30 days of incubation compared with those of T4, T8, and T12. At 30 days of incubation, the TC of T1 and T2 (treatments without chicken litter biochar) were not significantly different but lower than those amended with chicken litter biochar (Figure 1). Regardless of treatment, the soil TC at 30, 60, and 90 days of incubation were not significantly different. The differences in the TC suggest increase in organic matter and humic substances that are known to be effective in fixing Al and Fe instead of P availability (Chen et al. 2004; Ch'ng et al. 2014a).

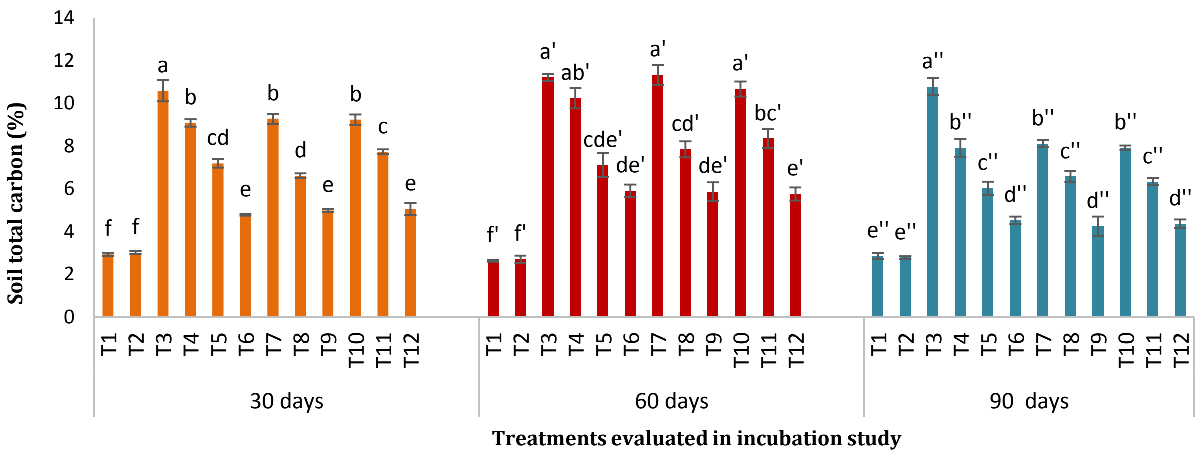

Figure 1. Effect of treatments on soil total carbon at 30, 60 and 90 DAI. Means with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

The interaction between treatments and incubation time significantly affected soil pH in water and KCl (Table 6). The soil pH in water (Figure 2) and in KCl (Figure 3) at 30 days of incubation show that, the soils with chicken litter biochar (T3, T4, T5, T6, T7, T8, T9, T10, T11, and T12) had significantly higher effect on soil pH than those of T1 and T2. This was due to the liming effect of the chicken litter biochar as it has high affinity for Al and Fe thus, reducing the hydrolysis of Al and Fe to produce hydrogen ions (Sparling et al. 1999; Ch'ng et al. 2014a). Instead, the reaction enabled the release of OH^- to increase soil pH. The pH of T3 increased at 30 days of incubation compared with T4, T5, T6, T7, T8, T9, T10, T11, and T12 (Figures 1 and 2) because the treatments with higher amounts of chicken litter biochar might have increased the contents of phenolic and humic-like materials in the soil during decomposition (Narambuye and Haynes, 2006) to form organic anions which consumed H^+ to increase the soil pH (Haynes and Mokolobate, 2001). The soil pH of T4, T7, and T10 significantly differed in spite of these treatments having the same amount of chicken litter biochar and this was due to the different amounts of the TSP used. The inherent content of Ca of the TSP might have contributed to the increase in the soil pH.

Table 5. Mean square values of analysis of variance (ANOVA) to evaluate the effects of treatments and incubation time on soil total carbon, total nitrogen, exchangeable K, exchangeable Ca, exchangeable Mg, exchangeable Na, exchangeable Fe, and CEC.

Source of variations	Degree of freedom	Total Carbon	Total Nitrogen	Exchangeable K	Exchangeable Ca	Exchangeable Mg	Exchangeable Na	Exchangeable Fe	CEC
Time	2	18.45*	0.0340*	2.00*	17.32*	364217799.74*	0.42*	0.81*	93.59*
Treatments	11	62.83*	0.0685*	443.57*	21.44*	18961253994.00*	50.05*	4.67*	83.85*
Time*Treatments	22	0.98*	0.0186*	0.98*	1.02*	143477376.03*	0.18*	0.12*	33.34*
Error	70								

Note: Asterisks (*) indicates significant at P ≤ 0.05

Table 6. Mean square values of analysis of variance (ANOVA) to evaluate the effects of treatments and incubation time on soil pH in water, pH in KCl, total P, available P, water soluble P, total acidity, exchangeable Al, and exchangeable H.

Source of variations	Degree of freedom	pH in water	pH in KCl	Total P	Available P	Water soluble P	Total acidity	Exchangeable Al	Exchangeable H
Time	2	0.0936*	0.0876*	1089444.7*	4901247.3*	1661.82*	0.0008	0.0041*	0.0056*
Treatments	11	5.7957*	8.6147*	24028249.4*	9884398.5*	57298.65*	0.1657*	0.1641*	0.0277*
Time*Treatments	22	0.0302*	0.0109*	591783.9*	357531.9*	363.8*	0.0061*	0.0042*	0.0023*
Error	70								

Note: Asterisks (*) indicates significant at P ≤ 0.05

It was also possible that the different amounts of the TSP used might have reacted with some of the soluble Al and Fe to reduce production of H^+ through the hydrolysis of Al and Fe (Jiao et al. 2007; Ch'ng et al. 2014a,b). The soil pH in water (Figure 2) and in KCl (Figure 3) after 60 and 90 days of incubation were also similar to that of 30 days after incubation. A similar finding had been reported by Ch'ng et al. (2014a).

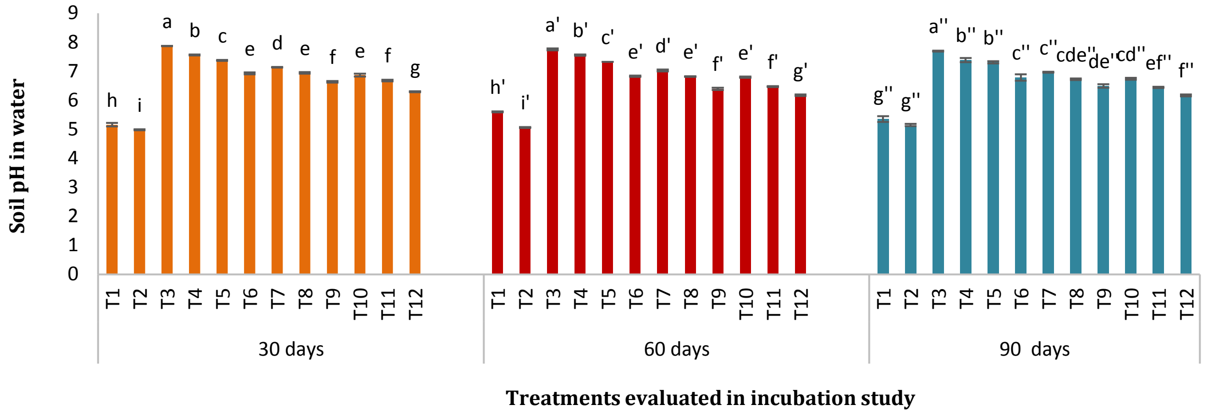

Figure 2. Effects of treatments on soil pH in water at 30, 60 and 90 DAI. Means with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

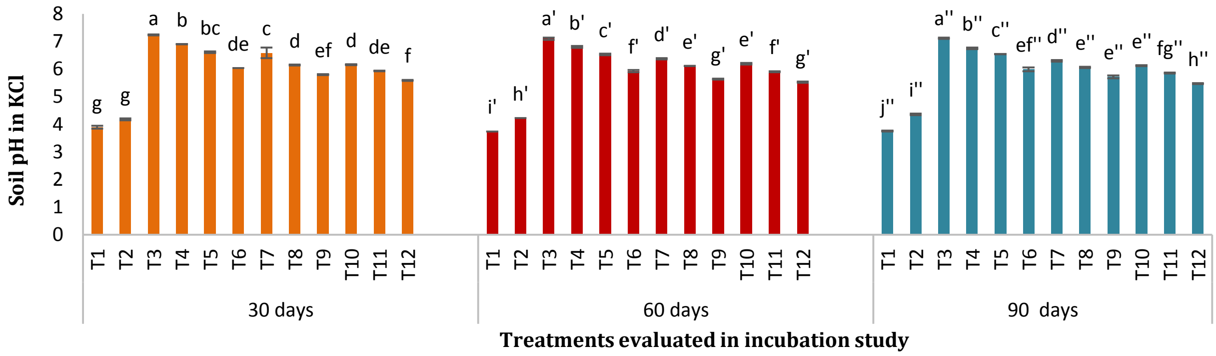

Figure 3. Effects of treatments on soil pH in KCl at 30, 60 and 90 DAI. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

Effects of different amounts of chicken litter biochar and phosphorus on soil phosphorus

The interaction between treatments and incubation time significantly affected soil total P, available P, and water soluble P (Table 6). The lower soil total P, available P, and water soluble P of T1 at 30, 60, and 90 days of incubation than those of T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, and T12 (Figures 4, 5, and 6) was due to higher P fixation. The soil total P, available P, and water soluble P of T2 at 30 days of incubation were significantly higher than those of T5, T6, and T9 (Figures 4, 5, and 6) because of the lower rates of chicken litter biochar and TSP, suggesting that the lower rates of chicken litter biochar in particular could not significantly reverse P fixation by Al and Fe (Cheng et al. 2008; Ch'ng et al. 2014a). However, the soil total P, available P, and water soluble P of T2 at 30 days of incubation were lower than those of T3, T4, T8, T10, and T11 (Figures 4, 5, and 6). This was due to the higher rates of the chicken litter biochar as the higher the rates of biochar the higher negative charges to fix Al and Fe ions instead of P (Cheng et al. 2008; Ch'ng et al. 2014a). The soil total P and water soluble P of T10 at 30 days of incubation was higher than those of T4 and T7 although T4 and T7 had the lowest TSP rate but the same amount of biochar (Figures 4, 5, and 6). This observation could be associated with the optimum reaction that occurred in T10 thus, enabling higher release of P into the soil.

At 60 days of incubation, P release was higher in all the treatments amended with chicken litter biochar than those of 30 days of incubation due to the slow release of nutrients from the biochar as biochar is recalcitrant to decomposition (Ch'ng et al. 2014a). At 90 days of incubation, the P release in the soils treated with chicken litter biochar were similar to those at 60 days of incubation, suggesting that the optimum release of P following the application of chicken litter biochar was within 60 days. This observation is related to the increase of P with time due to the increase in pH caused by the increase in net negative charge on Al and Fe oxide surfaces.

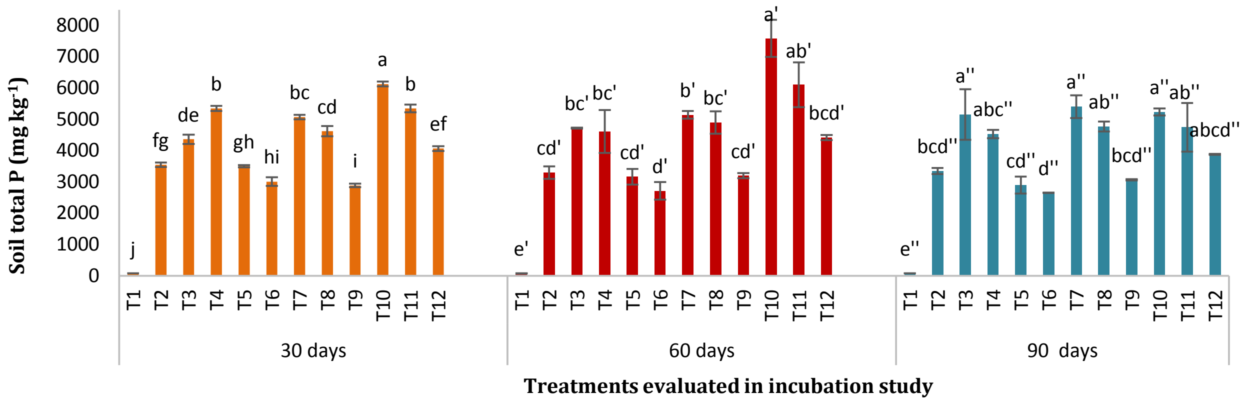

Figure 4. Effects of treatments on soil total P at 30, 60 and 90 DAI. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

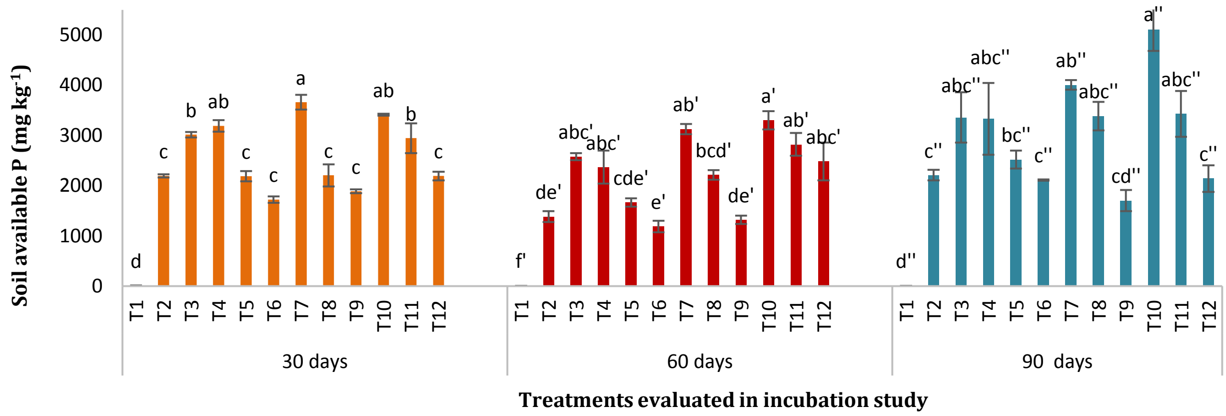

Figure 5. Effects of treatments on soil available P at 30, 60 and 90 DAI. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

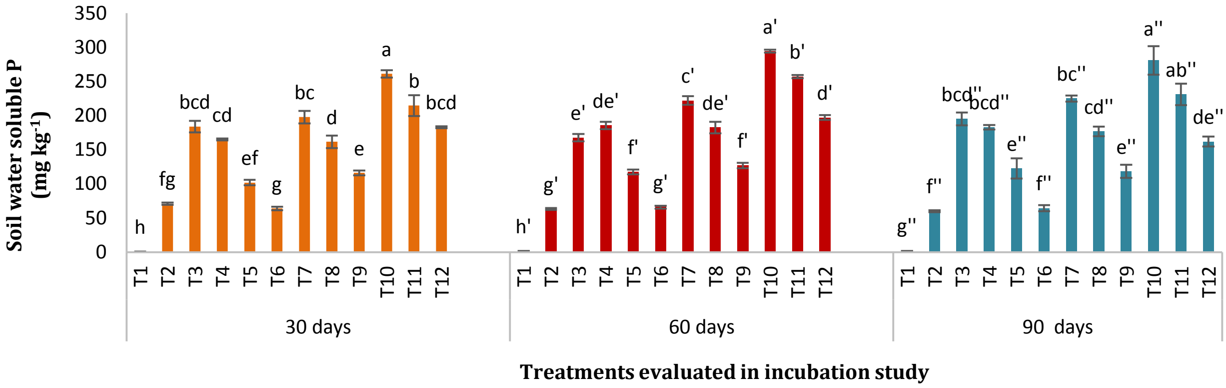

Figure 6. Effects of treatments on soil water soluble P at 30, 60 and 90 DAI. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

Effects of different amounts of chicken litter biochar and phosphorus on soil total acidity, CEC, and exchangeable Al^{3+}, H^{+}, Fe^{3+}, K^{+}, Ca^{2+}, Mg^{2+}, and Na^{+}

The interaction between treatments and incubation time significantly affected soil exchangeable Al^{3+}, and Fe^{2+} (Tables 5 and 6). Although the interaction between treatments and incubation time did not significantly affect soil total acidity, the soil total acidity, soil exchangeable Al^{3+}, and soil exchangeable Fe^{2+} of T1 at 30, 60, and 90 days of incubation were significantly higher than those of T2, T3, T4, T5, T6, T7, T8, T10, T11, and T12 (Figures 7, 8, and 9) because of the inherent contents of Al^{3+} and Fe^{2+} of the soil. This also indicates that the use of chicken litter biochar effectively reduced soil total acidity within 30 days period and can be used for plants that have short growth period. The total acidity, soil exchangeable Al^{3+}, and soil exchangeable Fe^{2+} of T2 at 30, 60, and 90 days of incubation were lower than those of T1 because the phosphate of T2 fixed some of the Al^{3+} and Fe^{2+} thereby reducing soil acidity, Fe^{2+} and Al^{3+} concentrations in the soil. The total acidity, Al^{3+}, and Fe^{2+} in the soil at 30, 60, and 90 days of incubation were similar in all the soils amended with biochar (T3, T4, T5, T6, T7, T8, T10, T11, and T12) (Figures 7, 8, and 9).

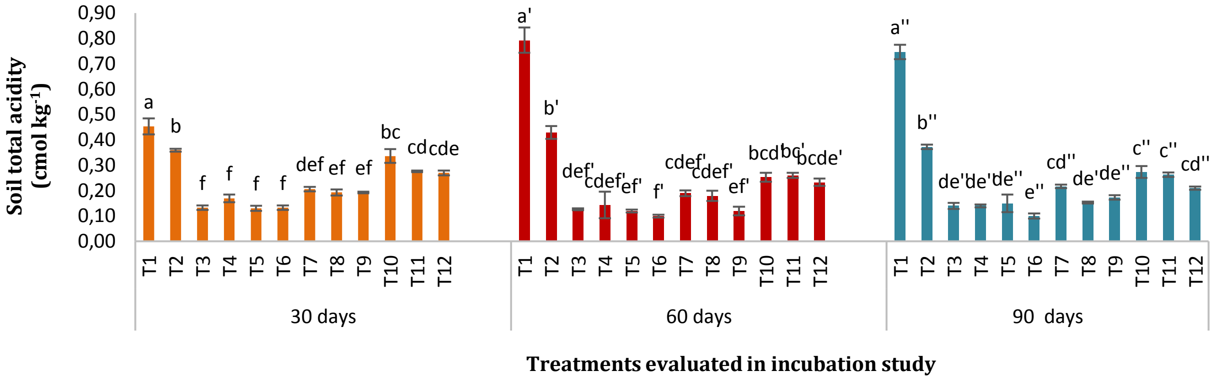

Figure 7. Effects of treatments on soil total acidity at 30, 60 and 90 DAI. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

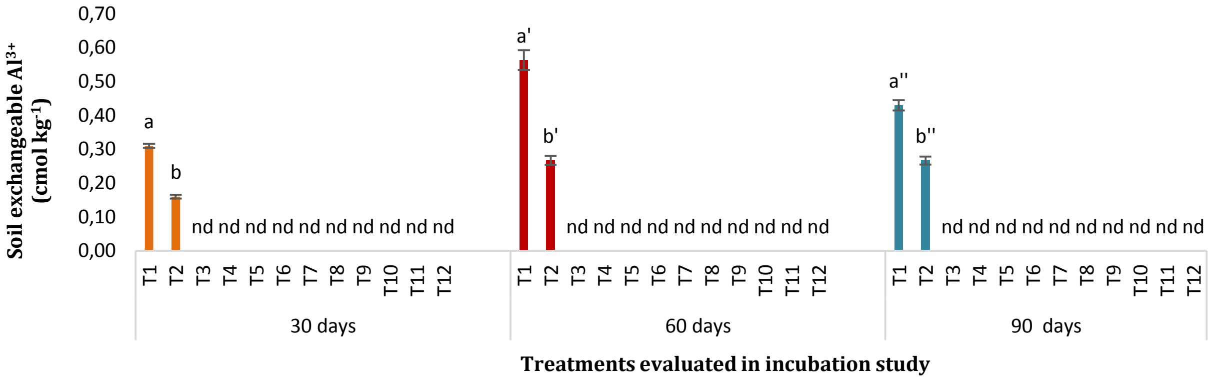

Figure 8. Effects of treatments on soil exchangeable Al^{3+} at 30, 60 and 90 DAI. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE. *Note*: (nd = not determine)

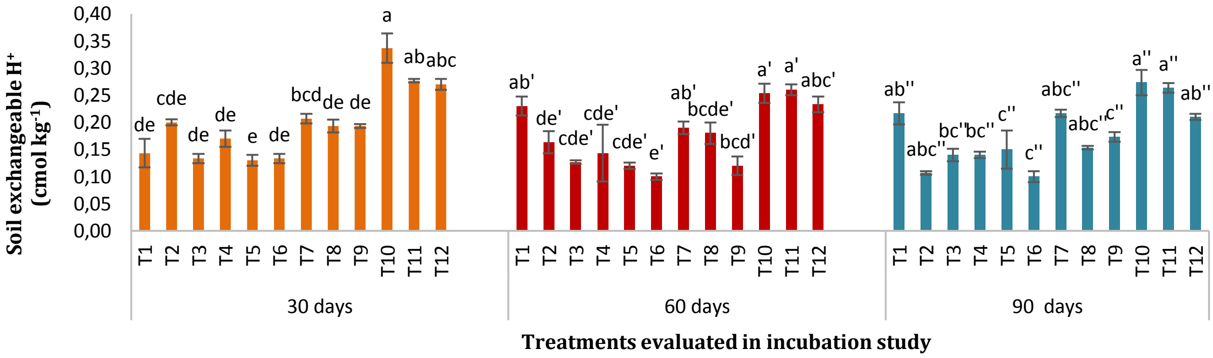

Figure 9. Effects of treatments on soil exchangeable H^{+} at 30, 60 and 90 DAI. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

The interaction between time of incubation and treatments significantly affected soil CEC, total N, exchangeable K^{+}, H^{+}, Ca^{2+}, Mg^{2+}, and Na^{2+} (Tables 5 and 6). The soil exchangeable H^{+} of T1 and T2 were not significantly different from those of T3, T4, T5, T6, T7, T8, and T9 but lower than those of T10 and T11

(Figures 9 and 10) because of the presence of soil exchangeable Fe^{2+}. This observation also suggests that the affinity of chicken litter biochar for Al^{3+} was higher than for Fe^{2+}. The soil exchangeable H^+ of T10 and T11 were significantly higher because of the lowest rate of TSP in these treatments. The differences in H^+ might be due to application of TSP which led to the release of H^+ as it reacted with water to produce orthophosphate ($Ca(H_2PO_4)_2 + 2H_2O \rightarrow CaHPO_4 + H^+ + H{+}PO_4^-$). The soil CEC and total N of T1 and T2 were significantly lower than those of T3, T4, T7, T8, and T10 (Figures 11 and 12). However, the exchangeable K^+, Ca^{2+}, Mg^{2+}, and Na^+ of T1 and T2 were significantly lower than those of T3, T4, T5, T6, T7, T10, T11, and T12 (Figures 13, 14, 15, and 16) because of the presence of these nutrients in chicken litter biochar. This observation is consistent with that of Ch'ng et al. (2014a).

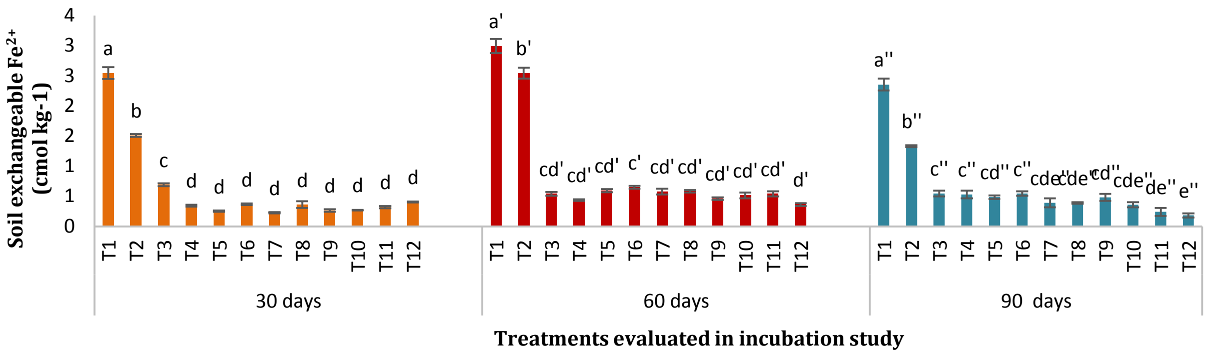

Figure 10. Effects of treatments on soil exchangeable Fe^{3+} at 30, 60 and 90 DAI. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

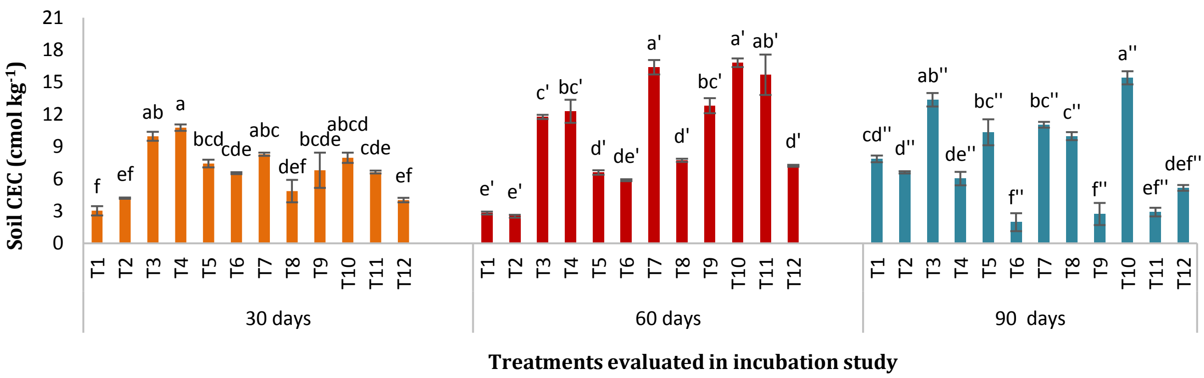

Figure 11. Effects of treatments on soil CEC at 30, 60 and 90 DAI. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

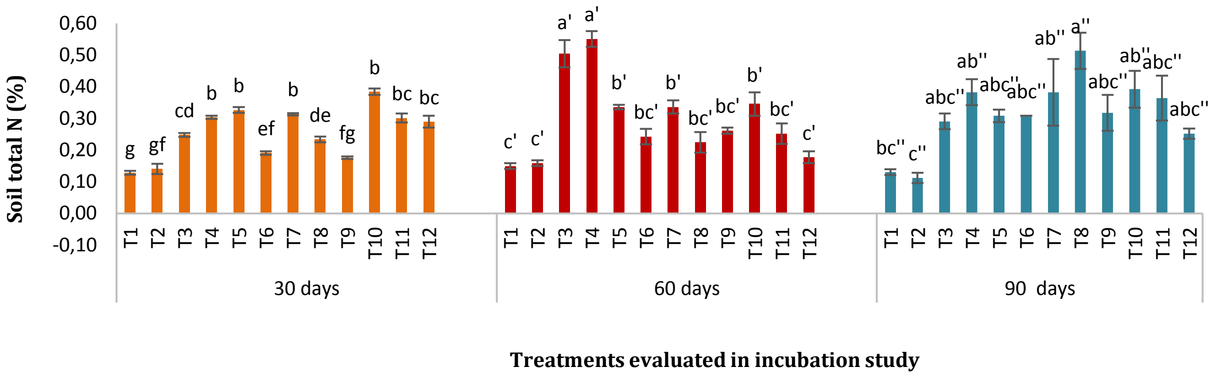

Figure 12. Effects of treatments on soil total N at 30, 60 and 90 DAI. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

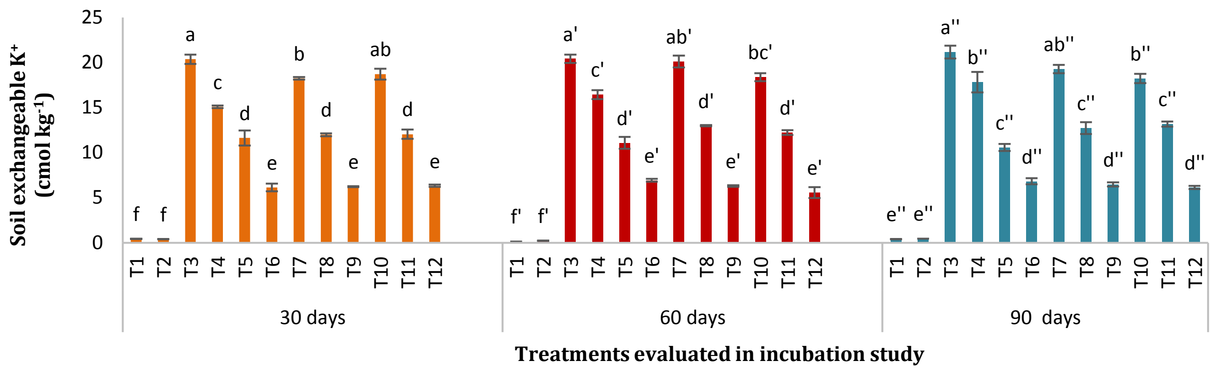

Figure 13. Effects of treatments on soil exchangeable K after 30, 60 and 90 DAI. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

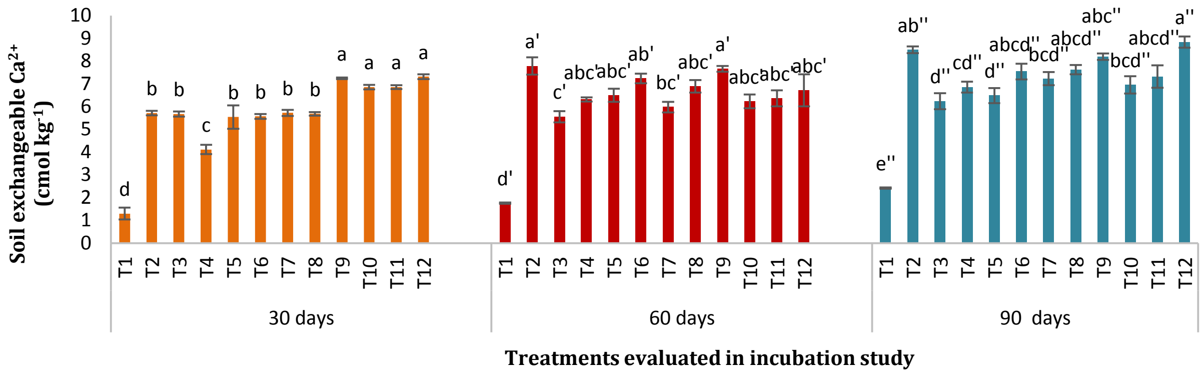

Figure 14. Effects of treatments on soil exchangeable Ca at 30, 60 and 90 DAI. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

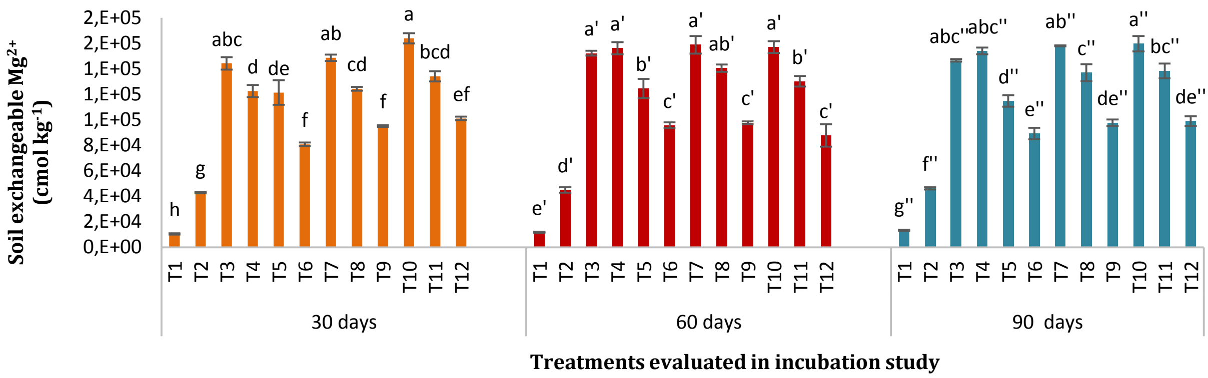

Figure 15: Effects of treatments on soil exchangeable Mg at 30, 60 and 90 DAI. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

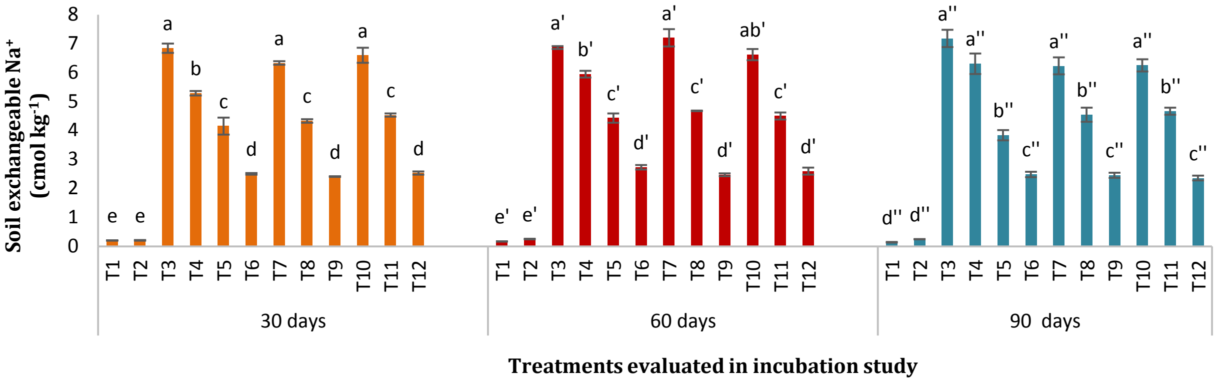

Figure 16. Effects of treatments on soil exchangeable Na at 30, 60 and 90 DAI. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

Conclusion

The use of 75% and 50% chicken litter biochar of 5 t ha^{-1} with 25% TSP showed greater interaction and higher release of soil total P, available P, and water soluble P because these rates were able to reduce Al and Fe ions in the soil. This study also showed that significant amounts of Al and Fe were fixed within the first 30 days of incubation. The soil total P, available P, and water soluble P increased with increasing incubation period because of continued decomposition of the chicken litter biochar. The significant fixation of Al and Fe by biochar within the first 30 days of incubation suggests that biochar can be used in the tropical acid soil to unlock P for short terms crops such as maize and some vegetables. 75% and 50% of 5 t ha^{-1} biochar with 25% TSP can be used to increase P availability for the cultivation of crops such as maize on tropical acid soils with high P fixing capacity.

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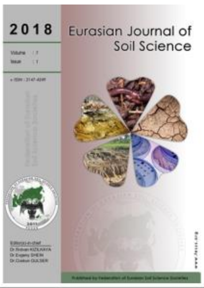

Soil physico-chemical properties and fertility status of long-term land use and cover changes: A case study in Forest vegetative zone of Nigeria

Idowu Ezekiel Olorunfemi [a,*], Johnson Toyin Fasinmirin[a,b], Funke Florence Akinola [c]

[a] Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Nigeria
[b] Department of Agricultural and Bio-systems Engineering, Landmark University, Omu Aran, Nigeria
[c] Department of Agricultural and Bio-environmental Engineering, Federal Polytechnic, Ado Ekiti, Nigeria

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Abstract

Proper utilization of land is essential to soil quality maintenance and sustainable agricultural development. This study was conducted to evaluate effects of land use management on physico-chemical characteristics of soils in Ekiti State, Southwestern Nigeria. In this study, a total of 105 sampling points in 35 locations comprising of the 3 land uses were sampled. Random sampling pattern of 3 sampling points per location were carried out and undisturbed soil samples were collected at depths up to 30 cm. Soil physical properties (bulk density (BD), water holding capacity (WHC), and particle size distribution) and chemical properties (organic matter content (SOM), cation exchange capacity (CEC), phosphorus (P) and organic nitrogen (SON)), were determined and evaluated. Results showed that natural forest on the overall accumulated more nutrients than plantations and cropland. The highest SOM value of 4.07 % was recorded in the natural forests, while the lowest value of 1.52 % was found in the croplands. Organic matter accumulation showed a decreasing trend in the order: forest > plantation > cropland. Natural forest soils had significantly higher volumetric moisture content (VMC) than plantations and croplands. Correlation analysis of the 11 physico-chemical properties for the study area, showed a significant correlation among 70 of the 190 soil attribute pairs. Land use system reveals a significant decline of soil quality under cropland. Management systems by which soil could be improved towards the development of suitable agricultural management systems must be incorporated during land cultivation. In order to have sustainable land use systems, land use development must not be only economically sustainable but also socially acceptable and environmentally sound. Therefore, strategies to improve agricultural productivity have to seek a sustainable solution that better addresses soil fertility management.

Keywords: Organic matter, bulk density, natural forest, croplands, plantation agriculture.

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Introduction

The rapidly increasing human populations and their needs/uses of the land for various agricultural activities have brought about extensive land use changes and soil management practices throughout the world (Cunningham et al., 2005). In the forest vegetative zone of Nigeria, the conversion of natural forests into low input agricultural systems and subsequent deforestation have tremendous impacts on physical and chemical properties of the soils which are of key importance to land management and sustainability. Over the years, soil biodiversity and its physical properties that control water movement and retention in the soils are

* Corresponding author.
Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Nigeria
Tel.: +234 7037986945 E-mail address: olorunfemiidowu@gmail.com
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largely affected due to human, animal activities as well as use of machine for soil tillage purposes (Tilahun, 2007). The ability of a soil to generate some products or perform some functions may decline with certain land uses. These manifests as changes in soil properties such as nutrient content (nitrogen, phosphorus, potassium, calcium, magnesium, sodium), pH, organic matter, cation exchange capacity, structure etc (Akinrinde and Obigbesan, 2000; Akamigbo and Asadu, 2001). It has been observed that as the fertility of soil declines, soil structure weakens and the soil becomes susceptible to erosion (Adetunji, 2004). The decline in soil fertility, therefore, has been caused by the increased withdrawal of plant nutrients from the soil without replenishment consequent to increased plant growth.

Soil fertility decline and hence reduced soil productivity is a subject of major concern in Africa as it contributes to hunger (famine), food insecurity and farm or household incomes (Nandwa, 2003). Agricultural sustainability requires periodic evaluation of soil fertility status. This is important in understanding factors which impose serious constraints to increased crop production under different land use types and for adoption of suitable land management practices (Chimdi et al., 2012). However, information about the effects of land use changes on soil physico-chemical properties is essential in order to present appropriate recommendations for optimal and sustainable utilizations of land resources.

Global land use and soil management play a central role in determining our food, material and energy supply because land is a finite resource. The effects of land uses on the environment ranges from minor land cover changes and soil modification to severe desertification, deforestation, erosion, and river encroachment problems. Therefore, there is increasing concern about the land use land cover changes and its negative impacts on soil quality and the environment in many part of the world due to the current global population growth and economic development. In order to have sustainable land use systems, land use development must not be only economically sustainable but also socially acceptable and environmentally sound. Therefore, strategies to improve agricultural productivity have to seek a sustainable solution that better addresses soil fertility management.

Soil physical and chemical properties play a central role in transport and reaction of water, solutes and gases in soils, their knowledge is very important in understanding soil behaviour to applied stresses, transport phenomena in soils, hence for soil conservation and planning of appropriate agricultural practices. The anthropogenic changes in land use have altered the characteristics of the Earth's surface, leading to changes in soil physico-chemical properties such as soil fertility, soil erosion sensitivity and content of soil moisture (Abad et al., 2014). These changes may be caused by soil compaction that reduces soil volume and consequently lowers soil productivity and environmental quality (Abad et al., 2014). Soil physical and chemical properties have been proposed as suitable indicators for assessing the effect of land-use changes and management (Janzen et al., 1992; Alvarez and Alvarez, 2000). This approach has been used extensively by several authors to monitor land-cover and land-use change patterns (Schroth et al., 2002; Walker and Desanker, 2004; Yao et al., 2010). Therefore, this study was carried out to in order to evaluate the influence of different land use types on soil physicochemical properties in soils of Southwestern Nigeria.

Material and Methods

Experimental Site and Procedure

Experimental Site

The study was conducted in Ekiti State in the forest vegetative zone of Nigeria. Ekiti State is located between Latitudes 7° 15' to 8° 5' N and Longitude 4° 45' to 5° 45' E (EKSG, 2009). The State is mainly an upland zone with elevation ranging from 250 to 540 m above sea level (a.s.l.) (Simon-Oke and Jegede, 2012). The State lies on an area underlain by metamorphic rock and is potentially rich in mineral deposits which include kaolin, columbite, channockete, iron ore, barite, aquamine, gemstone, phosphate, limestone, gold among others largely deposited in different towns and villages within the State (Olorunfemi and Fasinmirin, 2017). The climate of the State is a tropical climate with two distinct seasons (rainy season (April – October) and dry season (November – March)). The air temperature ranges between 21° and 28° with high humidity. Ekiti State has a total annual rainfall of about 1400 mm with a low co-efficient of variation about 30% during the peak of rainfall, and an average of about 112 rainy days per annum (Adebayo, 1993). The vegetation of Ekiti State is of the guinea forest with its attendant climate, flora and fauna (EKSG, 2009).

Experimental Procedure

Soil samplings were conducted across 35 different locations under three different land uses in Ekiti State (Figure 1) to determine their physiochemical properties. The different land uses (treatments) in the study area include intensive row crops under minor grazing, agricultural tree crop plantations *(Tectona grandis*, *Gmelina arborea*, *Elaeis guineensis, Musa acuminata)*, and forests (dominantly trees/woodlands/shrubs, disturbed and undisturbed forests). The croplands have been put under manual tillage (using Cutlass and Hoe) for cassava and yam cultivation sometimes intercropped with maize for more than 15 consecutive years according to the farmers. *Tectona grandis* plantations were established since the past 25 to 29 years while *Musa acuminata* has been under cultivation for over 10 years. *Elaeis guineensis* plantations are about 23 years old. The forest soils are uncultivated and comprise of shrubs, woodlands and deciduous trees under the protection of the state forest reserve agency. The land uses studied were categorized under three (3) main treatments, which include croplands (CP), plantation agriculture (PA) and natural forests (NF).

The three land uses represent the treatment with different numbers of replicates (locations) as stated. In all the 35 locations, 17 croplands, 11 plantation agricultural sites and 7 natural forests were examined. Three sampling points were randomly selected per location for each land use treatment for detailed infiltration measurements and soil sampling. For the determination of soil moisture content, bulk density, total porosity, macro and micro porosity, three (3) sampling points were randomly selected per location and three (3) undisturbed samples were collected at each sampling point. Soil samples collected were packed in plastic bags, and transferred to the laboratory for physiochemical analysis.

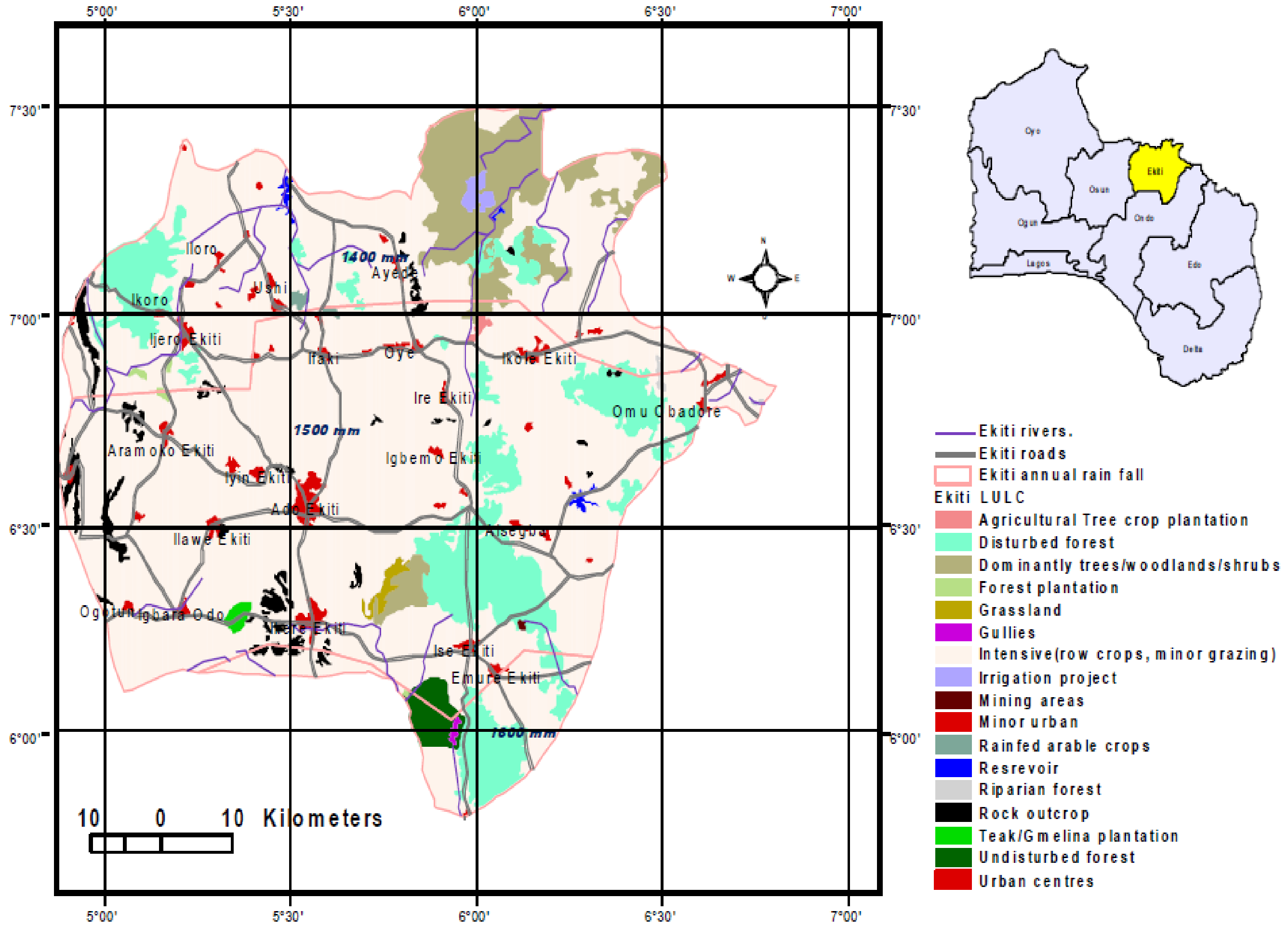

Figure 1. Land use and land cover map of Ekiti State (Source: EKSG, 2009).

Measurements

Physico-chemical characterization of soils

Chemical characterization of the sampled soils included the analysis of organic matter (SOM), organic carbon (SOC), cation exchange capacity (CEC) at pH 7.0, base saturation, Al^{3+} saturation and soil pH; whereas the physical characterization consists of particle size analysis, water holding capacity (WHC), bulk density (BD) and total porosity (PT) determination. The samples were allowed to dry in the open air until reaching friability. The organic carbon was determined using the Walkley - Black wet oxidation procedure and the soil organic matter content was determined from the organic carbon (Nelson and Sommers, 1996). Soil pH was determined in distilled water using the pH meter with water ratio of 1:2. Available phosphorus (P) and exchangeable cations were determined. Available P was determined by Bray-1 extraction followed by molybdenum blue colorimetry (Frank et al., 1998). The exchangeable potassium (K^+) and sodium (Na^+) was extracted with HCl solution and their levels determined by flame photometry (Vogelmann et al., 2010; Olorunfemi et al., 2016) and exchangeable magnesium (Mg^{2+}) and calcium (Ca^{2+}) determined by atomic absorption spectrophotometer after extraction with KCl 1.0 mol l^{-1} (Senjobi and Ogunkunle, 2010). The cation exchange capacity (CEC) at pH 7.0 was determined following the procedure described by Reeuwijk (2002). Soil particle sizes were determined using the hydrometer method described in Agbede and Ojeniyi (2009) and classification was carried out using the USDA classification system (Soil Survey Staff, 1999). Soil water holding capacity (WHC) was determined following the method described by Ibitoye (2006). The bulk density (BD) was obtained by the gravimetric soil core method described by (Blake and Hartage, 1986) and the particle density (PD) was assumed to be 2.65 g cm^{-3} (Osunbitan et al., 2005; Li and Shao, 2006; Zhang et al., 2006; Price et al., 2010). The total porosity (PT) was obtained from BD and PD using the equation and relationship developed by Danielson and Sutherland (1986).

$$PT = 1 - \frac{BD}{PD} \quad (1)$$

where: BD = Bulk density and PD = Particle density (= 2.65 Mg/m^3). The default value of 2.65 Mg/m^3 is used as a 'rule of thumb' based on the average bulk density of rock with no pore space (Fasinmirin and Olorunfemi, 2013). Micro porosity (Mic) and macro porosity (Mac) were obtained following the method described by Olorunfemi and Fasinmirin (2017).

Ca^{2+}, Mg^{2+}, Na^+ ions were isolated from the soil complex with flame photometer to estimate SAR and ESP using following equations.

$$SAR = \frac{Na}{\sqrt{\frac{1}{2} \times (Ca + Mg)}} \quad (2)$$

$$ESP = \frac{exchangeable\ Na^+}{CEC} \times 100 \quad (3)$$

where SAR is sodium absorption ratio and ESP is exchangeable sodium percentage.

Statistical Analysis

Each soil property was compared using Pearson correlation coefficient at 1 and 5% significant levels and the existence of inter-relationships between data set was tested by linear correlation. Soil properties were subjected to statistical analysis to determine the mean, standard deviation, coefficient of variation, and linear and nonlinear regressions using Statistical Analysis System (SAS) (SAS Institute Inc., Cary, NC) and MINITAB 17. Soil properties were subjected to the Tukey test at 5% level of significance. One way Anova was used to test for significance among the treatments and post hoc comparison was used to compare the soil physical and chemical properties from the different land uses.

Results and Discussion

Soil physical properties

Soil particle size analysis

The particle size distribution of the different land uses is shown in Table 1. The sand, silt, and clay percentages of the soil samples from the croplands sites at an average of 0 – 30 cm soil depth ranged from 240 g kg^{-1} to 540 g kg^{-1}, 120 g kg^{-1} to 320 g kg^{-1}, and 220 g kg^{-1} to 500 g kg^{-1} respectively, while soil samples from the plantation agriculture sites ranged from 300 g kg^{-1} to 640 g kg^{-1}, 400 g kg^{-1} to 280 g kg^{-1} and 220 g kg^{-1} to 560 g kg^{-1} for sand, silt, and clay, respectively. Similarly, the soil samples collected from the natural forests ranged from 240 g kg^{-1} to 540 g kg^{-1}, 100 g kg^{-1} to 300 g kg^{-1} and 200 g kg^{-1} to 500 g kg^{-1} for sand, silt, and clay respectively. Sampled soils did not show significant differences in the sand, silt, and clay percentages among CP, PA, and NF soils at 0.05 level. However, there were little variations in the particle size composition of the sampled soil of the different land uses. Numerically, croplands have the highest average sand contents (438.82 g kg^{-1}) and the least average clay content (328.24 g kg^{-1}) respectively. Despite the fact that texture is an inherent soil property, management practices may have contributed indirectly to the changes in particle size distribution particularly in the surface layers as result of removal of soil by sheet and rill erosions, and mixing up of the surface and the subsurface layers during continuous tillage activities (Tilahun, 2007). It can also be stated that the effect of soil tillage on soil particle size by Gülser et al. (2016) reported that heterogeneity and variation of soil physical parameters in a field due to soil plowing should be taken into consideration for a successful agricultural management. Therefore, differences in particle size distribution, which can be attributed to the impact of deforestation and farming practices such as continuous tillage or cultivation and intensive grazing, can be observed, though not significant ($p \leq 0.05$) (Tilahun, 2007).

Table 1. Summary statistics for surface soil parameters under different land uses

Land uses	Croplands	Plantations	Forests
Statistics	Mean ± STD (CV)	Mean ± STD (CV)	Mean ± STD (CV)
Sand (g kg^{-1})	438.82 ± 82.61(0.19)a	471.67 ± 101.79 (0.22)a	417.14 ± 124.05 (0.30)a
Silt (g kg^{-1})	232.94 ± 47.93 (0.21)a	185.00 ± 67. 76 (0.37)a	217.14 ± 68.73 (0.32)a
Clay (g kg^{-1})	328.24 ± 81.26 (0.25)a	343.33 ± 102.99 (0.19)a	365.71 ± 115.31 (0.32)a
Silt/Clay	0.76 ± 0.26 (0.34)a	0.61 ± 0.31(0.52)a	0.68 ± 0.39 (0.58)a
WHC (%)	43.14 ± 7.52 (0.17)b	42.93 ± 5.08(0.12)b	53.66 ± 10.56 (0.20)a

Means in a row that do not share 'a' letter are significantly different. Where STD = standard deviation and CV = coefficient of variation

Water holding capacity (WHC)

The WHC of all soil sites ranged widely from 29.27 to 71.83 % with an average value of 44.50 %. The average WHC value was found to be significantly affected by land uses [$F(2, 32) = 5.83$, $p \leq 0.01$] (Table 2). Post hoc comparisons of means showed that average WHC value of NF sites is significantly higher than that of PA and CP which are homogenous. The statistics of WHC of the different land uses show that NF has maximum WHC value of 71.83 % and minimum value of 43.38 % with an average of 53.66 % (± 10.56). The WHC of the PA ranged from 51.94 % to 34.86 % with an average value of 42.52 % (± 4.70) while that of CP has ranged from 64.49 % to 29.27 % with an average value of 43.07 % (± 7.76).

Table 2. Analysis of variance of the surface soil properties between land uses

Properties	Mean Square		F - Value	Significance
	Trt (Land use type)	Error		
Sand (g kg^{-1})	7833	9825	0.8	ns
Silt (g kg^{-1})	8779	3571	2.46	ns
Clay (g kg^{-1})	3558	9440	0.38	ns
Silt/Clay	0.08854	0.09627	0.92	ns
WHC (%)	330.35	56.64	5.83	**

*** = $P \leq 0.001$; ** = $P \leq 0.01$; * = $P \leq 0.05$ ns = not significant, Trt – treatment

The highest WHC value (71.83 %) was recorded in NF soil which also has the highest organic matter content (4.07 %), while the lowest (29.27 %) occurred in CP with organic matter content of 1.55 %, which was among the least recorded. Correlation between WHC and OMC (r = 0.58, N = 35, $p \leq 0.01$) showed a significant positive relationship. This was probably due to the ability of SOM to act as a sponge in the soil, thereby retaining soil moisture. Organic matter intimately mixed with mineral soil materials has a considerable influence in increasing moisture holding capacity (FAO, 2005). Soil organic matter is able to store a quantity of water which corresponds to a multiple of the organic matter's weight (Hudson, 1994; Emerson, 1995).

It is also noteworthy that soil texture also influences the water retention capabilities of soils of the different locations as soils with high clay percentage or both (high clay percentage and organic matter content) tends to have high water holding capacity. The results of the correlation analysis between WHC (%) and Clay percentage in all the 35 sites revealed a significant and positive relationship (r = 0.54, N = 35, $p \leq 0~.01$). Water holding capacity of any soil is determined by its texture, structure, and the amount of organic matter it contains. Olorunfemi and Fasinmirin (2017) from their findings reported that soils having high proportion of sands are associated with low WHC. Water holding capacity depends upon the capillary pore spaces in the soil. Soil with very high proportion of sand have very low water holding capacity due to large pore spaces between the particles which enables the water to percolate freely into deeper layers leaving upper layers practically dry. In clay soil, due to very small size of the pore spaces (fine capillaries) the water is retained in the capillary spaces as capillary water and therefore the water does not percolate freely. The result shows that if clay and organic matter contents increase, water holding capacity of the soil also increases (FAO, 2005). This observation is similar to the findings of Senjobi and Ogunkunle (2011) who state that the water holding capacity of the soils increases with increase in clay content of the soils in their study to assess the extent to which different land use types influences land degradation and productivity in Ogun State, Nigeria. Knowing the soil water storage capacity allows the irrigator to determine how much water to apply at one time and how long to wait between each irrigation schedule. The soil texture and the crop rooting depth affect the total amount of water that is stored in the soil within the plant's root zone.

Bulk density

The bulk density (BD) of soils in all project sites ranged from 1.15 Mg m^{-3} to 1.41 Mg m^{-3} with a mean value of 1.29 Mg m^{-3} (± 0.08) in the superficial layer (0 – 10 cm), 1.24 Mg m^{-3} to 1.5 Mg m^{-3} with a mean value of 1.34 Mg m^{-3} (± 0.06) in the 10 – 20 cm depth, and from 1.29 Mg m^{-3} to 1.54 Mg m^{-3} having an average value of 1.43 Mg m^{-3} in the 20 – 30 cm depth (Table 3). One – way ANOVA demonstrated that bulk density differed significantly among the soil depths ($F(2, 102) = 42.06$, $p \leq .05$). The mean bulk density was significantly lower in the 0 – 10 cm depth than in the 10 – 20 cm depth, and the BD of the 10 – 20 cm depth was equally significantly lower than that of the 20 – 30 cm soil depth. In all the sites of the different land uses, bulk density showed an increasing trend down the depths (0–10 cm, 10–20 cm and 20–30 cm) respectively. Bulk density typically increases with depth because of changes in soil texture, gravel content, and structure (Landsberg et al., 2003), but also because of biological activity on surface soils with high organic matter content and vegetation residues which decreases down the soil profile (Doerr et al., 2000). Reduced aggregation, root penetration and less pore space of the subsurface layers compared to surface layers equally lead to increase bulk density down the soil layers (USDA, 2008). This is also expected because of the overburden weight of soil above the subsurface layers (Sands et al., 1979). This is consistent with the findings of Price et al. (2010) who discovered that the mean bulk density of the upper layers was significantly ($p < 0.001$) lower than the lower layers in their study to characterize soil physical properties under three land-use classes (forest, pasture, and managed lawn) in the southern Blue Ridge Mountains of southwestern North Carolina. In all the sites, the bulk density showed a regular increase with depth (i.e. higher bulk density at the lower soil layers) (Table 3), except at four (4) locations whose bulk density decreased slightly in the 10 - 20 cm soil layer, though the general trend of increase in bulk density was observed in others layers. This is in agreement with the work of Siltecho et al. (2010), who obtained similar findings of regular increase in bulk density down the soil profiles under a young rubber tree plantation and a ruzi grass but observed a slight decrease in bulk density under natural forest.

Table 3. Summary of statistics for segmented soil physical parameters under different land uses

Parameters	Land uses	Croplands	Plantations	Forests
/Statistics	Depths (cm)	Mean ± STD (CV)	Mean ± STD (CV)	Mean ± STD (CV)
BD (Mg m^{-3})	0 – 10	1.30 ± 0.07 (0.06)a	1.29 ± 0.09 (0.07)a	1.27 ± 0.06 (0.05)a
	10 – 20	1.34 ± 0.05 (0.04)a	1.36 ± 0.07 (0.05)a	1.29 ± 0.06 (0.05)a
	20 – 30	1.43 ± 0.05 (0.04)a	1.43 ± 0.05 (0.04)a	1.41 ± 0.06 (0.04)a
PT (m^3 m^{-3})	0 – 10	0.51 ± 0.03 (0.05)a	0.51 ± 0.03 (0.07)a	0.52 ± 0.02 (0.04)a
	10 – 20	0.49 ± 0.02 (0.04)ab	0.48 ± 0.02 (0.05)b	0.51 ± 0.02 (0.05)a
	20 – 30	0.45 ± 0.02 (0.03)a	0.46 ± 0.02 (0.04)a	0.47 ± 0.02 (0.05)a
Mic (m^3 m^{-3})	0 – 10	0.10 ± 0.02 (0.14)a	0.10 ± 0.01 (0.10)a	0.13 ± 0.02 (0.16)b
	10 – 20	0.12 ± 0.02 (0.13)a	0.11 ± 0.01 (0.09)a	0.15 ± 0.03 (0.17)b
	20 – 30	0.13 ± 0.02 (0.14)a	0.12 ± 0.01 (0.06)a	0.17 ± 0.03 (0.17)b
Mac (m^3 m^{-3})	0 – 10	0.41 ± 0.03 (0.08)a	0.42 ± 0.04 (0.09)a	0.39 ± 0.03 (0.08)a
	10 – 20	0.37 ± 0.03 (0.08)a	0.37 ± 0.03 (0.08)a	0.36 ± 0.04 (0.10)a
	20 – 30	0.32 ± 0.03 (0.08)ab	0.34 ± 0.03 (0.08)a	0.30 ± 0.04 (0.12)b
VMC (m^3 m^{-3})	0 – 10	5.85 ± 2.51 (0.43)a	5.12 ± 1.70 (0.33)a	9.80 ± 4.09 (0.35)b
	10 – 20	8.66 ± 2.85 (0.33)a	7.27 ± 1.86 (0.26)a	12.85 ± 3.11 (0.32)b
	20 – 30	11.50 ± 3.42 (0.30)a	9.30 ± 0.87 (0.15)a	17.18 ± 4.50 (0.29)b

Means in a row that do not share 'a' letter are significantly different. Where BD = Bulk Density, PT = Total Porosity, Mic = Micro Porosity, Mac = Macro Porosity and VMC = Volumetric Moisture Content

There was no significant difference ($p \leq 0.05$) in the bulk density distribution down the depths among the various land uses. It is noteworthy that bulk density is primarily affected by soil texture (Canarache, 1991) since well graded soils containing both fine and coarse particles results in a higher number of contact points than in a poorly graded soil (Kohnke and Franzmeier, 1995) but in the case where the sites are subjected to different land uses, the bulk density cannot be restrictive as observed in the study sites. This observation agrees with that of Vogelmann et al. (2010).

Soil porosities

Table 3 showed the variation of the total porosity, microporosity and macroporosity with depth at the various experimental sites. The total porosity varies from 0.47 $m^3 m^{-3}$ to 0.57 $m^3 m^{-3}$ with a mean value of 0.51 $m^3 m^{-3}$, standard deviation of 0.03 and coefficient of variation of 6 % in all the locations (Table 4). The estimated total porosity is inversely related to the bulk density. This observation agrees with the works of Olorunfemi and Fasinmirin (2012) and Vogelmann et al. (2010). The microporosity values ranged from 0.02 $m^3 m^{-3}$ to 0.17 $m^3 m^{-3}$ having a mean value of 0.06. The standard deviation of the surface horizon (0 – 10 cm) for the microporosity is 0.04 with coefficient of variation of 61 %. Likewise, the sites' macropores ranged from 0.31 $m^3 m^{-3}$ to 0.52 $cm^3 cm^{-3}$ having a mean value of 0.46 $m^3 m^{-3}$, standard deviation of 5 % and a low coefficient of variation of about 12 %. %). The total porosity, microporosity and macroporosity data down the soil depths differ significantly among the three soil layers. The total porosity and macroporosity decreases down the depth while the microporosity increases down the soil depth because of changes in soil texture, gravel content, and structure, and also because of reduced effect of soil tillage operations. Soil macro and microporosity have been used in important studies on soil aeration, soil water dynamics and soil compaction (Scardua, 1972; Freire, 1975; Primavesi et al., 1984).

Table 4. Analysis of variance of the segmented soil physical properties between land uses

Properties	Depths	Mean Square		F - Value	Significance
		Trt (Land use type)	Error		
BD (Mg m^{-3})	0 – 10	0.001969	0.005867	0.34	ns
	10 – 20	0.010827	0.003643	2.97	ns
	20 – 30	0.001060	0.002936	0.36	ns
PT ($m^3 m^{-3}$)	0 – 10	0.000325	0.000813	0.40	ns
	10 – 20	0.001700	0.000546	3.11	*
	20 – 30	0.000317	0.000337	0.94	ns
Mic ($m^3 m^{-3}$)	0 – 10	0.002279	0.000224	10.18	***
	10 – 20	0.003193	0.000273	11.68	***
	20 – 30	0.004659	0.000341	13.64	***
Mac ($m^3 m^{-3}$)	0 – 10	0.000945	0.001181	0.80	ns
	10 – 20	0.000313	0.000975	0.32	ns
	20 – 30	0.003466	0.000775	4.47	*
VMC ($m^3 m^{-3}$)	0 – 10	52.153	6.314	8.26	***
	10 – 20	69.090	8.279	8.35	***
	20 – 30	135.97	11.13	12.22	***

*** = $P \leq 0.001$; ** = $P \leq 0.01$; * = $P \leq 0.05$ ns = not significant, Trt – treatment

Statistical analysis indicates significant ($p \leq 0.05$) difference in total porosity among the land uses at 5 – 10 cm soil depth indicating that not all the groups of the land uses resulted in the same total porosity value. Microporosity was significantly ($p \leq 0.001$) affected by land uses in all the soil depths while macroporosity was only significantly ($p \leq 0.05$) affected by land uses at 20 – 30 cm soil depth. High micropores in the natural forest may be due to the absence of tillage operations and continuity of pores. Tillage, especially plowing, creates macropores that cause saturated and near- saturated hydraulic conductivities to increase considerably, but also disrupts pore continuities that reduce hydraulic conductivities between plough layers and subsoils (Olorunfemi and Fasinmirin, 2012).

Volumetric moisture content

Volumetric moisture content (VMC) distribution with depth among the land uses is presented in Table 3 with NF having the highest mean volumetric moisture content value. The volumetric moisture content of soils in all project sites ranged widely from 1.97 $m^3 m^{-3}$ to 14.02 $m^3 m^{-3}$ with a mean value of 6.41 $m^3 m^{-3}$ (± 3.00) at the soil superficial layer (0 – 10 cm), 4.48 $m^3 m^{-3}$ to 16.79 $m^3 m^{-3}$ with a mean value of 9.06 $m^3 m^{-3}$ (± 3.44) at the 10– 20 cm depth and from 6.49 $m^3 m^{-3}$ to 21.60 $m^3 m^{-3}$ having an average value of 11.94 $m^3 m^{-3}$ (± 4.30) at the 20 – 30 cm depth. The volumetric moisture content data differ significantly among the three soil layers down the soil depths. The volumetric moisture content was significantly higher in the lower layer (20 – 30 cm) than in the middle layer (10 – 20 cm), and the VMC of the middle layer (10 – 20 cm) was equally significantly higher than the VMC value of the upper layer (0–10 cm) respectively. This is in agreement with the work of Halfmann (2005) who noted that soil moisture increases with depth and that there was a significant increase in soil moisture at the 5-10 cm depth. Reduced aggregation, less pore space of the subsurface layers and increase bulk density down the soil layers compared to surface layers (USDA, 2008) equally lead to high volumetric moisture content.

Statistical analysis showed significant difference in VMC among the land uses down the soil layers (0 – 10 cm, 10 – 20 cm and 20 – 30 cm) indicating that not all the groups of the land uses resulted in the same VMC value. In this study, NF soils had significantly higher VMC than PA and CP and Tukey simultaneous 95% confident interval for the difference of means between the different land use types shows that the corresponding means between PA and CP are not significantly different down the soil depths. The high volumetric moisture content in NF may not be unconnected with the high micro porosity values. Very small pores pull water through capillary action in addition to and even against the force of gravity, while smaller pores offer greater resistance to gravity (Devore, 1995). The high VMC in the natural forest was also a reflection of its high soil organic matter content (SOM) and an indication of the affinity of organic matter for water (Oguike and Mbagwu, 2009). However, several studies have demonstrated no significant differences between the volumetric moisture content at field capacity of disturbed and undisturbed soils (Jusoff, 1989). Price et al. (2010) found consistent and significantly higher VMC at field capacity in forest than pasture and lawn soils, by a factor of nearly 20%. The observed results generally showed that the soils under different land uses may also differ in their water content at both FC and PWP because they vary in sand, silt and clay contents as rightly observed by Yeshaneh (2015).

Soil chemical properties

Soil organic carbon and organic matter

The soil organic carbon (SOC) of the soils of all the locations varies from 0.88 % to 2.36 %. Overall, the mean of the SOC of all soil sites is 1.42 % ± 0.38 with coefficient of variation of about 27 %. The organic carbon which is an index of the soil organic matter differs among the different land uses. In the natural forests, SOC varies from 1.24 % to 2.36 % having a mean value of 1.73 % ± 0.44 and coefficient of variation of 39 % (Table 5). The PA has organic carbon ranging from 0.88 % to 2.16 % with a mean value of 1.42 %. The coefficient of variation is about 41 %. In the same way, in the agricultural land organic carbon value has a maximum value of 1.74 % and a minimum value of 0.88 % averaging 1.26 % ± 0.28 with a coefficient of variation of about 32 % (Table 5). Soil organic carbon varied among the land uses studied (Table 5 and 6). The three land uses considered were significantly different ($F(2, 32) = 5.67$, $p \leq 0.01$) in soil organic carbon (Table 5 and 6). In this study, NF on the overall accumulated more organic carbon than PA sites and cultivated CP. The SOC is of the order NF > PA > CP. Natural forest naturally had the highest organic carbon value as forests play a vital role in the global carbon cycle. Forests absorb carbon through photosynthesis and sequester it as biomass, thus creating a natural storage of carbon. Croplands on the other hand had the least soil organic carbon. Much of this loss in soil organic carbon can be attributed to reduced inputs of organic matter, increased decomposability of crop residues, and tillage effects that decrease the amount of physical protection to decomposition (Post and Kwon, 2000). A great number of studies have reported similar observations. Paustian et al. (1996) observed that a greater frequency of cropping with associated increases in SOC is due to greater return of crop residues. Yimer et al. (2007) in Ethiopia also compared croplands, forestlands and grazing lands and found that soil organic C and total N decreased in croplands as compared to forestlands. Also, high temperature and high relative humidity, which favor rapid mineralization, might be responsible for decreasing order of magnitude of organic carbon (NF > PA > CP) in conformation with the finding of Senjobi and Ogunkunle (2011).

Soil organic matter comprises an accumulation of partially disintegrated and decomposed plant and animal residues and other organic compounds synthesized by the soil microbes as the decay occurs (Brady, 1990). The results of the soil organic matter (SOM) of all the 35 locations show that the percentage organic matter of the different land uses ranged from 1.52 % to 4.07 % with an average of 2.46 % ± 0.66. The coefficient of variation of SOM is about 29 %. The three land uses considered (Croplands, Plantations and Natural forests) were significantly different ($F(2, 32) = 5.63$, $p \leq 0.01$) in soil organic matter content. Tukey HSD showed that SOM was significantly higher in the natural forests as compared with that in the croplands. The highest SOM value of 4.07 % was recorded in the natural forests, while the lowest value of 1.52 % was found in the croplands. Soil organic matter ranged from 2.14 % to 4.07 % in the natural forests with an average value of 2.98 % ± 0.79. The spatial variability of the SOM of the natural forests is about 27 %. The organic matter of the plantation agriculture showed a variability of 24.5 % ranging from 1.62 % to 3.72 %. It has an average value of 2.46 % with a standard deviation of 0.6. The organic matter content value of CP ranged from 1.52 % to 3 % averaging 2.17 % ± 0.48 and with a variability of 22.33 %. In all, the NF has the highest average organic matter content; this may be due to findings that soils underlying native vegetation (e.g., undisturbed natural forest) generally feature high SOM, as a result of ample litter cover, organic inputs, root growth and decay, and abundant burrowing fauna (Price et al., 2010). The CP have the least average SOM, as cropping of the soils may have led to erosion and leaching of soil nutrients which in turn, adversely affects the physico – chemical properties of the soils (Oguike and Mbagwu, 2009). Also, Sombroek et al. (1993) reported a 20–50% reduction of SOM as a result of clearing tropical forests and their subsequent conversion into farm land. The clearing of forests for annual crop production invariably resulted in a loss of soil organic matter because of the removal of large quantities of biomass during land clearing, a reduction in the quantity and quality of organic inputs added to the soil and increasing soil organic matter decomposition rates. These higher decomposing rates are due to enhanced biological activity caused by soil mixing from tillage and higher temperatures from increased soil exposure (Barber, 1995). Furthermore, Lal (1986) and Oguike and Mbagwu (2009) reported that with continuous cultivation, physical properties and productivity of many soils commonly decline due to decrease in SOM and soil pH. However, the level of response to changing management practices differs across eco-regions and strongly interact with local climate, land use, farming systems and soil/crop management systems (Post and Kwon, 2000).

Table 5. Summary statistics for surface soil chemical parameters under different land uses

Land uses	Croplands	Plantations	Forests
Statistics	Mean ± STD (CV)	Mean ± STD (CV)	Mean ± STD (CV)
Soil pH	5.93 ± 0.30 (0.05)a	5.90 ± 0.41(0.07)a	6.06 ± 0.72 (0.01)a
Available Phosphorus (ppm)	18.43 ± 11.11 (0.60)a	23.76 ± 13.12 (0.55)a	24.03 ± 14.19 (0.59)a
SOC (%)	1.27 ± 0.28 (0.22)a	1.48 ± 0.38 (0.26)ab	1.78 ± 0.44 (0.25)b
SOM (%)	2.19 ± 0.48 (0.22)a	2.59 ± 0.65(0.25)ab	3.06 ± 0.76 (0.25)b
SON (%)	0.065 ± 0.015 (0.24)a	0.072 ± 0.018 (0.26)ab	0.089 ± 0.022 (0.25)b
CEC (cmol+kg^{-1})	5.98 ± 1.79 (0.30)a	6.54 ± 2.22(0.34)ab	8.08 ± 1.42 (0.18)b
SAR	0.084 ± 0.023 (0.27)a	0.079 ± 0.016 (0.21)ab	0.058 ± 0.022 (0.37)b
ESP (%)	2.11 ± 0.78 (0.37)a	1.94 ± 0.55 (0.28)ab	1.29 ± 0.54 (0.41)b
BS (%)	81.80 ± 10.94 (0.13)a	81.83 ± 9.16(0.11)a	88.75 ± 3.17 (0.04)a
ASP (%)	11.33 ± 5.73 (0.51)a	12.01 ± 3.92(0.33)a	7.36 ± 1.90 (0.26)a

Means in a row that do not share a letter are significantly different. Where SOC = Soil organic Carbon, SOM = Soil Organic Matter, SON = Soil Organic Nitrogen, CEC = Cation Exchange Capacity, SAR = Sodium Absorption Ratio, ESP = Exchangeable Sodium Percentage, BS = Base Saturation and ASP = Aluminum Saturation Percentage

Soil organic nitrogen

The soil organic nitrogen (SON) in all 35 sites varies from 0.044 % to 0.118 %. It has an average value of 0.071 % ± 0.02 with a coefficient of variation of 27.5 % (Table 5). The NF soils have the highest mean organic nitrogen of 0.09 % while the croplands have the least average value of 0.06 %. Difference in SON among the land uses were statistically significant ($F(2, 32) = 4.49$, $p \leq 0.05$) (Table 6). The mean SON of NF is significantly higher than that of CP while mean SON of PA soils did not differ significantly from that of NF and CP ($p \leq 0.05$). This can be attributed to the land use and management system as roughly 95% of soil organic nitrogen is found in soil organic material in undisturbed, natural soils (Walworth, 2013). Soil organic material in the naturals soils are as a result of ample litter cover, organic inputs, root growth and decay, and abundant burrowing fauna (Price et al., 2010). Al-Kaisi et al. (2005) investigated soil carbon and nitrogen changes as influenced by tillage and cropping systems in some Iowa soils and discovered No-tillage increased total nitrogen content by 9.1% (0.3 Mg ha $^{-1}$) over chisel plowing averaged across five soil associations at the 0–15 cm soil depth. Increase in the intensity and frequency of tillage operations which produces more soil disturbance decreased total nitrogen contents (Franzluebbers et al., 1999). Meysner et al. (2006) reported that there are variations in mineral nitrogen leaching between farming systems due to differences in production mix within farm types. Previous findings by Havlin et al. (1990), Franzluebbers et al. (1995) and Halvorson et al. (2002) have shown that soil can be managed to increase soil organic carbon and nitrogen storage from a long- term (>10 years) perspective. This can be achieved by implementing conservation soil and crop management practices such as conservation tillage.

Cation exchange capacity (CEC)

The CEC of all the sampled soils (which is a measurement of its ability to bind or hold exchangeable cations) shows a variability of about 32 % ranging from 3.43 $cmol_c.kg^{-1}$ to 11.97 $cmol_c.kg^{-1}$ with PA having the highest mean value and CP having the least mean value (Table 6). The soils of all the sites have an average CEC value of 6.53 $cmol_c.kg^{-1}$ ± 2.01. The statistics of the CEC with respect to land uses shows that average values of the CEC for the different land uses are 8.08 $cmol_c.kg^{-1}$ ±1.42, 6.38 $cmol_c.kg^{-1}$ ± 2.26 and 5.98 $cmol_c.kg^{-1}$ ± 1.79 for NF, PA and CP, respectively (Table 5). In the NF, CEC vary from 5.53 $cmol_c.kg^{-1}$ to 10 $cmol_c.kg^{-1}$ with a coefficient of variation of 17.6 %. The Croplands CEC values ranged from 3.43 $cmol_c.kg^{-1}$ to 9.58 $cmol_c.kg^{-1}$ with a higher coefficient of variation of 30 % while in the PA, it varied from 4.28 $cmol_c.kg^{-1}$ to 11.97 $cmol_c.kg^{-1}$ with the largest coefficient of variation (37 %).

Table 6. Analysis of variance of the surface soil chemical properties between land uses

Properties	Mean Square		F - Value	Significance
	Trt (Land use type)	Error		
Soil pH	0.05943	0.10165	0.58	ns
Available phosphorus (ppm)	129.1	153.3	0.84	ns
SOC (%)	0.6388	0.1126	5.67	**
SOM (%)	1.9036	0.3379	5.63	**
SON (%)	0.00141	0.00032	4.49	*
CEC ($cmol^{+}kg^{-1}$)	11.107	3.591	3.09	*
SAR	0.001666	0.000433	3.85	*
ESP (%)	1.6858	0.4528	3.72	*
BS (%)	140.03	90.07	1.55	ns
ASP (%)	56.62	21.97	2.58	ns

*** = $P \le 0.001$; ** = $P \le 0.01$; * = $P \le 0.05$ ns = not significant, Trt – treatment.

There was a statiscally significant difference ($p \le 0.05$) in CEC among the treatments (Table 6). Comparisons of means by Tukey procedure was used to determine which pairs of the three treatments means differed. The results indicate that the mean CEC of NF and CP are significantly different. In absolute term, NF has highest average CEC of 8.08 $cmol_c.kg^{-1}$ (± 1.42) which may be due to their high organic matter content while croplands have the least average CEC of 5.98 $cmol_c.kg^{-1}$ (± 1.79). The lowest CEC under the cultivated lands may be due to the depletion of organic matter which is as a result of intensive cultivation and this is in agreement with findings from previous researches (Abebe, 1980; Gao and Chang, 1996).

Characterizing soils cation exchange capacity (CEC) is of utmost importance as it can be a good indicator of soil productivity and is also useful for making recommendations of phosphorus, potassium, and magnesium for soils of different textures. The results of the correlation analysis between CEC (%) and Clay percentage (r = 0.36, N = 35, p ≤ 0 .05) and also CEC (%) and SOM (%) (r = 0.54, N = 35, p ≤ 0 .001) in all the sites revealed a significant and positive relationship (Table 7). From our observation, high CEC values were found in soils with high organic matter content and clay particles. This shows that CEC is mainly dependent on soil clay minerals and organic matter (Martel et al., 1978; Manrique et al., 1991; Harada and Inoko, 2012) and silt to a lesser extent (Rashidi and Seilsepour, 2008). There is a strong correlation between the CEC values, and the amount of organic matter present in the soil as Organic matter is a major source of negative electrostatic sites. The research findings conform to the works of Bayer and Bertol (1999); Vogelmann et al. (2010) and Fasinmirin and Olorunfemi (2012) who all reported that soil samples with higher values of CEC were found to have high levels of organic matter and pH levels. Likewise, in any given soil, soil pH; type, size and amount of clay; and amount and source of the organic material influenced the number of exchange sites (Kamprath and Welch 1962; Parfitt et al., 1995; Miller, 1970; Rashidi and Seilsepour, 2008).

Soil pH

The results of the chemical properties of the sample soils are presented in Table 6. The average pH value of all the locations is 5.95. The pH level of the soil directly affects soil life and the availability of essential soil nutrients for plant growth. Factors such as parent material, rainfall, and type of vegetation are dominant in determining the pH of soils. Under cultivation, however, organic acids from plant roots, repeated use of acid-forming fertilizers, plant removal, and replacement of calcium and magnesium by hydrogen eventually lowers the pH of topsoil. The pH value for the NF soils ranged from 5.96 to 6.17 with an average value of 6.06 ± 0.07 while in the PA, the max. and min. pH value are 6.36 and 4.95 respectively with an average pH value of 5.90 ± 0.43. Likewise, the CP have a pH value ranging from 5.46 to 6.31 with an average value of 5.93 ± 0.30. In all the sites, there was no definite sequence in the distribution of their degree of acidity and alkalinity but in general the soil pH values fall within the acceptable limit for maximum utilization of soil nutrients (Soil Survey Staff, 2009). Analysis of variance of the soil properties between land uses showed that the pH distribution is homogenous ($p \le 0.05$) among the different treatments. Inherent factors affecting soil pH such as climate, mineral content and soil texture cannot be changed. The slightly lower average value of soil pH under the cropland and plantations may be due to the depletion of basic cations in crop harvest and due to its highest microbial oxidation that produces organic acids, which provide H ions to the soil solution lowers its soil pH value (Chimdi et al., 2014).

Available Phosphorus

The available phosphorus of all sites ranged from 3.92 ppm to 43.54 ppm. The available phosphorus was not significantly different among the land uses. Croplands slightly have lower values than soils under PA and NF. This may be due to soil organic matter being the main source of available Phosphorus (Mamo and Haque, 1987). The availability of phosphorus under most soils decline by the impacts of fixation, abundant crop harvest and erosion (Yeshaneh, 2015).

However, it was observed that 45.71 % (16 experimental sites) of the soil sites showed low phosphorus availability (<20 ppm) compared with the critical level of 10 – 16 ppm (Adeoye and Agboola, 1985) while the rest 54.29 % (19 experimental sites) fall in the medium category (20 ppm – 40 ppm). Availability of Phosphorus is maximized when soil pH is between 5.5 and 7.5 (Mullen, 2004) which happen to be the ideal pH range for optimal availability of plant nutrients for most crops. Also soils with inherent pH values between 6 and 7.5 and by moist, warm conditions are ideal for P-availability, while pH values below 5.5 and between 7.5 and 8.5 limits P-availability to plants due to fixation by aluminum, iron, or calcium, often associated with soil parent materials (Soil Survey Staff, 2009).

Sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP)

There was a significant difference ($P < 0.05$) for SAR and ESP among the three land use types. SAR was highest in CP (0.084 %), followed by PA (0.079 %) and least in forest (0.058 %). Likewise, ESP was highest in CP (2.11 %), followed by PA (1.94 %) and least in NF (1.29 %). Soils that have more than 6% ESP are considered to have structural stability problems related to potential dispersion (van de Graaff and Patterson, 2001).

Total base saturation (BS) and aluminium saturation (ASP)

In all sites, the base saturation ranged from 57.73 % to 94.49 % (Table 6). It has an average value of 83.10 % ± 9.64 with a coefficient of variation of about 12%. Soils with 70% or greater BS are unlikely to limit agronomic crop growth due to acidity. The values of the base saturation showed no definite sequence in their distribution among the different land uses in the study sites. Likewise, the percentage of aluminium saturation in all the locations ranged from 2.70% to 23.32 % with an average percentage of 10.85 % ±4.9 and coefficient of variation of 45.2 %. The average aluminium saturation percentages across the different land uses showed that NF have the least ASP (7.37 % ± 1.9) while soils of PA have the highest ASP (12.33 % ± 3.94). Croplands have average ASP of 11.34 % ± 5.74. The total base saturation (BS) and aluminium saturation (ASP) were not significantly or highly affected by land use systems.

Correlation between base saturation (%) and aluminium saturation (%) showed that base saturation (%) correlated negatively and significantly with aluminium saturation (%) ($r = -0.70$, $N = 35$, $p = 0.001$) indicating that higher values of base saturation are associated with lower levels of aluminium saturation (Table 7). The correlation was strong in strength and higher values of base saturation (%) were also associated with lower values of aluminium saturation (%). The soils that have high base saturation were found having low aluminium saturation and high pH values and vice versa. This is in agreement with the findings of Streck et al. (2008), who reported that low saturation of bases could be traced to high Al saturation and low pH in Oxisols and Alfisol. Vogelmann et al. (2010) also reported low base saturation in Paleodult and Hapludox, which together had low pH and high Al saturation in their research to identify and determine the hydro-repellency of soils of Rio Grande do Sul, Southern Brazil. Higher values of base saturation were associated with higher levels of soil pH. The base saturation is inversely related to aluminum saturation and directly related to the levels of organic matter, pH and CEC as reported by Vogelmann et al. (2010). High base saturation in soils are associated with high CEC (Souza and Alves, 2003). Zalamena (2008) also observed similar findings especially in the lower horizons.

The results of the correlation analysis between base saturation (%) and soil pH at $p < 0.05$ revealed a significant difference and positive correlation. Correlation analysis between aluminium saturation (%) and soil pH revealed a negative relationship for all the experimental sites. In all, higher values of base saturation were associated with lower levels of soil pH (negative correlation).

Exchangeable cations and acidity of the land uses

The means of the exchangeable cations and exchangeable acidity are presented in Table 4 and 5. The five (5) most abundant cations in soils are calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}) and in strongly acid soils, aluminium (Al^{3+}). These are summed up to give an approximate value of CEC called effective CEC. The individual cations can be expressed as a percentage (%) of the effective CEC (Abbott, 1989). The exchangeable bases (K, Ca, Mg and Na) in all the land uses were dominated by calcium and magnesium. The exchangeable calcium (Ca^{2+}) varied from 1.2 $cmol_c.kg^{-1}$ (240 ppm) to 6.3 (1260 ppm) $cmol_c.kg^{-1}$ with an average value of 3.35 $cmol_c.kg^{-1}$ ±1.27. It has a variability of 38 %. The mean percent base saturation of calcium (50.46 %) of all the sites falls within the ideal base cation saturation ration (BCSR) of 50 % – 70 % for calcium which is ideal for pH range of 5.8 to 6.5 (www.hill-laboratories.com) but less than that (60 % - 70 %) recommended by Albrecht (1975). Calcium is rarely deficient when soil pH is adequate and in a soil where calcium is deficient, the soil will require an application of lime ($CaCO_3$) to increase the base saturation of Ca before it will be a productive soil. In the natural forest, the exchangeable calcium ranged from 3 $cmol_c.kg^{-1}$ (600 ppm) to 6 $cmol_c.kg^{-1}$ (1200 ppm) with a mean value of 4.51 $cmol_c.kg^{-1}$ ± 0.94 (903 ppm) and coefficient of variation of 21 %. The average exchangeable calcium of the plantation agriculture is 3.13 $cmol_c.kg^{-1}$ ± 1.24 (626 ppm) with a higher variability of 40 % ranging from 2 $cmol_c.kg^{-1}$ (400 ppm) to 6.3 $cmol_c.kg^{-1}$ (1260 ppm). The exchangeable calcium of the croplands varied from 1.2 $cmol_c.kg^{-1}$ (240 ppm) to 5.6 (1120 ppm) $cmol_c.kg^{-1}$. It has an average value of 3.01 $cmol_c.kg^{-1}$ ± 1.18 (602 ppm) with a variability of 39 %.

The exchangeable magnesium of all soil sites ranged from 0.5 $cmol_c.kg^{-1}$ (61 ppm) to 3 $cmol_c.kg^{-1}$ (363 ppm) which is within the medium (0.5–2.5 $cmol_c.kg^{-1}$/ 60 – 300 ppm) and high (>2.5 $cmol_c.kg^{-1}$ / >303 ppm) categories of exchangeable magnesium for crop production (Horneck et al., 2011). Overall, the mean of exchangeable magnesium of all soil sites is 1.43 $cmol_c.kg^{-1}$ ± 0.59 (173 ppm) with a coefficient of variation of 41 %. The overall mean of the exchangeable magnesium cation falls within the range (100 ppm – 250 ppm) given as the optimum magnesium levels for crop production. The amount of magnesium adequate for crops can be further determined by its base saturation, which should be between 10 -20 % (Albrecht, 1975; Young, 1999). The mean base saturation of magnesium of all soils sites is 21. 44 % which is very slightly higher than the recommended range. Soils having a magnesium base saturation in excess of 30 - 35 % may exhibit serious problems, such as soil crusting and restricted root development. In respect to the different land uses, the magnesium in the NF ranged from 1.1$cmol_c.kg^{-1}$ (133 ppm) to 2.2 $cmol_c.kg^{-1}$ (266 ppm) with a mean value of 1.83 $cmol_c.kg^{-1}$ ± 0.39 (221 ppm) and coefficient of variation of 21 %. Likewise, the PA has a mean value of 1.45 $cmol_c.kg^{-1}$ ± 0.65 (175 ppm) ranging from 1 $cmol_c.kg^{-1}$ (121 ppm) to 3 $cmol_c.kg^{-1}$ (363 ppm) with a variability of 45 %. The exchangeable magnesium of the croplands varied from 0.5 $cmol_c.kg^{-1}$ (61 ppm) to 2.6 $cmol_c.kg^{-1}$ (315 ppm). The average magnesium is 1.26 $cmol_c.kg^{-1}$ ± 0.56 (152 ppm) and the coefficient of variation is 44 %.

The exchangeable sodium of all sites indicates the degree of which the soil exchange sites are saturated with Sodium. The exchangeable sodium of all sites ranged from 0.03$cmol_c.kg^{-1}$ (6.9 ppm) to 0.16 $cmol_c.kg^{-1}$ (36.8 ppm) with an average value of 0.11 $cmol_c.kg^{-1}$ ± 0.02 (25.96 ppm). The variability of exchangeable sodium in all soil sites is 22 %. Sodium (Na), though is not an essential element for plant growth, but is important for diagnosing problem soils that may contain high amounts of sodium. High levels of exchangeable sodium affect soil structure, soil permeability and may be toxic to sensitive plants (Horneck et al., 2011). Sodium levels are evaluated based on exchangeable sodium percentage (ESP) which is the percent of the CEC occupied by sodium (Na). The exchangeable sodium percentage (ESP) of all sites ranged from 0.42 % to 4.27 %. The average ESP of the soil samples of all the locations (1.89 % ± 0.72) with a variability of 38 % falls within the recommended range (0.5 - 3% Na) given by Albrecht (1975) and also within the ideal sodium base saturation level (1-2 %) (www.hill-laboratories.com). The mean ESP of the different land uses are 1.29% ± 0.53, 1.94% ± 0.55 and 2.11% ± 0.78 for NF, PA and CP respectively which are within the recommended range. Exchangeable sodium greater than 2.5% may cause adverse physical and chemical conditions to develop in the soil that may prevent plant growth. Sodium base saturation values over 7% can represent a water permeability problem. When the estimated exchangeable sodium exceeds 15%, the soil is considered "sodic," but crop production problems may occur at lower levels (Espinoza et al., 1996). Reclamation involves establishment of drainage followed by gypsum application and leaching with low-sodium water (Horneck et al., 2011).

Potassium is the third most important plant nutrient along with nitrogen and phosphorus. The potassium of all soil sites ranged from 0.18 $cmol_c.kg^{-1}$ (70 ppm) to 1.69 $cmol_c.kg^{-1}$ (659 ppm falling within the low (< 0.4 18 $cmol_c.kg^{-1}$ / 150 ppm), medium (0.4 – 0.6 18 $cmol_c.kg^{-1}$ / 150 – 250 ppm) and high (0.6 – 2.0 18 $cmol_c.kg^{-1}$ / 150 – 800 ppm) potassium categories for crop production (Horneck et al., 2011). The potassium is 0.62 $cmol_c.kg^{-1}$ ± 0.36 (243 ppm) on average with coefficient of variation of 58 %. The average potassium of all the soil sites falls within the Medium category regarded as the optimum level. Soils commonly contain over 20, 000 parts per million (ppm) of total potassium. Nearly all of this is a structural component of soils mineral and is unavailable to plants. Plants use only the exchangeable potassium on the surface of soil particles and potassium dissolved in the soil water and this often amounts to less than 100 ppm (Schulte and Kelling, 2011). The potassium can also be evaluated based on the potassium base saturation level. The potassium base saturation level of all soil sites ranged from 3.98 % to 20.14 % with a mean value of 9.03 % ± 3.91 and a variability of 42 %. The mean potassium base saturation of all soil sites is above the recommended range of 2 – 5 % (Albrecht, 1975; Young, 1999). The NF exchangeable potassium ranged from 0.51 $cmol_c kg^{-1}$ (199 ppm) to 1.1 $cmol_c kg^{-1}$ (429 ppm), PA ranged from 0.28 $cmol_c kg^{-1}$ (109 ppm) to 1.46 $cmol_c kg^{-1}$ (569 ppm) while that of CP varied from 0.18 $cmol_c kg^{-1}$ (70 ppm) to 1.69 $cmol_c kg^{-1}$ (659 ppm).

The exchangeable cations can be divided into two groups: bases and acids. The soil pH will be affected by whichever cations predominate on these exchange sites. The more base cations present, the more alkaline the soil (i.e. the higher soil pH will be), whereas the more acid cations present, the more acidic the soil (i.e. the lower the pH). Hydrogen and Aluminium are acid cations which increase soil acidity and therefore lower pH. The hydrogen cation in all soil sites ranged from 0.05 $cmol_c kg^{-1}$ to 1.31 $cmol_c kg^{-1}$ with a mean value of 0.37 $cmol_c kg^{-1}$ ± 0.35. The coefficient of variation is 95 %. Evaluating the hydrogen base saturation levels, it varied widely from 0.59 % to 24.62 % with a mean value of 6.05 % ± 6.26 and coefficient of variation of 103 %. The recommended range of hydrogen base saturation is 10 – 15 % (Young, 1999).

The descriptive statistics of the hydrogen cation of the different land uses showed that the H^+ of the NF ranged from 0.59 $cmol_c kg^{-1}$ to 6.07 $cmol_c kg^{-1}$. It has an average value of 3.89 $cmol_c kg^{-1}$ ± 2.00 and a variability of 51 %. The H^+ in the PA showed the highest variation of 113% ranging from 0.91 $cmol_c kg^{-1}$ to 22.20 $cmol_c kg^{-1}$ with an average value of 6.17 $cmol_c kg^{-1}$ ± 6.99. The CP demonstrated an H^+ variability of 101 %. The H^+ of the CP ranged from 0.82 $cmol_c kg^{-1}$ to 24.62 $cmol_c kg^{-1}$. It has an average value of 6.86 $cmol_c kg^{-1}$ ± 6.96.

Correlation between soil properties

There was a considerable degree of correlation between the physical properties and the various chemical properties measured (Table 7). The linear correlation analysis of the 11 soil physico-chemical properties for the study area, showed a significant correlation among 70 of the 190 soil attribute pairs ($P \leq 0.01$; $P \leq 0.05$) (Table 7). Increasing soils ability to retain water (i.e increasing micropores) reduces their water transmitting ability. The micropores are small enough that the adhesive and cohesive forces holding the water to the pore wall are stronger than the gravitational force trying to drain the soil. The data collected revealed that soil texture influences the water retention capabilities of soils of the experimental locations. We observed a significant and positive relationship (r = 0.54**, N = 35) between WHC (%) and Clay percentage in all the sites. This shows that soils with high clay percentage tends to have high water holding capacity. Likewise, soil with very high proportion of sand have very low water holding capacity due to large pore spaces between the particles which enables the water to move freely (relatively higher hydraulic conductivity) into deeper layers leaving upper layers practically dry. Increases sand and silt content in soil texture increases ratio of macro porosity in total porosity (Gülser and Candemir, 2014). According to Hillel (1998), "a sandy soil will absorb water more rapidly during infiltration, but clay can sustain the evaporation process longer." Clay can hold a large volume of water per volume of bulk material, but they do not release water rapidly. Clay soil, on the other hand, due to very small size of the pore spaces (fine capillaries) retained more water in the capillary spaces as capillary water and as a result, water does not transmit easily.

Cation exchange capacity showed positive correlation with soil pH (r = 0.441**), SOC (r = 0.580**), SOM (r = 572**), WHC (r = 0.580**) and clay content (r = 0.356 *) respectively amongst all the soil samples in the experimental locations (Table 7). It was observed that soils with high organic matter content and clay particles demonstrated high CEC values. The reason for this observation has been stated earlier. Organic matter being a major source of negative electrostatic sites in soils; therefore, there is a strong correlation between CEC value and amount of organic matter present in the soil. Soil water holding capacity correlated positively with clay content (r = 0.539**) and negatively with sand content (r = - 0.517**). Results of the correlation analysis between WHC (%) and SOM (%) revealed a significant and positive relationship (r = 0.584**, N = 35). Olorunfemi and Fasinmirin (2017) reported that soils having high proportion of sands are associated with low WHC. The result also shows that increase in clay and organic matter contents increased the water holding capacity of the soil (FAO, 2005). This observation conformed to the findings of Senjobi and Ogunkunle (2011) who reported that water holding capacity of soils increase with increase in clay content of soils in their study to assess the extent to which different land use types influences land degradation and productivity in Ogun State, Nigeria.

Table 7. Correlation matrix among the different parameters

	Sand	Silt	Clay	Silt/Clay	BD	PT	MIC	MAC	VMC	WHC	pH	P	SOM	SOC	SON	CEC	BS	ASP	SAR	ESP
Sand	1																			
Silt	-.366*	1																		
Clay	-.794**	-.275	1																	
Silt/Clay	.266	.772**	-.794**	1																
BD	.049	-.039	0.077	-.078	1															
PT	-0.16	.093	-.044	.091	-.975**	1														
MIC	-.409*	.282	.238	.036	.056	.007	1													
MAC	.283	-.135	-.205	.041	-.721**	.693**	-.716**	1												
VMC	-.417*	.270	.255	.018	.161	-.098	.993**	-.785**	1											
WHC	-.517**	-.008	.539**	-.306	-.031	.117	.596**	-.347*	.583**	1										
soil pH	.088	.065	-.134	.085	-.181	.139	-.074	.155	-.092	.152	1									
P	.195	-.132	-.115	.012	-.247	.282	.107	.117	.067	.106	-.068	1								
SOM	-.339*	-.137	.440**	-.347*	.070	-.003	.316	-.229	.306	.584**	.139	-.095	1							
SOC	-.363*	-.140	.467**	-.370*	.051	.015	.338*	-.232	.327	.610**	.128	-.089	.993**	1						
SON	-.352*	-.122	.443**	-.344*	.052	.016	.312	-.213	.303	.602**	.116	-.093	.975**	.981**	1					
CEC	-.281	-.101	.356*	-.252	-.027	.089	.297	-.149	.294	.569**	.441**	-.090	.572**	.580**	.543**	1				
BS	-.201	.144	.114	.088	-.192	.245	.179	.048	.159	.462**	.426*	.102	.206	.206	.227	.510**	1			
ASP	.253	-.078	-.210	.045	.061	-.139	-.311	.121	-.306	-.591**	-.254	.035	-.351*	-.370*	-.381*	-.700**	-.824**	1		
SAR	.374*	.105	-.455**	.365*	.120	-.150	-.345*	.144	-.326	-.526**	-.216	-.136	-.485**	-.512**	-.487**	-.633**	-.369*	.526**	1	
ESP	.326	.167	-.446**	.395*	.036	-.073	-.354*	.203	-.346*	.530**	-.251	-.079	-.534**	-.555**	-.523**	-.756**	-.311	.550**	.961**	1

Conclusion

This research evaluated and characterized physiochemical properties of soils of similar geological substrate and climatic conditions but under different land uses (i.e croplands, plantation agriculture and natural forests) in Southwestern Nigeria. Bulk density showed a regular increase with depth (i.e. higher bulk density at the lower soil cores) and has no definite sequence in their distribution across the different land uses. The high volumetric moisture content in natural forest may not be unconnected with their high micro porosity values. The high VMC in the NF was also a reflection of its high soil organic matter content (SOM) and an indication of the affinity of organic matter for water. Water holding capacity of the soils increases with increase in clay and soil organic matter (SOM) content of the soil. Organic carbon and organic matter accumulation follows the order NF > PA > CP. Soils with high organic matter content and clay particles demonstrated high CEC values. Natural forest naturally had the highest organic carbon value as forests play a vital role in the global carbon cycle. In all, the natural forest has the highest average organic matter content; this may be due to findings that soils underlying native vegetation (e.g., undisturbed natural forest) generally feature high SOM, as a result of ample litter cover, organic inputs, root growth and decay, and abundant burrowing fauna. The clearing of forests for annual crop production invariably resulted in a loss of soil quality because of the removal of large quantities of biomass during land clearing, a reduction in the quantity and quality of organic inputs added to the soil and increasing soil organic matter decomposition rates. Land uses and soil management appear to be good predictor of soil fertility status. Success in soil management depends on the understanding of how the soil responds to agricultural practices over time. Reliable knowledge on soil fertility and other soil properties under different land uses and evaluation of the land use systems affecting them can be of great interest in understanding the influences of human activities on soil fertility and possible implications for livelihoods in consideration of increasing food insecurity and soil degradation changes.

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Characterization and classification of soils of Yikalo Subwatershed in Lay Gayint District, Northwestern Highlands of Ethiopia

Endalkachew Fekadu [a,*], Kibebew Kibret [a], Bobe Bedadi [a], Asmare Melese [b]

[a] School of Natural Resources Management and Environmental Sciences, Haramaya University, Dire Dawa, Ethiopia

[b] Department of Plant Science, Debre Berhan University, Debre Berhan, Ethiopia

Abstract

Soil resource information is vital for sound land use planning and sustainable fertility management. This study was carried out with the objective of characterizing and classifying soils of Yikalo Subwatershed at Lay Gayint district, Northwestern Ethiopia. Representative soil pedons were opened along topographic positions and described on genetic horizon basis in the field for their morphological characteristics and analyzed in the laboratory for selected physical and chemical soil properties. The soils were classified following the FAO (2014). The results revealed the presence of variations in the selected morphological properties within a pedon and along the topographic positions. Soils differed in reaction from 4.57 to 6.42. On the surface horizons of the soil pedons, available P content varied from 0.21 to 3.25 mg kg^{-1}, while exchangeable acidity ranged from 0.17 to 3.65 cmol$_c$ kg^{-1} soil. There was no consistent trend for cation exchange capacity (CEC) and PBS (percent base saturation) with soil depth and topographic positions. The soils in Yikalo Subwatershed were classified as Hyperdystric Cambisols (Humic), Haplic Alisols (Humic), Cambic Umbrisols (Colluvic), Haplic Luvisols (Epidystric), and Pellic Vertisols (Mesotrophic). Optimum rates of organic and inorganic amendments should be applied to reduce the level of soil acidity, and improve the fertility level of the soils for better crop production and productivity.

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Introduction

Soil is slowly renewable dynamic natural resource that determines the ultimate sustainability of any agricultural system. Water movement, water quality, land use, and vegetation productivity all have relationships with soil. Soils provide food, fodder and fuel for meeting the basic human and animal needs (Schoonover and Crim, 2015). However, due to the increasing rate of population demanding food, the nutrients have been depleted and the productive capacity of soils has diminished through changes in soil characteristics. This demands systematic evaluation of soil resources with respect to their extent, distribution, characteristics, and use potential, which is very important for developing an effective land use system for augmenting agricultural production on a sustainable basis (Pulakeshi et al., 2014).

The main task of soil classification is to reflect real diversity of soils to make decisions about adequate or sustainable land use. An in-depth study of the soil characteristics and classification will provide baseline information on the physical, chemical, and mineralogical properties of the soil for precision agriculture, land use planning, and management (Ukut et al., 2014). Classification of soils is also useful to facilitate technology

[*] Corresponding author.
School of Natural Resources Management and Environmental Sciences, Haramaya University, P.O. Box 138, Dire Dawa, Ethiopia
Tel.: +251 935723891
E-mail address: endalkf@gmail.com
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transfer and information exchange among soil scientists, decision makers, planners, researchers, and agricultural extension advisors (Assen and Yilma, 2010).

The process of developing a soil map forces one to understand the fundamentals of soils, how they were formed, occur across the landscape or the globe, and how they might respond to use and management. Soil mapping also aims to unravel deficiencies in our understanding of soil properties and processes both in time and space (Hartemink et al., 2012). Hence, the Ethiopian Soil Information System (EthioSIS) led by the Ethiopian government has recently developed soil fertility map for fertilizer recommendations in various regions of the country and, in collaboration with capacity building for scaling up of evidence based best practices in agricultural production in Ethiopia (CASCAPE) project, has published soil maps in selected thirty districts of the country. Major soil types identified in five districts of the Amhara region include Luvisols, Nitisols, Leptosols and Vertisols (Mekonnen, 2015). The existing few soil maps in the country are dominantly smaller scale maps of scattered areas with limited analytical data, which could not help for necessary interpretations and making site-specific land use decisions. Thus, it is imperative to undertake detailed soil survey and mapping for a better understanding of soil resources so that soil patterns and distribution could be predicted and mapped more precisely.

One of the critical constraints hampering agriculture in Ethiopia is unavailability of site-specific information on soil and land characteristics. Adequate information on soil and land characteristics is required for maintaining soil productivity and realization of land use planning. In view of this, soil characterization and classification has been carried out across different parts of Ethiopia (Negassa and Gebrekidan, 2003; Ashenafi et al., 2010; Mulugeta and Sheleme, 2010; Yitbarek et al., 2016) in the western and southern part of Ethiopia. Most of the studies reported depletion of cation exchange capacity (CEC), organic carbon (OC), and total nitrogen (TN) (Ashenafi et al., 2010; Yitbarek et al., 2016). Available soil phosphorus (P) was found to be deficient in most soils of cultivated lands (Mekonnen, 2015; Melese et al., 2015). More recently, variations of soil properties such as TN, organic matter (OM), and CEC with topographic positions and soil depth in some areas of north and south Wollo of the Amhara region have been reported (Nahusenay et al., 2014; Alem et al., 2015). Different soil units such as Acrisols, Cambisols, Fluvisols, Leptosols, Luvisols, Nitisols, Vertisols and Umbrisols with various qualifiers have been identified in the country (Ashenafi et al., 2010; Mulugeta and Sheleme, 2010; Nahusenay et al., 2014; Alem et al., 2015; Yitbarek et al., 2016). However, the studies are limited as compared to the large land mass, landform complexity, and soil variability of the country. This necessitates characterization and classification of soils at a larger scale to produce meaningful soil maps for soil management.

The alarming increase in population in the highlands of Ethiopia is putting persistent pressure on land resources, leading to the removal of soils on slopes and tilling soil without proper soil management practices put in place. This has serious management implications, because the more intensively cultivated upland soils deteriorate rapidly due to erosion and fertility depletion. Investigation of the relationship between landscape and soil properties enhances the effort to improve the fertility and productivity of land. Hence, topography based soil studies play a significant role in the process that dictates the distribution and use of soils on the landscape (Esu et al., 2008). It is widely reported that topography affects soil types and properties at a watershed level (Shimelis et al., 2007; Sheleme, 2011).

Undulating topography and large variations in slope are the characteristic features of Yikalo subwatershed which result in large variations in soil types. The soils have not been characterized and classified for sound land management at Lay Gayint district where agriculture has been widely practiced for thousands of years. Farmers continue to use the land with limited input to improve soil fertility. Moreover, the prevailing land use system and management interventions are not supported with information that shows the potentials and constraints of soil resources. On the other hand, land degradation due to the use of incompatible land management practices has continued unabated. As a consequence, the production and productivity of the smallholder farmers' subsistence farming is declining from time to time. This decline in production and productivity has threatened the food and nutrition security of the community in the study area. Given the population size, which is increasing from time to time at a rate that is not commensurate with the carrying capacity of the land resources in the study area, there is no opportunity for extensification. In order to use the limited land resources more efficiently, site-specific management recommendations based on site-specific information are very much required. Therefore, there is a dire need to characterize soils to pinpoint their constraints and potentials, and classify and map to depict their geographical distribution in the study area. This study was therefore, initiated to characterize the morphological, physical and chemical properties of soils, and classify and map the soils of Yikalo subwatershed.

Material and Methods

Location and topography

The study was conducted at Lay Gayint district of South Gondar Zone of the Amhara National Regional State (ANRS), Ethiopia (Figure 1). The district lies within the geographical grid coordinates of 11°32'-12°16' N and 38°12'-38°19' E, and covers an estimated area of 1548 km^2. It is one of the districts of the ANRS where food and nutrition insecurity is a chronic problem for the majority of the rural population. It is located at about 175 km from Bahir Dar, the capital of the ANRS, in the northeast direction, along the Woreta-Woldia highway.

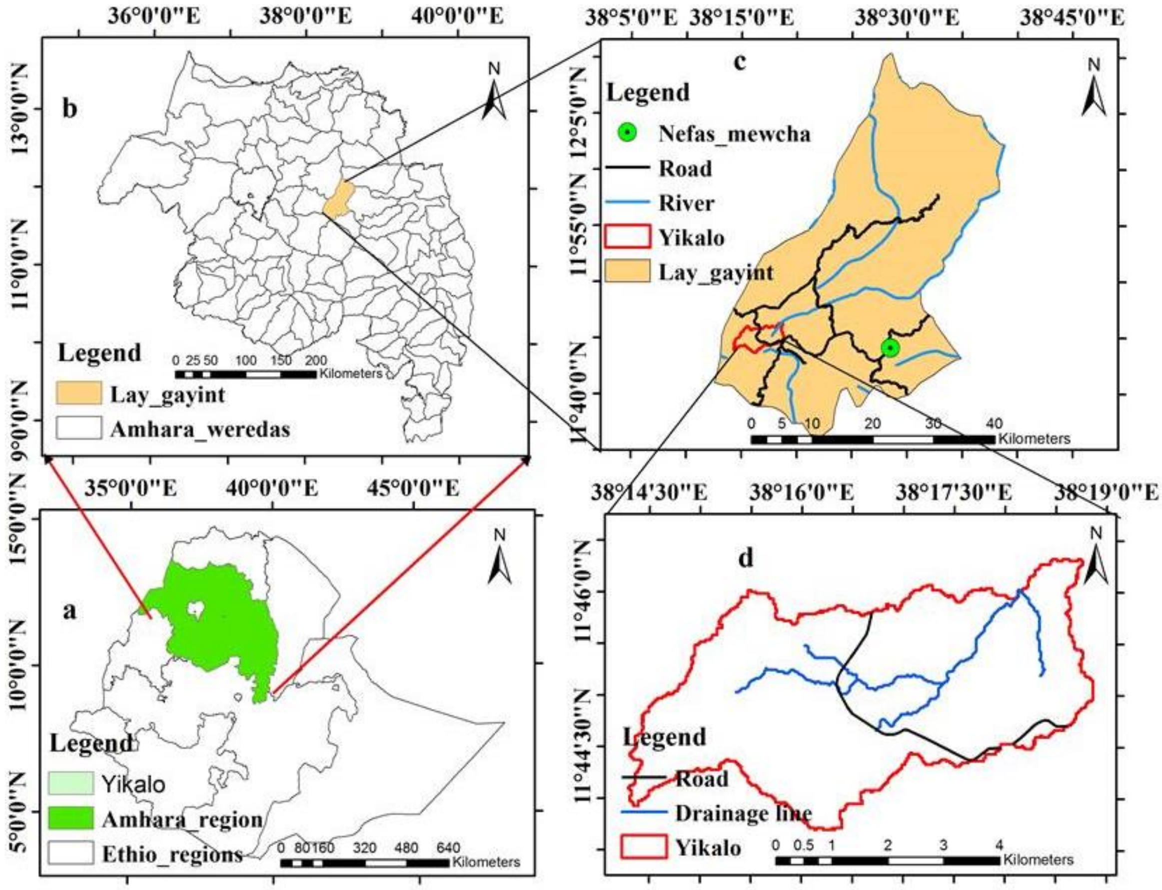

Figure 1. Location map of the study area: (a) ANRS in Ethiopia (b) Lay Gayint district in ANRS (c) Yikalo sub-watershed in Lay Gayint district (d) Drainage lines in Yikalo sub-watershed

The topography of the district is mostly characterized by a chain of mountains, hills, and valleys extending from Tekeze Gorge (1500 m a.s.l.) to the summit of Guna Mountain (4235 m a.s.l.). It is characterized by plain (10%), undulating (70%), mountainous (15%), and gorge and valley (5%) topographic features. The major land use patterns of the study area comprise of cultivated land (44%), grazing land (14%), forest/bush land (5%), water body (2%), infrastructure and settlement (6%), and unproductive land (29%) (Addisu and Menberu, 2015).

Agro-ecology and climate

Agro-ecologically, the district is divided into four elevation and temperature zones, namely: lowland (*kolla*) (12.5%), midland (*woina-dega*) (39.42%), highland (*dega*) (45.39%), and *wurch* (very cold or alpine) (2.71%). Based on a 20 years climate data (1997-2016) obtained from the Ethiopian National Meteorological Service Agency (ENMSA, 2017), Lay Gayint district receives a mean annual rainfall of 1020 mm. The main rainy season, which represents the long rainy season (*meher*) occurs between June and September, while the small rainy season (*belg*) occurs between March and May. The mean minimum and maximum air temperatures of the district are 6.9 and 21.9 ^{0}C, respectively (Figure 2). The coldest month is November, while the warmest month in February. Deforestation, overgrazing, poor quality soil, lack of compatible soil and water conservation measures, and erratic rainfall have contributed to the prevalence of drought in the district.

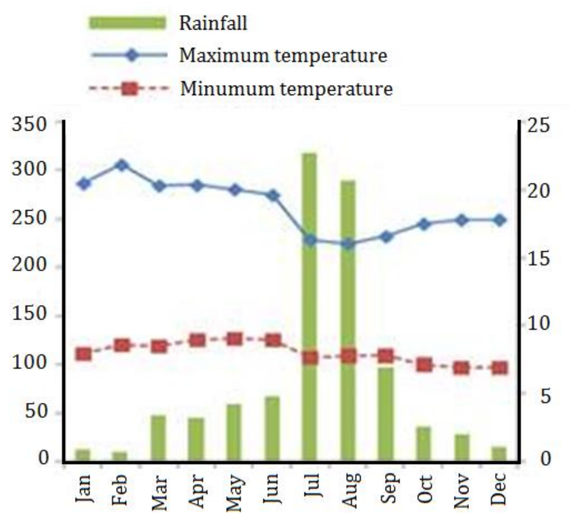

Figure 2. Mean monthly rainfall and mean monthly maximum and minimum temperatures (1997-2016) of Lay Gayint district

Geology and soils

Yikalo subcatchment is part of the Guna volcanic massif, which is one of the huge volcanic centers in the northwestern Ethiopian plateau. It is found between Seimen and Choke Miocene- Pliocene shield volcanoes, east of Lake Tana. The stratigraphy of Guna includes trap basalt, rhyolite lava flow, and pyroclastic flow deposits erupted during Cenozoic Tertiary period in the Pliocene (Adise, 2006). Based on the general soil survey of FAO (1981), the soils in Lay Gayint district include Cambisols, Luvisols, Leptosols and Regosols.

Land use/ farming system and vegetation cover

Most of the people in the district are engaged in mixed crop-livestock agriculture. Crop production is entirely rain-fed, except in some very specific and small areas where vegetables are grown using traditional small-scale irrigation. The most commonly produced crops in the study area are annual crops such as *Triticum aestivum* L., *Eragrostis tef* (Zuccagni), *Zea mays* L., *Sorghum bicolor* L., *Hordeum vulgare* L., *Cicer arietinum* L., *Vicia faba* L., *Phaseolus vulgaris* L., and *Solanum tuberosum* L. The natural vegetation in the study area consists of some tree species that are remnants of a once dense evergreen forest occurring on slopes and sparse grass complex in various spots. *Juniperus procera, Olea africana and Hajenia abyssinica* are the dominant species.

Traditionally, farmers around the study area maintain the fertility status of the soil through applications of compost, farmyard manure (FYM) and crop rotation practices. They also add inorganic fertilizers such as urea, diammonium phosphate (DAP), and blended fertilizers have been introduced recently. Soil and water conservation activities, though inadequate in quality and area coverage, soil bund, stone bund, checkdams, and hillside terraces could be mentioned. The agricultural activity in the area is not productive enough because of the recurrent natural calamities. Natural resources are deteriorating and soil erosion is marked by the presence of expanding gullies. Rapid population growth has resulted in shrinking the farmland sizes and grazing lands. Land degradation, moisture shortage, ground and surface water depletion, increasing infertility of soil and natural hazards like drought, landslide, incidence of crop pests and weed and livestock diseases, coupled with cultural and attitudinal factors are among the major problems in the study area. All these, in turn, have made the district one of the food and nutrition insecure areas of the ANRS.

Soil survey

Before the start of the study, physical observation with the help of 1:50000 topographic maps, obtained from the Ethiopian Mapping Agency, were conducted and general soil site information was recorded. The boundaries of the watershed were determined from the 30 m-resolution digital elevation model (DEM), and the soil mapping units were determined based on slope positions, and after taking 115 auger pit observation points (Figure 3). Accordingly, four mapping units namely: Upper-slope, Middle-slope, Lower-slope, and Toe-slope were identified along the landscape (Figure 3). The free survey method described by Dent and Young (1981) was followed. The depth of auger points was 0-20 and 20-40 cm. The hand held GPS (global positioning system) was used to record location of the pits, augers, and the boundaries of the different mapping units.

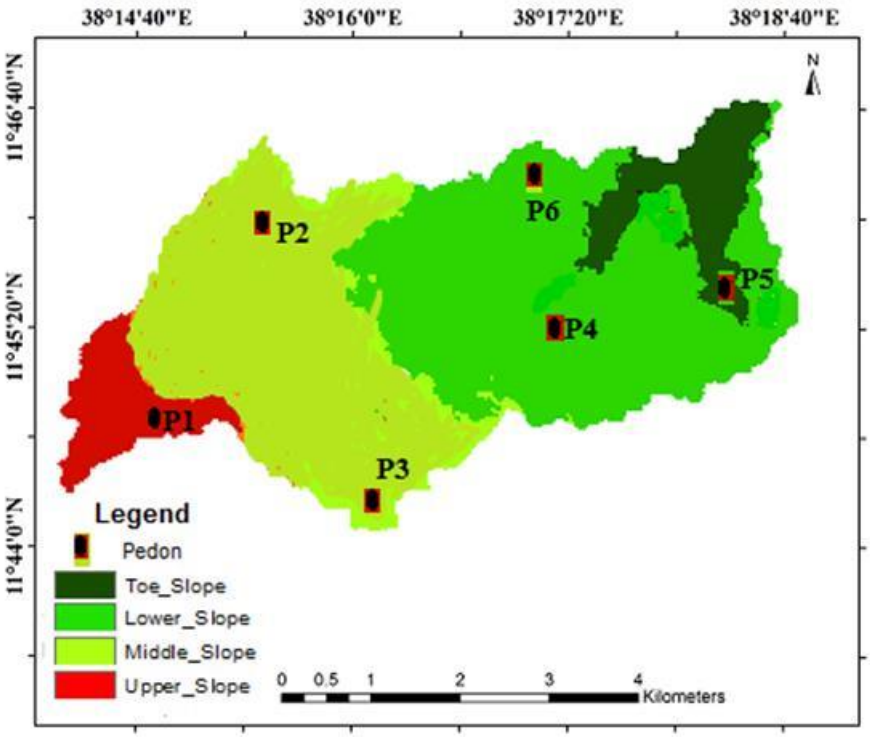

Figure 3. Slope positions and pedon points in Yikalo subwatershed

Soil pedon description, sampling, and sample preparation

The middle and lower slope positions, each consisted of two representative pedons. The upper and toe slope positions, each had one representative pedon. These representative soil pedons were opened and described *in situ* (Tables 1and 2). For each identified mapping unit, 1 m width x 2 m length x 2 m depth pit was opened for soil morphological examination and soil sample collection for laboratory analysis. After cleaning away loose debris from pit face, color, texture, consistence, structure, plant rooting patterns, and other soil features were examined to determine which horizons are present and at what depth their boundaries occur. A soil description was then done using a standard format developed following the Guidelines for Soil Description (FAO, 2006). Both disturbed and undisturbed soil samples were collected from each genetic horizon. Soil color was determined using the Revised Munsell Soil Color Chart (Munsell Soil Color Chart, 1994). Soil structure was described in terms of the sequence: grade, size, and type (shape) of aggregates whereas horizon boundaries were described in terms of depth, distinctness, and topography. The soil consistence was identified at dry, moist and wet moisture conditions. Core samples were collected at different points across each horizon for determination of bulk density. A cylindrical metal core with volume of 100 cm^3 was pressed in to the soil until it is completely filled. The soil was trimmed at both ends with a knife and covered with a cap, labeled and packed in box. The soil samples collected from the study area were bagged, labeled and transported to the laboratory for preparation and analysis of selected soil properties following standard laboratory procedures. In preparation for laboratory analysis, the soil samples were air dried, crushed, and made to pass through a 2 mm sieve size for the analysis of soil pH, texture, available P, exchangeable bases, exchangeable acidity, and CEC, whereas, for analysis of OC and total N, samples were made to pass through 0.5 mm sieve size.

Laboratory analysis of soil physical and chemical properties

Soil texture was determined using the Bouyoucos hydrometer method (Day, 1965). Bulk density (BD) was determined from the weight of undisturbed (core) soil samples, which were first weighed at field moisture content and then dried in an oven at 105 ^{o}C to constant weight (Baruah and Barthakur, 1997). The bulk density was calculated from the mass of oven dry soil and the volume of the core. The average soil particle density (PD) (2.65 g cm^{-3}) was used for estimating total porosity. The moisture content at field capacity (FC) and permanent wilting point (PWP) was measured at the soil water potentials of -1/3 and -15 bars, respectively, using the pressure plate apparatus technique (Richards, 1965). The results were converted into volume percent (Vol %) by multiplying the gravimetric water content with the ratio of soil bulk density to the density of water. The available water content (AWC) was obtained by subtracting water content at PWP from FC and finally converted to mm/ m of soil depth by multiplying it by 1000.

The pH of the soil was measured potentiometrically in the supernatant suspension of a 1:2.5 soil to water ratio using a pH meter as described by Chopra and Kanwar (1976). Organic carbon was determined using the wet oxidation method (Walkley and Black, 1934) whereby the carbon was oxidized under standard conditions with potassium dichromate in sulfuric acid solution. Total N was determined by the micro-Kjeldahl method (Jackson, 1967) while available P was extracted using the sodium bicarbonate solution following the procedure described by Olsen et al. (1954). The exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, and Na^+) in the soil were extracted with 1 M ammonium acetate (NH_4OAc) solution at pH 7.0 (Jackson, 1967). Exchangeable Ca^{2+} and Mg^{2+} in the leachate were determined by atomic absorption spectrophotometer, while exchangeable K^+ and Na^+ were determined by flame photometry (Rowell, 1994). The potential cation exchange capacity (CEC) of the soil was determined from the NH_4^+ saturated samples that were subsequently replaced by K^+ using KCl solution. The excess salt was removed by washing with ethanol and the ammonium that was displaced by K^+ was measured using the micro-Kjeldahl procedure (Chapman, 1965) and reported as CEC. Total exchangeable acidity was determined by saturating the soil samples with 1 M KCl solution and was titrated with 0.02 M NaOH as described by Rowell (1994). From the same extract, exchangeable Al^{3+} in the soil samples was determined by application of 1 M NaF, which forms a complex with Al^{3+} and releases NaOH and then NaOH was back titrated with a standard solution of 0.02 M HCl (Sahlemedhin and Taye, 2000). Cation exchange capacity due to the clay fraction (CEC_{clay}) was estimated by subtracting the value of CEC associated with the percent of OM from the value of soil (CEC_{soil}) assuming OC has a cation exchange capacity of 200 $cmol_c\ kg^{-1}$ (Yerima, 1993) as:

$$CEC_{clay} = [CEC_{soil} - (OM \times 200)] / \%clay$$

Soil classification and mapping

Based on the morphological characteristics and the laboratory analysis, the soils of the study area were classified based on FAO (2014). The geographic coordinates of each soil observation and the boundaries of each mapping unit were recorded in the field using GPS. Later, soil map was prepared by employing Arc GIS 10 (Geographic Information System). The auger points and identified map units coordinates were recorded in excel spread sheet, and later displayed in Arc map. Based on soil-landscape relations, soil depth and texture, soil boundaries were identified in each topographic positions, and the coordinates were recorded with GPS. The respective map units were later polygonized and their area was determined. Each polygon was labeled with the classified taxononomic soil unit.

Results and Discussion

Morphological properties

Soil color

The soil color (moist) in the surface layers varied from very dark (2.5 YR 2/1) in Pedon 1 to dull reddish brown (2.5 YR 4/3) in Pedon 2. Similarly, the subsurface color (moist) changed from grayish red (2.5 YR 3/1) in Pedon 2 to brown (7.5 YR 3/4) in Pedon 4. The variation in color change among the pedons and within a pedon could be attributed to difference in OM content, parent material, and drainage conditions (Ashenafi et al., 2010; Buol et al., 2011; Nahusenay et al., 2014; Alem et al., 2015).

Table 1. Selected site characteristics of representative soil pedons

Pedon	Location (UTM)		Altitude	Slope	Slope	Drainage	Erosion /	Parent	Land use
	Latitude	Longitude	(m)	(%)	position	class	deposition	material	
1	1298509	418572	3596	45	Upper slope	Well drained	Sheet and rill erosion	Eluvium of basalt	Annual field cropping/barely/
2	1298954	419888	3318	20	Middle slope	Well drained	Sheet	Eluvium of basalt	Annual field cropping/wheat/
3	1300063	420744	3268	12	Middle slope	Well drained	Sheet	Eluvium of basalt	Natural forest
4	1299895	422253	3174	8	Lower slope	Moderately drained	Deposition	Colluvium from Basalt fragments	Grazing
5	1300117	421692	3173	2	Toe slope	Weakly drained	Deposition	Colluvium from Basalt fragments	Annual field cropping/potato/
6	1298413	421195	3227	6	Lower slope	Weakly drained	Deposition	Colluvium from Basalt fragments	Annual field cropping/potato/

Table 2. Selected morphological characteristics of soil pedons

Depth (cm)	Horizon	Color		Structure grade /size/ type/	Consistence Dry/moist/wet			Root abundance /size	Boundary distinct/ topography/
		Dry	Moist		Dry	Moist	Wet		
Pedon 1 (Upper slope)									
0-20	A	2.5 YR 2/2	2.5 YR 2/1	WE,FI,GR	SHA	FR	SST, SPL	C, F	A, S
20-60	B	2.5 YR 3/2	2.5 YR 2/1	MO, ME, SB	HA	FR	SST, NPL	F,VF	C, S
Pedon 2 (Middle slope)									
0-20	Ap	2.5 YR5/3	2.5 YR4/3	WE, FM, GR	SHA	FR	SST, SPL	F, VF	A, S
20-100	Bt_1	2.5YR 4/2	2.5YR 3/1	WE, ME, SB	SHA,	FR	SST, SPL	V, VF	C, W
100-125	Bt_2	2.5YR 5/2	2.5YR 3/1	MO, ME, SB	HA	FI	SST, SPL	V, VF	C, B
125-190+	C	2.5YR 5/2	2.5YR 4/3	ST, MC, SB	VA	FI	SST, SPL	N	------
Pedon 3 (Middle slope)									
0-20	A	7.5YR 4/3	7.5YR 3/2	WE, FI, GR	SHA	FR	SST, SPL	C, C	G, W
20-105	Bt_1	7.5YR 4/4	7.5YR 3/4	MO, FM, GR	SHA	FR	ST, NPL	F, M	C, S
105-135	Bt_2	7.5YR 4/3	7.5YR 4/3	MO, FM, AB	HA	FI	ST, SP	F, F	G, B
135-210+	C	7.5YR 4/3	7.5YR 3/3	ST, ME, SB	HA	FI	SST, NPL	V, VF	------
Pedon 4 (Lower slope)									
0-20	Ap	7.5YR 2/3	7.5YR 3/2	WE, FI, GR	SHA	FR	SST, SPL	C, C	G, W
20-95	Bt_1	7.5YR 4/4	7.5YR 3/4	MO, FM, GR	SHA	FR	ST, NPL	F, M	C, S
95-180	Bt_2	7.5YR 4/3	7.5YR 4/3	MO, FM, AB	HA	FI	ST, SP	F, F	G, B
180-225+	C	7.5YR 4/3	7.5YR 3/3	ST, ME, SB	VHA	FI	SST, NPL	V, VF	------
Pedon 5 (Toe slope)									
0-20	A	2.5YR 5/4	2.5YR 4/3	WE, FI, GR	SHA	FR	SST, PL	C, F	D, S
20-50	B	2.5 YR 5/3	2.5 YR4/2	WM, ME, AB	HA	FI	ST, VPL	F, F	C, S
50-110	C	2.5YR 5/1	2.5YR 4/1	MO, ME, AB	VHA	FI	ST, VPL	N	------
Pedon 6 (Lower slope)									
0-20	A	10YR 3/2	10YR 3/2	WE, FI, GR	SHA	FR	SST, SPL	C, F	G, W
20-45	B	10 YR 4/2	10YR 3/1	WM, ME, AB	HA	FI	ST, PL	F, VF	G, W
45-95	BC	7.5 YR 3/1	7.5 YR3/1	MO, ME, AS	VHA	FI	ST, PL	F, VF	D, W
95-165+	C	7.5 YR 4/1	7.5 YR4/1	ST, ME, AS	VHA	VFI	VST, VPL	N	------

Notes: Structure: WE = weak, MO = moderate, ST= strong, WM = weak to moderate, FI = fine, FM=fine medium, ME = medium, MC=medium and coarse, AB = angular blocky, AS = angular and sub-angular blocky, SB = sub-angular blocky, GR = granular, Horizon Boundary: A = abrupt, C = clear, D=diffuse, G = gradual S = smooth, W = wavy, B = broken. Consistence: SHA = slightly hard, HA = hard, VHA = very hard, FR = friable, VFR = very friable, FI = firm, SST = slightly sticky, ST = sticky, VST = very sticky, NPL = non-plastic, SPL = slightly plastic, PL = plastic, VPL = very plastic. Root abundance: C=common, F=few, V=very few, N=none. Root size: C=coarse, M=medium, F=fine, VF=very fine (FAO, 2006).

Soil structure and consistence

The structure of all pedons in the surface soils were weak, fine, granular, gradually changing in the subsurface from weak to moderate, medium angular blocky in Pedon 4 to strong, medium, angular and sub-angular blocky in Pedon 6. Similar results were reported by (Yitbarek et al., 2016; Kebede et al., 2017) who found granular soil structure in the surface horizons that changed to angular and sub-angular structure in the subsurface pedons. The presence of OM in the surface soil might be attributed to the formation of granular type of soil. Pressure faces on soil matrix due to micro-swelling, the low level of OM, reduction in abundance of plant roots and higher clay in subsurface may be mentioned for the formation of blocky structure. The dry consistence varied from slightly hard to very hard, whereas the moist consistence varied from friable to firm. On the other hand, the wet consistence ranged from slightly sticky/slightly plastic in the surface layers to very sticky/very plastic in the subsurface soil layers (Table 2). The very friable and friable consistence observed in the surface soils of the pedons could be attributed to the higher OM content (Table 4). In consent with this finding, the contribution of OM in modifying soil consistence was pointed out by Mulugeta and Sheleme (2010). Ashenafi et al. (2010) also reported that the friable consistence of the soils show workability of the soils at appropriate moisture content. In contrast, the sticky, very sticky, plastic and very plastic consistencies show the presence of high clay content, and difficulty to till (Abay et al., 2015). The presence of very sticky and very plastic consistence could be indicative of presence of smectitic clays in the soils (Ashenafi et al., 2010).

Soil depth and horizon boundaries

Based on soil depth class described by USDA (2010), all the pedons are very deep (> 150 cm) except Pedon 1, which was moderately deep (50-100 cm) and limited by massive basalt. For any given soil, the greater the rooting depth, the larger will be the quantity of soil water available to the crop. This is particularly important for annual crops as they have less time to develop deep and extensive rooting systems than perennial crops (FAO, 2003). The lower boundaries of surface horizons in Pedons 1 and 2 were abrupt and smooth that changed into clear and smooth, and clear and wavy, respectively in the subsurface horizons. This could be due to repeated anthropogenic influence like plowing the land for crop production (Alem et al., 2015). Pedons 3 and 4 had gradual and wavy lower boundaries of surface horizons grading to clear and smooth in the subsurface horizons as these lands are under forest and grazing land uses, where there is no soil mixing by plowing, gradual transformation, homogenization, or erosional/depositional processes (Ande, 2010).

Soil physical properties

Soil particle size distribution

The particle size distribution in most of the studied pedons did not show any consistent trend with both depth and topographic position (Table 3). However, the clay content observed in the B horizons of all the pedons was higher than the clay content of the surface horizons. Lack of definite trend in soil separates along the topographic position might be due to the dominance of erosion and accumulation in influencing the pedogenic processes (Alem et al., 2015), whereas irregular trend with depth, might be due to variation in weathering of parent material (Sekhar et al., 2014). The general increase in clay content with depth might be attributed to the vertical translocation of clay through the processes of lessivage and illuviation. Higher clay content in the B horizon of soils as a result of illuviation, predominant *in situ* pedogenetic formation of clay in the subsoil, and destruction of clay in the surface horizon, have been reported (Chukwu, 2013; Yitbarek et al., 2016; Kebede et al., 2017).

Table 3. Selected physical characteristics of soil pedons

Depth (cm)	Horizon	Particle size analysis (%)			Textural class	Si/C	BD (g cm^{-3})	Porosity (%)	FC (%V/V)	PWP (%V/V)	AWC (mm m^{-1})
		sand	silt	clay							
Pedon 1 (Upper slope)											
0-20	A	28.7	48.6	22.7	Silt loam	2.1	0.92	65	28.5	20.2	83
20-60	B	32.7	44.6	22.7	Silt loam	2.0	1.16	56	38.3	30.2	81
Pedon 2 (Middle slope)											
0-20	Ap	16.7	36.6	46.7	Clay	0.8	1.07	60	40.7	34.2	65
20-100	Bt_1	0.7	36.6	62.7	Clay	0.6	1.44	45	59.0	48.9	101
100-125	Bt_2	26.7	28.6	44.7	Clay	0.6	1.47	45	48.5	38.2	103
125-190+	C	12.7	24.6	62.7	Clay	0.8	1.49	44	58.1	46.2	119
Pedon 3 (Middle slope)											
0-20	A	36.7	32.6	30.7	Clayloam	0.4	1.07	60	32.1	21.4	107
20-105	Bt_1	18.7	28.6	52.7	Clay	1.1	1.33	50	37.2	27.9	93
105-135	Bt_2	16.7	14.6	68.7	Clay	0.5	1.45	45	52.2	40.6	116
135-210+	C	14.7	22.6	62.7	Clay	0.2	1.59	40	49.3	38.2	111
Pedon 4 (Lowerslope)											
0-20	Ap	28.7	30.6	40.7	Clay	0.4	0.89	66	34.7	19.6	151
20-95	Bt_1	16.7	24.6	58.7	Clay	0.8	1.14	57	49.0	43.3	57
95-180	Bt_2	16.7	20.6	62.7	Clay	0.4	1.42	46	64.8	53.3	115
180-225+	C	32.7	18.6	48.7	Clay	0.3	1.44	46	46.9	42.6	43
Pedon 5 (Toe slope)											
0-20	A	28.7	22.6	48.7	Clay	0.4	1.25	53	46.3	40.0	63
20-50	B	22.7	10.6	66.7	Clay	0.5	1.43	46	58.6	48.6	100
50-110+	C	38.7	12.6	48.7	Clay	0.2	1.45	45	52.2	42.1	101
Pedon 6 (Lower slope)											
0-20	A	14.7	16.6	68.7	Clay	0.3	1.17	56	39.8	25.8	140
20-45	B	14.7	14.6	70.7	Clay	0.2	1.43	46	55.8	45.8	100
45-95	BC	10.7	12.6	76.7	Clay	0.2	1.43	46	58.6	52.9	57
95-165+	C	10.7	8.6	80.7	Clay	0.2	1.50	43	67.5	58.5	90

Bulk density and porosity

The bulk density varied from 0.89 to 1.25 g cm^{-3} on the surface, and from 1.14 to 1.59 g cm^{-3} in the subsurface horizons of the soil pedons (Table 3). The relatively lower bulk density values (< 1 g cm^{-3}) in the surface horizons of Pedons 1 and 4 could be related to the structural aggregation of the soils as a result of relatively high OM content. The bulk density in soils, irrespective of landforms, increased with depth which might be due to weight of the overlying soil and the relatively low amount of OM in the subsurface soil layers. Similarly, Chaudhari et al. (2013) reported increase in bulk density with pedon depth, due to changes in OM content, porosity, and compaction. The critical value of bulk density for plant growth at which root penetration is likely to be severely restricted is 1.4 g cm^{-3} for clay soils (Hazelton and Murphy, 2007). Following this critical value, the bulk density values of the surface horizons in the crop lands were in the favorable range. In contrast, the total porosity decreased along the horizons of all soil profiles in the watershed (Table 3). However, it did not show clear trend with topographic positions. Total porosity ranged from 53% in Profile 5 to 66% in Profile 4 of the surface soil horizons. On the other hand, it varied from 40% in Profile 3 to 57% in Profile 4 of the subsurface soil horizons (Table 3). According to Brady and Weil (2008), the ideal porosity value for healthy root growth is > 50%. Thus, porosity values of the recognized pedons in the surface layers are in the acceptable range for crop production.

Soil water retention characteristics

Except in Pedons 1 and 6 where it increased with soil depth, water retention at FC and PWP did not show any consistent pattern with soil depth (Table 3). Also, the retention at both points did not vary consistently along the topographic positions albeit relatively higher values for each were recorded in the toe slope position where the clay content is also high at the surface layer. Available water content varied from 63 mm m^{-1} in Pedon 5 to 151 mm m^{-1} in Pedon 4 of the surface soil horizons, and from 43 mm m^{-1} in Pedon 4 to 119 mm m^{-1} in Pedon 2 of the subsurface soil horizons. In soil Pedons 2 and 5, AWC increased with depth. Various reports (Gill et al., 2012; Nagaraju and Gajbhiye, 2014) indicated the positive relationship between clay content and the amount of water retained at -33 and -1500 kPa. The high amount of water at both FC and PWP in some of the soils with high clay content, thus resulting in small AWC might be due to the water is held so tightly in the micropores that the plants cannot access it (Easton and Bock, 2016).

Soil chemical properties

Soil pH and exchangeable acidity

The pH (H_2O) values increased along soil depth in Pedons 1, 2, 3 and 6 (Table 4). In Pedons 4 and 5, there was no regular variation of soil pH with soil depth except slight decrease at the bottom layers. Similarly, the pH of the surface layer soils did not show any systemic variation along the topographic positions although relatively higher values were recorded in soils of Pedons 3 and 6. Following the pH rating suggested by Hazelton and Murphy (2007), the pH of the soils was within the range of very strongly acid in Pedon 4 of the surface layer (4.5-5.0) to slightly acid (6.1-6.5) in the bottom layer of Pedon 6. The increased pH values with soil depth might be due to less H^+ ions released from low OM decomposition, which is caused by decreased OM content with depth (Abay and Sheleme, 2012). Furthermore, the increase with soil depth might be related to the increase in some of the basic cations with soil depth. The low pH in most of the pedons could be due to the high rainfall in the study area that activates leaching and continuous removal of bases from the soil surface. Several researchers in different parts of Ethiopia reported various values of pH for acid soils (Mulugeta and Sheleme, 2010; Abreha et al., 2013; Melese et al., 2015). The exchangeable acidity decreased with depth in all the pedons except in the bottom layers of Pedons 2 and 5. The values of exchangeable acidity decreased with increased pH in the soil pedons studied regardless of the landform in the watershed. Baquy et al. (2017) suggested that the critical level of exchangeable Al^{3+} concentration ranged from 0.56-1.72 $cmol_c$ kg^{-1} depending on the type of crops and soils. The exchangeable Al^{3+} values of the surface horizons of cultivated lands (Pedons 1 and 4) are within this range to influence crop growth adversely.

Organic carbon, total N, and C:N ratio

Topographic position, and elevation of the soils affected the spatial variability of OC and TN. Considering the depth of the pedon, OC and TN showed a decreasing pattern (Table 4). Relatively higher values were recorded in the upper slope positions of the surface horizons of all the soil pedons. The OC of the surface layer soils ranged from 0.90% in the lower slope position (Pedon 6) to 5.60% in the freshly cultivated Pedon 1 of the upper slope position (Table 4). As per the rating criteria set by Tekalign (1991), the OC contents of surface soil horizons in Yikalo subwatershed were in the range of high (> 3.3%) to low (0.5-1.5%) category.

Table 4. Selected chemical characteristics of soil pedons

Depth (cm)	Horizon	pH (H_2O)	TN (%)	OC (%)	Av.P (mg kg^{-1})	C/N	Exchangeable bases and CEC cmol$_c$ kg^{-1} soil					CEC/Clay cmol$_c$ kg^{-1}	BS (%)	Ex Acidity cmol$_c$ kg^{-1}	Ex Al cmol$_c$ kg^{-1}
							Ca	Mg	K	Na	CEC				
Pedon 1 (Upper slope)															
0-20	A	5.24	0.34	5.60	0.77	16.54	6.68	3.38	0.05	-	53.44	150.20	19	1.60	0.69
20-60	B	5.43	0.25	3.56	0.77	14.21	6.93	4.14	0.05	-	46.57	151.00	24	1.57	0.67
Pedon 2 (Middle slope)															
0-20	Ap	5.3	0.29	2.93	3.25	10.25	12.17	7.95	0.07	-	38.26	60.25	53	0.58	0.26
20-100	Bt_1	5.48	0.25	2.77	0.75	10.86	13.52	0.51	0.09	-	42.48	52.52	33	0.45	0.21
100-125	Bt_2	5.89	0.10	1.03	0.30	9.87	14.54	1.10	0.21	-	29.06	57.01	55	0.23	-
125-190+	C	6.02	0.06	0.13	1.65	2.27	17.50	7.78	0.07	-	30.32	47.64	84	0.33	-
Pedon 3 (Middle slope)															
0-20	A	5.46	0.26	2.09	0.66	7.98	9.21	10.90	0.12	-	37.79	99.56	54	0.46	0.25
20-105	Bt_1	5.81	0.17	1.19	5.33	7.00	9.72	6.93	0.26	-	34.75	58.17	48	0.23	-
105-135	Bt_2	5.82	0.06	0.05	19.47	0.86	10.90	3.47	0.12	-	35.35	51.17	41	0.18	-
135-210+	C	6.00	0.05	0.30	15.99	5.65	19.44	0.59	0.05	-	38.78	60.15	52	0.10	-
Pedon 4 (Lower slope)															
0-20	Ap	4.57	0.33	3.51	2.20	9.98	7.78	7.52	0.09	-	42.54	74.73	36	3.65	1.93
20-95	Bt_1	5.13	0.21	1.53	0.96	7.28	12.26	3.72	0.12	-	40.98	60.82	39	2.90	1.16
95-180	Bt_2	6.24	0.09	0.54	1.97	6.09	14.71	7.52	0.14	-	51.27	78.79	44	0.27	-
180-225+	C	5.98	0.03	0.01	0.96	0.33	17.08	9.89	0.12	-	44.77	91.83	60	0.07	-
Pedon 5 (Toe slope)															
0-20	A	5.18	0.15	1.51	2.70	10.26	13.19	9.38	0.12	-	36.02	63.26	63	0.17	-
20-50	B	6.13	0.06	0.57	3.62	9.71	15.38	3.47	0.07	-	42.82	61.25	44	0.08	-
50-110+	C	6.08	0.01	0.01	1.13	0.84	15.55	7.69	0.09	-	37.32	76.52	63	0.11	-
Pedon 6 (Lower slope)															
0-20	A	5.40	0.14	0.90	0.21	6.58	18.51	9.55	0.16	-	51.40	70.30	55	0.57	0.25
20-45	B	5.57	0.06	0.43	2.08	6.74	20.46	10.31	0.09	-	54.14	74.44	57	0.19	-
45-95	BC	5.86	0.05	0.08	4.49	1.65	24.85	9.13	0.05	-	52.80	68.46	65	0.06	-
95-165+	C	6.42	0.04	0.03	0.98	0.67	29.42	7.19	0.12	-	54.10	66.91	68	0.05	-

The high level of OC in the surface horizon of Pedon 4 could be due to biomass turnover of grass on the grazing land. The studied soils were located in an elevation of above 3000 m that might favor lower rate of decomposition and a relatively higher accumulation of OC in the upper slope positions. Abayneh et al. (2006) marked that soils located at elevations higher than 1850 m, the relatively lower temperatures may facilitate the organic C accumulation. However, the observed low OC content in some of the pedons could be ascribed to the complete removal of crop residues, and reduced input of organic amendments such as FYM and compost to these cultivated lands. Moreover, repeated tillage of the land might favor the mineralization of OC in the lower and toe slope positions. In line with this, variable distribution in OC content of soils in different areas of the country was reported by different researchers (Ashenafi et al., 2010; Daniel and Tefera, 2016).

Total N varied from 0.34% in the upper slope to 0.14% in the foot slope position of the surface horizons. The TN content of the surface horizons was higher as compared to the subsurface soil horizons and it followed similar pattern with that of OC in all the studied pedons implying that there is a strong relation between OC with TN in the soil system. In agreement with this result, Meysner et al. (2006) indicated that as much as 93 to 97% of the total N in soils is closely associated with OC. Based on the rating of total N set by Tekalign (1991), the total N contents of the surface layers of Pedons 1, 2, 3, and 4 were rated as high (> 0.25%), while it was medium (0.12 and 0.25%) in Pedons 5 and 6. The high total N content in the surface layers indicates that the soils of the study area have the potential in N to support proper growth and development of crops. The medium total N content in Pedons 5 and 6 might be due to weakly drained condition, which slows down mineralization. However, the site must be fertilized with external N inputs for sustainable production as N is dynamic and prone to leaching and volatilization loses. Similar to the current finding, high total N was found in Arsi highlands (Assen and Yilma, 2010) whereas, low to medium in total N was reported in Delbo Wegene watershed, Wolaita zone (Ashenafi et al. 2010).

The carbon-to-nitrogen ratio (C:N) demonstrates a systematic variation with depth for some of the studied pedons (Pedons 1, 4, and 5), suggesting the existence of similar conditions of mineralization in the recognized horizons. The high C: N ratio (16.54) was observed for the surface horizon of Pedon 1, which has low temperature at the highest elevation. The C: N ratio for Pedon 1 was higher than the ideal 10, indicating the slower decomposition rate of OM and organic N by the soil microbial activity (Ge et al., 2013). In general, a C: N ratio of about 10:1 suggests relatively better decomposition rate, serving as index of improved N availability to plants and possibilities to incorporate crop residues to the soil without having any adverse effect of nitrogen immobilization (Assen and Yilma, 2010).

Available P

Available P contents did not show consistency across the slope positions and soil depth (Table 4). Available P contents varied from 0.77 mg kg^{-1} in the surface horizons of Pedon 1 in the upper slope to 19.47 mg kg^{-1} in the subsurface horizon of the middle slope positions. Based on the rating of available P suggested by Jones (2003), the available P content of the soils in the surface horizons of all the pedons was in the range of low (6-10 mg kg^{-1}) to very low (1-5 mg kg^{-1}) rating. Phosphorus deficiency in Ethiopian soils is well documented in various research works (Melese et al., 2015; Daniel and Tefera, 2016; Kebede et al., 2017). On top of the inherent low occurrence of P, its availability is limited by strongly acid characteristics of the soils in the study environment.

Cation exchange capacity and exchangeable bases

The CEC of the soils in all the pedons did not show any regular pattern with either soil depth or topographic positions (Table 4). On the other hand, it somehow followed the trend of the clay content particularly in the soils of the lower and toe slopes. The higher values of CEC in the upper slope could be attributed to the recent land use change from virgin to cultivation that implied better OC content and less nutrient depletion through crop removal, whereas that in Pedon 6 of the lower slope position might be due to the deposition of various cation-rich materials. According to Landon (1991), the CEC of the soils in the watershed qualifies for the high and very high signifying that the soils have better nutrient reserve.

The principal cations occupying the exchange site were in the order of Ca^{2+}>Mg^{2+}>K^{+}>Na^{+}. The concentration of Ca increased consistently with depth of the soil pedons. The highest value (29.42 $cmol_c\,kg^{-1}$) was recorded in the bottom layer of Pedon 6 and the lowest (6.68 $cmol_c\,kg^{-1}$) was in Pedon 1. Considering the effect of topographic positions, the content of Ca^{2+} increased from the upper slope to the toe slope except Pedon 3 of the middle slope and Pedon 4 of the foot slope positions. The consistent accumulation of Ca^{2+} with depth could be ascribed to the leaching by high amount of rainfall in the area. Supporting to this finding, other authors (Ashenafi, et al., 2010; Nahusenay et al., 2014) indicated that accumulation of exchangeable Ca^{2+} with depth could be due to leaching from the overlying horizons. The trend of Ca^{2+} on the surface horizons across the landscape may be due to the lateral movement of the ion from the upper slope to the toe slope (Lawal et al., 2013). According to Hazelton and Murphy (2007) rating of exchangeable Ca^{2+}, the soils were in the medium to very high range. Exchangeable Mg contents varied from 3.38 $cmol_c\ kg^{-1}$ in Pedon 1 to 10.9 $cmol_c\ kg^{-1}$ in Pedon 3 of the surface horizons and 0.5 $cmol_c\ kg^{-1}$ in Pedon 2 to 10.3 $cmol_c\ kg^{-1}$ of Pedon 6. Higher Mg^{2+} content was observed in the middle slope of Pedon 3 and the lower slope of Pedon 6. Generally, the Mg content was rated as low to very high in the exchange site of the soil pedons (Hazelton and Murphy, 2007). Exchangeable K^+ varied from low to very low in all the pedons and was not consistent with depth. Though soils were rich in CEC, they were deficient in K^+, which is one of the major elements limiting crop production in the area. The exchangeable K^+ content was below the critical level of 0.38 $cmol_c\ kg^{-1}$ (Landon, 1991). The result was in agreement with the findings of Tena and Beyene (2011) who reported K^+ deficiency in Alfisols. Therefore, K fertilization is required to enhance crop production in the study area, where K removal takes place through crop harvest. Exchangeable Na^+ is well below the permissible limit of exchangeable sodium percentage (ESP) throughout the pedons of the studied soils (Table 4). The variation was irregular with depth of the pedons.

The percent base saturation increased with depth in Pedons 1, 4, and 6, while it was inconsistent in the other pedons, and topographic positions (Table 4). Percent base saturation of surface soil horizons ranged from 19% in Pedon 1 to 63% in Pedon 5. In the subsurface soils, PBS ranged from 24% in the B horizon of Pedon 1 to 84% in the bottom layer of Pedon 2. The higher values in some of the subsurface horizons marked the accumulation of soluble bases due to rainfall prevailing in the watershed and the composition of the parent material. According to the rating described by Hazelton and Murphy (2007), Pedon 1 in the upper slope and Pedon 4 in the lower slop positions were very low (<20%) and low (20-40%), respectively in PBS, whereas soils represented by Pedon 5 in the toe slope position were high in PBS. The higher values of per cent base saturation observed is due to higher amount of exchangeable Ca^{2+} ions occupying the exchange sites on the colloidal sites (Sekhar et al., 2014). Soils of Pedons 2, 3, and 6, on the other hand, were within the range of medium PBS (40-60%). The variation observed in PBS indicates the degree of leaching which was used as diagnostic character for classifying soils (Meena et al., 2014). Furthermore, the low PBS of the soils might indicate the leaching of bases due to the high rainfall in the study area. These situations may result in low and unbalanced availability of exchangeable bases for plants to be taken up. Therefore, liming may be required in the cultivation of soils of the study area and elsewhere in similar environments (Assen and Yilma, 2010).

The CEC/clay ratios are also greater for the surface than the subsoil horizons of some of the studied pedons (Pedons 1, 2, and 3). High CEC/ clay ratio was recorded for Pedon 1, which is found at the upper slope of the watershed. The CEC of clay fraction can be used as an indication of type of clay mineralogy (Buol et al., 2003). Accordingly, most of the horizons of Pedons 4, 5, and 6 are expected to have smectite group clay minerals (60-100 $cmol_c\ kg^{-1}$).

Soil classification

Pedon 1 is limited in depth, loam in soil texture and granular in structure. The soil was recently cultivated, high in OC but low in PBS. The subsurface horizon has pedogenetic transformation of the rock, indicating that the soil pedon was developed through subsurface soil formation following initiation of structure and color change. These attributes of the pedon qualify the diagnostic criteria for *cambic* subsurface horizon. Furthermore, the pedon has a base saturation of less than 50% between 20 and 50 cm of the soil surface, which qualifies for *hyperdystric* principal qualifier. In addition to this, the presence of more than 1% OC to a depth of 50 cm from the mineral soil surface indicates the soil to have *humic* supplementary qualifier. Based on the diagnostic horizon and the qualifiers identified, the soil is classified as Hyperdystric Cambisols (Humic) (FAO, 2014). This soil covers 471 ha in the watershed (Figure 4).

Pedons 2 and 3 are characterized by subsurface horizons with higher clay content than the overlying horizon. The textural differentiation may be caused by an illuvial accumulation of clay. This characteristic may indicate the development of *argic* subsurface horizon in these pedons. Additionally, the *argic* subsurface horizons in Pedons 2 and 3 are characterized by having a CEC of ≥ 24 cmolc kg^{-1} clay throughout or to a depth of 50 cm of its upper limit, and having a base saturation, calculated on the sum of exchangeable bases plus exchangeable Al of < 50% in the major part between 50 and 100 cm from the mineral soil. The leaching of base cations particularly exchangeable Ca^{2+} was also observed owing to the humid environment in these pedons. Hence, these soils meet the definition of Alisols soil unit. Since no other principal qualifier can express the soil unit, *haplic* is prefixed, while for the presence of more than 1% OC to a depth of 50 cm from the mineral soil surface, *humic* is suffixed to classify the soil as Haplic Alisols (Humic), with an area coverage of 660 ha (Figure 4).

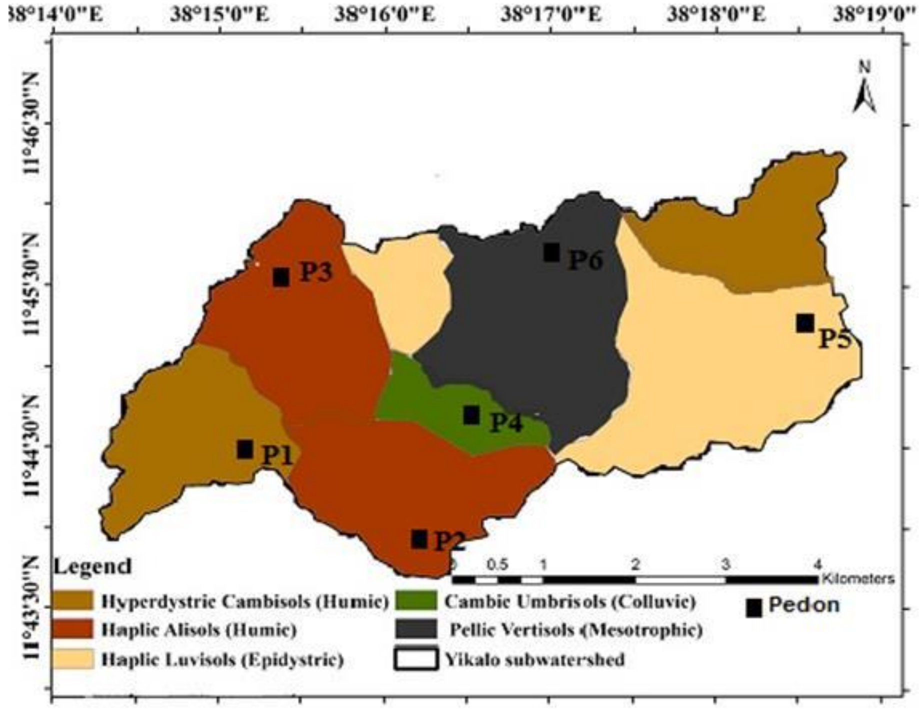

Figure 4. Soil map of the study area

Pedon 4 was dug in the lower slope position of the grazing land. Soils in this pedon have weak fine granular structure on the surface, high OC with dark brown color, and a base saturation of < 50% on a weighted average, throughout the entire thickness of the horizon with acid in reaction thus qualifying as *umbric* A horizon (FAO, 2014). The horizon has significant accumulation of OC in the mineral surface soil and a low base saturation within the first 100 cm. This pedon was therefore, recognized to meet Umbrisols at reference soil level. The subsurface horizon shows some evidence of pedogenetic alteration, and higher clay content than the bottom layer. The pedogenetic alteration is identified from the overlying mineral horizon, which is richer in OM and therefore have a darker colour, indicating *cambic* as a principal qualifier. Due to the accumulation of colluvic materials which has been transported as a result of erosional wash or soil creep in the slope positions, the supplementary qualifier *colluvic* is added as a suffix, and hence the soil is classified as Cambic Umbrisols (Colluvic), covering 116 ha of land.

Pedon 5 was opened on the cultivated land at the toe slope position, where there was higher clay content in the subsoil than in the topsoil. The movement and build up of clay formed *argic* subsoil horizon. Soils with high activity clays throughout the *argic* horizon and a high base saturation in the 50-100 cm depth satisfy the definition of Luvisols as a reference soil group. These characteristics entirely defined the soil without the requirement of other principal qualifier and thus *haplic* was prefixed. However, the presence of a base saturation of less than 50% between 20 to 50 cm from the surface makes the use of *epidystric* supplementary qualifier to classify the soil as Haplic Luvisols (Epidystric), which covers 607 ha.

Pedon 6 was excavated in the lower slope position where the pedon was developed with weathered and deposited sediments with large proportion of clay. The soil in the subsurface is rich in clay content exceeding 30% throughout the pedon; hard to very hard during dry, and sticky and plastic consistence during wet conditions that shrink and swell alternatively to form deep cracks and slickensides in the surface and subsurface horizons to meet *vertic* subsurface diagnostic horizon. A *vertic* horizon starting ≤ 100 cm from the soil surface, clay content higher than 30% between the soil surface and the vertic horizon throughout, and shrink-swell cracks that start at the soil surface meets the requirements of Vertisols. Vertisols having in the upper 30 cm of the soil a Munsell colour value of ≤ 3 and a chroma of ≤ 2, both moist are prefixed by *pellic* principal qualifier. Moreover, according to FAO (2014), soils having a base saturation of < 75% at a depth of 20 cm from the soil surface were defined with *mesotrophic* supplementary qualifier. Therefore this soil was identified as Pellic Vertisols (Mesotrophic), and covers an area of 440 ha.

Conclusion

Adequate information on soil and land characteristics is required for maintaining soil productivity and realization of land use planning. Therefore, soil characterization, classification and mapping of soils were conducted at subwatershed level of the Guna Mountain in Lay Gayint district. The morphological, physical and chemical characteristics of the soils showed variation along the topographic positions and soil depth. The soils represented by pedon 1 in the upper slop position were relatively shallow whereas the pedons in the middle and lower slope positions were very deep. The clay content in the B horizons of all pedons was higher as compared to the surface horizons. Soil formation in most of the pedons is characterized by clay illuviation from the surface to the subsurface soil horizons. Soils differed from very strongly acid to slightly acid in reaction. The exchangeable Al^{3+} values of the surface horizons of cultivated lands (Pedons 1 and 4) are with the range that may influence crop growth adversely. The soils had medium to high total N, very low to high OC, low to high available P, high to very high CEC, medium to very high exchangeable Ca, low to very high exchangeable Mg, very low to low exchangeable K. Based on the studied morphological, physical and chemical parameters, Hyperdystric Cambisols (Humic), Haplic Alisols (Humic), Cambic Umbrisols (Colluvic), Haplic Luvisols (Epidystric), and Pellic Vertisols (Mesotrophic) were the identified soil types in Yikalo subwatershed of Lay Gayint district.

In general the soil characteristics and pedon development of Yikalo subwatershed is affected by topographic positions, leading to erosion and leaching. Thus, the upper and middle slope positions need soil management practices such as bench terraces in the upper slope, and stone bunds in the middle slope reinforced with suitable grass and tree species. Excess water in the areas dominated by Vertisols should be drained during rainy season. In addition to this, application of optimum rates of FYM, compost, biofertilizers, and lime integrated with inorganic fertilizers containing N, P and K may help to reduce the level of soil acidity, and improve the fertility level of the soils for better crop production and productivity.

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Soil-landscape relationship as indicated by pedogenesis data on selected soils from Southwestern, Iran

Hamidreza Owliaie [a,*], Mahdi Najafi Ghiri [b], Sirous Shakeri [c]

[a] Department of Soil Science, College of Agriculture, Yasouj University, Yasouj, Iran
[b] College of Agriculture and Natural Resources, Darab University, Darab, Iran
[c] Department of Agriculture, Payame Noor University, Tehran, Iran

Abstract

Soils of semiarid regions of Dehdasht and Choram in Southwestern Iran have formed on alluvium derived from mixed calcareous-gypsiferous materials from Lower Miocene to Upper Pliocene. In order to characterize and classify the soils and to determine the soil-landscape relationship in the area, nine pedons located on different physiographic positions including plateau, river alluvial plain, piedmont plain, alluvial plain and alluvial fan have been described, sampled and analyzed. Physicochemical analyses, clay mineralogy and micromorphological studies were performed. The results showed that topography and parent material were two important soil forming factors affecting soil formation in the area. The soils were dominated by carbonate, gypsum, and clay illuviation and accumulation. More developed soils were found on the stable plateau and piedmont plain. Clay illuviation and argillic horizon development in soils of the more stable alluvial plain were assumed to be relict features from presumably more humid climates. Palygorskite, illite, chlorite, smectite, kaolinite, and quartz clay minerals were identified in almost all physiographic surfaces, but more palygorskite and less smectite were found in the soils with gypsiferous parent materials. Observations by SEM revealed the occurrence of neoformed palygorskite as thread-like faces and coating of gypsum crystals and marly matrix. Coating and infilling of gypsum and calcite crystals in voids and channels were common pedofeatures observed in the soils studied. Two different distribution patterns of Fe-Mn oxides were identified in aquic and non-aquic soils.

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Introduction

There have been many attempts to correlate soil properties with various factors, such as parent material and topography (McBratney et al., 2000). Soil geomorphology is an assessment of the genetic relationships between soils and landforms (Gerrard, 1992). Birkeland (1999) defined soil geomorphology as the study of soils and their use in evaluating landform evolution, age and stability, surface processes and paleoclimates.

The differences in soil properties with landscape position are usually attributed to differences in runoff, erosion, and deposition processes, which affect soil genesis and vegetation development (Dahlgren et al., 1997; Lark, 1999). Moazallahi and Farpoor (2011) found the landscape as a significant soil forming factor causing different physicochemical and clay mineralogical properties in soils of southern Iran. Khresat and Qudah (2006) found that carbonate, clay elluviation–illuviation, and salt accumulation are the dominant pedogenic processes in the arid soils of northeastern Jordan.

Sanjari et al. (2011) investigated paleosols with argillic horizons on stable pediment surfaces in Jiroft area, central Iran. They found that secondary gypsum and calcite were accumulated in mantled pediments, but

* Corresponding author.
Department of Soil Science, College of Agriculture, Yasouj University, Yasouj, 75918-74831 Iran
Tel.: +98 7431006112
E-mail address: owliaie@gmail.com

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moving down the slope toward lowlands, salts-more soluble than gypsum-have been accumulated. Nooraie (2010) in the study performed in Loot Desert, reported a close relationship between geomorphic position and soil genesis and evolution. He pointed out that undeveloped Entisols were formed on young unstable pediment surfaces. On the other hand, salic, gypsic, petrosalic, and petrogypsic horizons were formed on developed soils of playa landform.

Study of clay minerals and their alteration provides important information on the pedogenic history of soils as well as soil genesis and evolution (Wilson, 1999). Clay mineralogy in soil studies helps in better conception of soil genesis and development (Moore and Reynolds, 1997). Soil clay minerals have two main sources: (1) neoformation and transformation by pedogenic processes, and (2) inheritance from parent rocks, or addition by eolian or fluvial processes to soil surface (Schaetzl and Anderson, 2005).

Palygorskite, smectite, chlorite, illite, kaolinite, and vermiculite have been reported as dominant clay minerals in arid and semi-arid areas of Iran (Salehi et al., 2002; Khormali and Abtahi, 2003; Owliaie et al., 2006; Nadimi and Farpoor, 2013; Sarmast et al., 2016; Sarmast et al., 2017). Neoformation of palygorskite as a result of calcite and gypsum precipitation seems to be a major pathway for the occurrence of this mineral in the studied soils of southwestern Iran. Moreover, large amounts of smectite seem to be inherited from the Miocene marl formations (Owliaie et al., 2006). A close relationship between geomorphic positions and palygorskite morphology and its origin was reported by Farpoor et al. (2002) in Rafsanjan area in the south-central part of Iran.

High amounts of gypsum are frequently found in soils of arid and semi-arid environments. Many macro and micro forms of soil gypsum have been reported in the literature. Owliaie et al. (2006) reported prismatic, lenticular, platy, tabular, pseudo-hexagonal, and hexagonal as well as interlocked plates of gypsum in relation to stage of soil development of the studied soils of southwestern part of Iran. They found a clear relationship between the size of pore space in soil matrix and dimensions of lenticular crystals.

Hashemi et al. (2011) reported that soil moisture, texture, and landscape position play an important role in the formation of pedogenic gypsum. They stated that well-crystallized gypsum was observed in soils with the lighter texture. The shape, size, and position of gypsum crystals, within the soil matrix, were used to determine their source (Buck and Van Hoesen, 2002; Carter and Inskeep, 1988).

Calcite is one of the best studied, but also one of the most flexible pedogenic minerals. It shows a wide variety of shapes and habits, and occurs as well in arid and semiarid soils with restrained drainage (Stoops and Delvigne, 1990). The occurrence of calcitic pedofeatures in calcareous soils of southern and southwestern Iran has often been reported in the literature (Khormali et al, 2006; Owliaie et al., 2006; Owliaie, 2012). According to Wright (1987), the type of pedogenic calcium carbonate is controlled mainly by the parent material, climate, and vegetation.

Iron and manganese oxides as well as hydroxide minerals are very active constituents in soils because they are sensitive to environmental changes and they move frequently along soil cracks or holes and deposit in peds (McKenzie 1989; Dixon and Skinner, 1992). In soils, the reduction and oxidation of iron and manganese, as a result of seasonal changes in soil moisture, contributes to the formation of cutans, forming coatings and concretions (Zhang and Karathanasis, 1997; Liu et al., 2002). Owliaie (2014) reported two different distribution patterns of Fe-Mn oxides in aquic and non-aquic soils due to more mobility of these oxides in aquic conditions.

The Dehdasht and Choram Plains in the center of Kohgilouye Province have relatively large diversity in terms of topography, soil types, and geological formations that have made this an appropriate area to study the relationship between these factors. Limited data are available for the pedogenesis of this area; therefore, the aims of the present research were to study 1) the physicochemical and morphological soil properties, and micromorphology of the soils related to physiographic positions, 2) the soil genesis and classification using both Soil Taxonomy and World Reference Base (WRB) Systems, and 3) the mineralogy of clay fraction in the studied soils.

Material and Methods

Study area

Dehdasht and Choram Plains are located in the central part of Kohgilouye Province, Southwestern Iran (Figure 1). Mean elevation of Dehdasht and Choram Plains are 790 and 735 m above sea level (a.s.l.), respectively. Two seasonal rivers which pass through the plain, have distinctive effects on transportation and sedimentation of materials (Figure 2).

Figure 1. Location of Kohgilouye Province, southwestern Iran and the study area

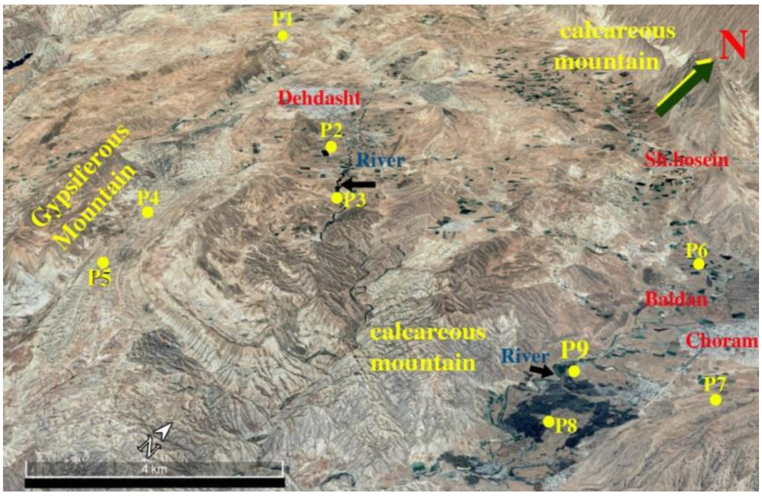


Figure 2. Map of the study area indicating topographic positions and representative pedons.

This region is part of the Zagros orogenic zone, which extends throughout the province. As indicated in Figure 3, four main geological units are recognized in the area. The Bakhtiari Formation, exposed in the east and southeast Mountains, consist of sandstone, limestone, conglomerate and gray marl (Upper Pliocene). The Gachsaran Formation (Lower Miocene) is composed of thick bedded alternating layers of anhydrite and marls (exposed in the east and south of the region) (Figures 2, 3). The Mishan Formation (Lower to Middle Miocene) consists of gray marls with ferruginous materials at its base (exposed parallel to Gachsaran Formation). The Aghajari Formation (Upper Miocene to Pliocene) consists of red sandstone, pebbly sandstone and silty marls with gypsum interlayer (exposed in central and northeast of the region. Overlying the Aghajari Formation are Quaternary alluvium and recent deposits (Geological Survey of Iran, 1995).

The soil moisture regime of the study area is ustic, and the temperature regime is hyperthermic (Banaei 1998). Climatic data indicates a mean annual rainfall of 478 mm, and a mean annual temperature of 21.5 °C (for a 25-year recording period at Dehdasht weather station).

Soil transect and field characterization

Different landforms in the area were identified using Google Earth and topographical maps, together with detailed field work. Piedmont plain, alluvial fan, alluvial plain, river alluvial plain, and plateau were dominant physiographic units recognized in the area studied (Figure 2).

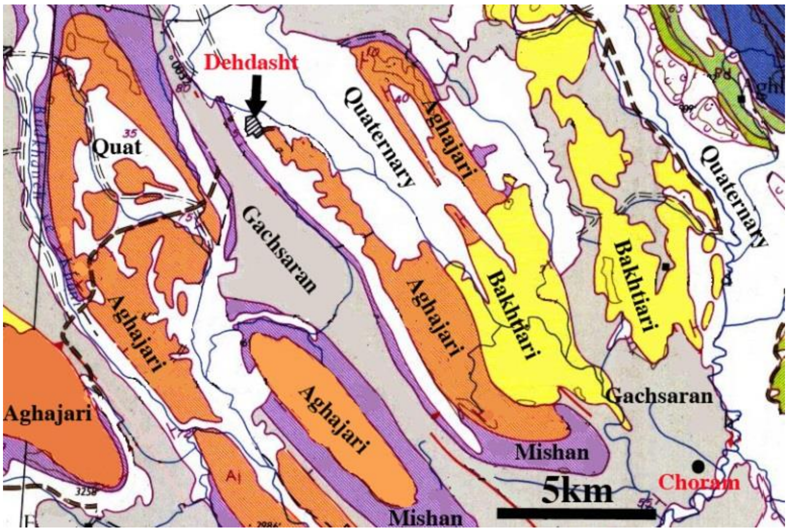


Figure 3. Regional geological map of the study area

Nine representative pedons on different physiographic units were sampled and studied, (Figure 2). Pedon 1 on plateau, pedons 2, 4, 6 and 8 on the piedmont plain, pedons 3 and 9 on the river alluvial plain, and pedons 5 and 7 on the alluvial fan were studied. Soil pedons were classified according to Taxonomy (Soil Survey Staff, 2014) and WRB (FAO, 2015) systems.

Air-dried soil samples were sieved through a 2 mm sieve and routine soil physical and chemical properties were investigated. Organic carbon was measured by wet oxidation with chromic acid and back titration with ferrous ammonium (Jackson, 1975). Calcium carbonate equivalent (CCE) was measured by acid neutralization and gypsum was determined by precipitation with acetone (Salinity Laboratory Staff, 1954). Cation exchange capacity (CEC) was determined using sodium acetate (NaOAc) at a pH of 8.2 (Chapman, 1965). Soil pH was measured with a glass electrode in a saturated paste and electrical conductivity (EC) was determined in the saturation extract (Salinity Laboratory Staff, 1954). Soil texture was determined using the pipette method (Day, 1965).

Fifteen soil samples were selected for clay mineralogical analysis. Calcium carbonate, organic matter, and iron oxides were removed and clay fraction was separated (Jackson, 1975; Kittric and Hope, 1963). Four slides including Mg saturated, Mg saturated and treated by ethylene glycol, K saturated, and K saturated and heated to 550 °C were analyzed using a Philips D500 diffractometer, using Ni-filtered Cukα radiation (40 kV, 30 mA). Four major geological strata were sampled for mineralogical studies. The semi-quantitative contents of the clay minerals were estimated according to Johns et al. (1954). Semi-quantitative assessments make the identification of individual components in polymineralic samples much more valuable. Small soil clods were mounted on aluminum stubs and coated with gold for scanning electron microscopy (SEM) observation using a Cambridge SEM.

Thin sections were prepared using the methods described by Murphy (1986). Undisturbed soil samples were impregnated under vacuum with an acetone-diluted polyester resin (60/40 ratio). Oriented sections were cut with a diamond saw and cemented onto glass microscope slides. They were ground and polished to a thickness of about 20-30 µm. Micromorphological descriptions were made according to Stoops (2003) using a Zeiss petrographic microscope.

Results and Discussion

Physicochemical properties

Table 1 shows the physicochemical properties of the studied pedons. All the soils are calcareous or gypsiferous throughout the profile. Calcium carbonate equivalent (CCE) varied between 38.1 and 86.3%. An increasing trend of calcium carbonate with depth was recorded in most of the pedons studied. Electrical conductivity of saturation extracts (ECe) was between 0.2 and 2.3 dSm^{-1}. More EC contents were measured in gypsic horizons. The soils exhibited a narrow range of pH (7.4 to 8.2) within their solums. Clay content was measured to be between 20 and 55% and gypsum content to be between trace amounts and 8.6 %. The organic carbon content is generally low to moderate, varied between 0.12 and 4.84%. The most content of OC was measured in mollic epipedon of pedon 8. The low organic matter content of the studied soils contributed to land degradation. CEC varied between 6.3 to 36.8 cmol$_{(+)}$kg^{-1}. More CEC was measured in the soils of physiographic surfaces of piedmont plains and plateau with more clay content.

The studied soils were classified as Entisols, Inceptisols, Alfisols, and Mollisols with calcic, gypsic, cambic, and argillic horizons and ochric and mollic epipedons based on Soil Taxonomy (Soil Survey Staff, 2014) and Calsisols, Cambisols, Regosols, Gypsisols, Luvisols, and Kastanozems based on WRB (FAO, 2015).

Table 1. Physicochemical properties of representative pedons

Horizon	Depth (cm)	EC (dS/m)	pH	CCE (%)	Gypsum (%)	OC (%)	Sand (%)	Silt (%)	Clay (%)	CEC cmolkg^{-1}
Pedon 1 (Plateau)										
Ap	0-25	0.8	7.7	41.5	ng	1.25	33.0	42.0	25.0	15.1
Btk1	25-70	0.6	7.8	45.1	ng	0.62	25.0	42.0	34.0	17.0
Btk2	70-110	0.5	8.0	43.7	0.7	0.42	38.0	22.0	40.0	14.9
C	110-140	0.4	8.2	48.8	0.8	0.12	32.0	38.0	30.0	11.8
USDA: Calcic Haplustalfs					WRB: Calcic Luvisols (Ochric)					
Pedon 2 (Piedmont plain)										
Ap	0-25	0.7	7.6	44.0	ng	1.48	17.0	43.0	39.0	18.6
Btk	25-50	0.8	7.7	51.1	0.5	0.70	15.0	30.0	55.0	19.8
Bk1	50-85	1.8	8.0	56.1	1.0	0.62	11.0	38.0	51.0	16.1
Bk2	85-115	2.0	7.7	58.4	1.4	0.32	23.0	35.0	42.0	13.5
USDA: Calcic Haplustalfs					WRB: Calcic Luvisols (Ochric)					
Pedon 3 (River alluvial plain)										
Ap	0-30	0.5	7.9	45.0	0.7	0.95	29.0	30.0	31.0	14.8
C1	30-75	0.3	7.8	86.3	0.9	0.72	38.0	27.0	35.0	10.8
C2	75-125	0.7	8.1	83.0	1.0	0.52	27.0	40.0	33.0	10.2
USDA: Typic Ustorthents					WRB: Calcaric Regosols (Loamic, Ochric)					
Pedon 4 (Piedmont plain)										
Ap	0-20	0.7	7.9	49.8	0.9	0.81	42.0	32.0	26.0	9.2
Bw	20-60	1.4	7.8	60.2	3.9	0.51	44.0	26.0	30.0	9.5
Bky1	60-95	1.9	7.5	57.3	5.7	0.37	41.0	31.0	28.0	6.8
Bky2	95-125	2.3	7.5	58.2	8.6	0.25	46.0	28.0	26.0	6.4
USDA: Gypsic Calciustepts					WRB: Calcic Gypsisols (Loamic, Ochric)					
Pedon 5 (Alluvial fan)										
Ap	0-20	1.2	7.6	55.2	2.2	0.81	45.0	35.0	21.0	8.8
Bky	20-55	1.7	7.8	59.9	6.4	0.35	46.0	29.0	25.0	6.9
C	55-100	1.5	7.4	66.7	3.7	0.20	43.0	34.0	23.0	6.3
USDA: Gypsic Calciustepts					WRB: Calcic Gypsisols (Loamic, Ochric)					
Pedon 6 (Piedmont plain)										
Ap	0-30	0.6	7.5	52.5	1.7	0.92	17.0	46.0	37.0	21.5
Bk1	30-60	0.4	7.7	56.0	0.5	0.42	21.0	36.0	43.0	19.0
Bk2	60-90	0.2	7.8	53.5	0.2	0.33	22.0	42.0	36.0	14.9
Ck	90-125	0.3	7.9	62.8	0.1	0.12	28.0	42.0	30.0	12.4
USDA: Typic Calciustepts					WRB: Haplic Calcisols (Loamic, Ochric)					
Pedon 7 (Alluvial fan)										
Ap	0-30	0.5	7.9	70.0	0.5	1.32	36.0	27.0	37.0	16.5
Bw1	30-75	0.3	8.1	73.3	0.4	0.65	42.0	20.0	38.0	12.2
Bw2	75-120	0.3	8.4	78.2	0.7	0.42	49.0	23.0	28.0	8.4
USDA: Fluventic Haplustepts					WRB: Fluvic Calcaric Cambisols (Loamic, Ochric)					
Pedon 8 (Piedmont plain)										
Apg	0-25	0.4	7.4	38.1	0.4	4.84	34.0	33.0	33.0	36.8
Bkg	25-80	0.3	7.8	58.3	0.6	2.02	36.0	26.0	38.0	21.4
C	80-130	0.3	8.0	67.7	0.5	0.49	31.0	33.0	36.0	12.2
USDA: Typic Calciaquolls					WRB: Calcic Gleyic Kastanozems (Loamic)					
Pedon 9 (River alluvial plain)										
Ap	0-25	0.9	7.4	64.1	0.4	1.40	41.0	30.0	29.0	12.5
C1	25-75	0.5	7.9	68.4	0.5	0.79	33.0	33.0	34.0	11.0
C2	75-130	0.3	8.1	72.8	0.5	0.56	29.0	35.0	36.0	11.7
USDA: Typic Ustifluvents					WRB: Calcaric Fluvisols (Loamic, Ochric)					

EC electrical conductivity, OC organic carbon, CCE calcium carbonate equivalent, CF coarse fragments (more than 2 mm), ng negligible

The soils formed adjacent to Gachsaran Formation (pedons 4 and 5), in the west of the study area, have a mixture of gypsiferous and calcareous parent materials. The formation of secondary gypsum and calcite is the dominant pedogenic process in these soils. The depth of calcic and gypsic horizons in these soils was highly related to the amount of precipitation and physiographic position. These pedons were classified as Gypsic Calciustepts. Pedon 8 in Choram region (piedmont plain) is a paddy soil with a locally aquic soil moisture regime and a mollic epipedon at surface and a calcic horizon at subsurface. This pedon was classified as Typic Calciquolls (Table 1).

Undeveloped Entisols (pedons 3 and 9) were formed on young unstable river alluvial plain with seasonal sedimentation by Dehdasht and Choram Rivers, respectively. These pedons were classified as Typic Ustorthents and Typic Ustifluvents, respectively. The northern sector of the region shows stable physiographic units of plateau and piedmont plain. The most evolved soil pedons were described in this sector (Calcic Haplustalfs).

Clay content increased with depth in most of the pedons, indicating illuviation of clay. The presence of argillic horizons in the more stable positions of plateau and piedmont plain (Pedons 1 and 2) in a semi-arid region, indicated a more humid paleoclimate in the history of the area. Micromorphological observations support these findings (Figure 6e). No argillic horizon was found in the other unstable positions. It seems that the stability of the geomorphic surface has been an important factor affecting the formation/preservation of argillic horizon through time. Besides, the formation of argillic horizons in arid soils of Central Iran was attributed to a more humid paleoclimate reported by Nadimi and Farpoor (2013).

The size, shape, and position of gypsum crystals, within the soil matrix, have been used to determine their origin (Buck and Van Hoesen, 2002). It has been suggested that diversity of crystal morphology results from changing micro-environmental conditions in soils through time (Amit and Yaalon, 1996). SEM observations of the present study showed that pedogenic gypsum crystals can occur individually or in clusters (nodules and plugs) within the soil groundmass and pores (Figures 5e and 5f). Amit and Yaalon (1996) identified four different crystal forms of gypsum included lenticular, prismatic, alabastrine microcrystalline, and fibrous crystals in relation to stage of soil development.

Clay minerals

Rocks

Chlorite, illite, smectite, palygorskite, quartz, and interstratified minerals are the major clay minerals within the rock samples studied (Table 2). Smectite was dominant in the younger sediments (Bakhtiari and Aghajari formations), in comparison with the older sediments (Mishan and Gachsaran formations) in which palygorskite was most abundant. The inverse correlation between smectite and palygorskite supports the hypothesis of the conversion of these two minerals to each other. Only small amounts of palygorskite were observed in the youngest formation. The association of smectite and palygorskite in the Oligo–Miocene limestone and marl is consistent with the results of the others (Pletsch et al., 1996; Khormali and Abtahi, 2003). Moderate to large quantities of illite and chlorite were found in all formations. Khademi and Mermut (1998) found palygorskite and sepiolite and appreciable amounts of mica and smectite in the clay fraction of the Oligo–Miocene limestone of central Iran. All formations contained small quantities of interstratified minerals, but only the youngest contained measurable amounts of quartz.

Table 2. Relative abundance of different clay minerals in the clay fraction of the carbonate-free residues of the rock samples studied[a]

Rock	Age	Ch.	Il.	Sm.	Pa.	Qr.	Is.
R1	Lower Miocene	++	+++	+	+++	+	+
R2	Lower to Middle Miocene	+++	++	++	++	+.	+
R3	Upper Miocene to Pliocene	++	++	+++	+	+	+
R4	Upper Pliocene	++	++	+++	+	++	+

+: Relative abundance of minerals, tr=trace. [a]Ch, chlorite; Il, illite; Sm, smectite; Pa, palygorskite; Qr, quartz; Ve, vermiculite; Is, Interstratified minerals. R1=Gachsaran, R2=Mishan, R3=Aghajari, R4=Bakhtiari.

Soils

Palygorskite, chlorite, illite, smectite, vermiculite, kaolinite, quartz and interstratified minerals are the major clay minerals within the soils (Table 3). The presence of moderate to high contents of illite and chlorite in the soils can be related to inheritance from parent rocks. Larger contents of these minerals in parent rocks or sediments support this hypothesis. High leaching together with low pH and removal of interlayer hydroxides were reported as the ideal conditions for chlorite formation in soils (Branhisel and Berstesch, 1992). That is why the arid moisture regime of the present research is not favorable for the pedogenic formation of chlorite. Thus, chlorite in soils of the study area is inherited (Owliaie et al., 2006).

However, there is some indication that mica may form pedogenically in arid soils as well, but only in special conditions, mainly through K fixation of pre-existing smectite (Mahjoory, 1975; Sanguesa et al., 2000). Simple transformation of illite to smectite may play a major role in decreasing illite content at soil surface (i.e. pedons 1, 2, 6 and 8). Climatic condition in the study area can provide a leaching environment for the release of K^+ from illite. Moreover, the soil environment, high in Mg and Si mobility, may create favorable condition for the formation of smectite through transformation at the soil surface (Owliaie et al., 2006).

Table 3. Relative abundance of clay minerals [a] (<2 μm)

Pedon/horizon	Ch.	Il.	Sm.	Pa.	Ka.	Ve.	Qr.	Is.
1/Ap	++	+	+++	+	+	+	tr.	tr.
1/Btk2	+++	++	++	++	tr.	+	+	+
2/Ap	++	+	+++	++	+	tr.	tr.	+
2/Btk	++	+++	+	++	tr.	tr.	+	+
2/Bk2	++	+++	+	++	+	tr.	++	+
4/Ap	++	+	++	++	+	tr.	+	tr.
4/Bky1	++	+	+	++++	+	tr.	+	tr.
5/Ap	+	++	++	++	+	+	+	tr.
5/Bky	++	++	+	++++	+	tr.	+	+
6/Ap	++	+	+++	+	tr.	+	tr.	tr.
6/Bk2	+++	++	+	++	tr.	tr.	+	+
8/Apg	+	+	++++	+	tr.	tr.	+	+
8/Bkg	++	++	+++	tr.	+	+	tr.	tr.
9/Ap	+	+	+++	tr.	+	+	+	tr.
9/C2	++	++	+	++	+	tr.	+	tr.

+: Relative abundance of minerals, tr= trace.

[a]Ch, chlorite; Il, illite; Sm, smectite; Pa, palygorskite; Ka, kaolinite; Qr, quartz; Ve, vermiculite; Is, Interstratified minerals.

Maximum content of smectite is noticed in pedon 8 with aquic soil moisture regime (Table 3 and Figure 4d). The presence of large amounts of this mineral in poorly soils is reported by Abtahi and Khormali (2001) and Aoudjit et al. (1995). They discussed there are three main sources of smectite in soils: (1) neoformation from soil solution, (2) detrital origin or inheritance, (3) transformation of other clay minerals. Low-lying topography, poor drainage and base-rich parent material, favorable chemical conditions characterized by high pH, high silica activity and an abundance of basic cations are the factors strongly influenced the origin and distribution of smectite in soils.

Some part of the smectite is inherited from highly smectite marl formations, but the distinction between inherited and newly-formed clay minerals is difficult to discern. Some part of the smectite is inherited from highly smectite marl formations, although some may be the product of palygorskite weathering and transformation of illite particularly at the surface horizons.

A broad smectite peak (Figures 4a and 4b) after ethylene glycol treatment of some horizons (i.e. Btk2 horizon of pedon 4 and Ap horizon of pedon 2) appeared indicating the presence of high charge and/or low crystalline smectite in the soil, which suggests the inheritance origin of this mineral in the studied soils. In contrast, a sharp smectite peak in aquic soil (pedon 8), suggests a pedogenic origin of this mineral (Figure 4d). Smectites with lower layer charge are present in the soils having a longer effective time of pedogenesis, suggesting alteration of the high-charge smectites with time (Gillot et al., 2001). Rezapour et al. (2012) and Rezapour (2014) reported low crystalline smectite in the cultivated soils of northwestern of Iran, suggested a neoformed clay mineral.

Trace to very low contents of vermiculite is observed in surface horizons of the soils studied. The occurrence and stability of vermiculite in calcareous and silica-rich soils have not been well-documented (Boettinger and Southard, 1995). According to Wilson (1999) with regard to the transformation of clay minerals, a general example would be: illite →vermicullite →smectite.

At about pH > 6 (as in case of the studied soils), Al is not soluble. In contrast, Si is highly soluble especially in the common pH of around 8 (as in calcareous soils of southern Iran). Therefore, high Mg present in calcareous materials can substitute Al in the lattice and form smectite. However, vermiculite is not stable and there is no evidence showing the existence of this mineral in the studied soils. Alteration of mica is the main pathway for the occurrence of pedogenic vermiculite in the soils (Churchman and Lowe, 2012).

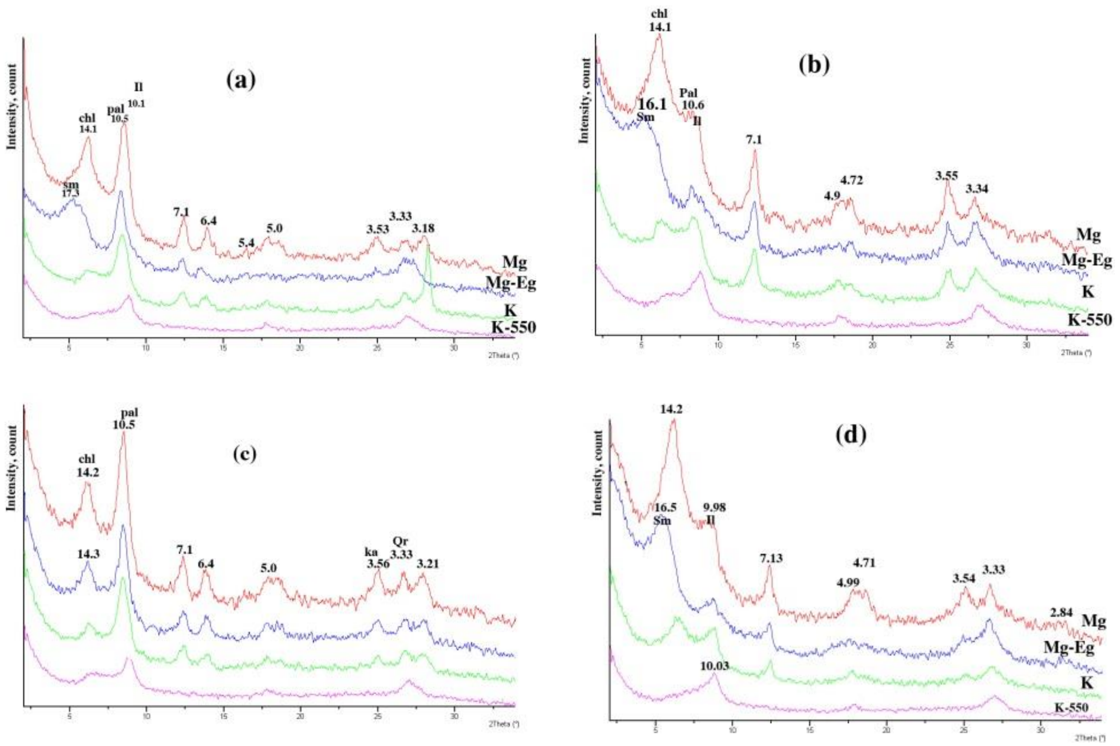


Figure 4. X-Ray diffractograms of the clay fraction, a) Btk2 horizon of pedon 1, b) Ap horizon of pedon 2, c) Bky1 horizon of pedon 4, d) Apg horizon of pedon 8, Sm: Smectite, I: Illite, Pa: Palygorskite, Ch: Chlorite, Ka: Kaolinite. Mg=Mg saturated; Mg-Eg=Mg saturated with Ethylene glycol; K=K saturated; K-550=K saturated and heated to 550 °C.

The results of the current research indicate that inheritance origin due to a moderate to large amount of smectite in parent rocks especially in younger formations and transformation from palygorskite are the main pathways for the occurrence of smectite in the soils studied (except for the pedon 8 with aquic condition). Illite is a main precursor mineral for the formation of smectite in soils, particularly at the surface horizons. Palygorskite is another possible precursor mineral for smectite formation in similar environments. The results indicate that there is a reverse correlation between smectite and palygorskite in the studied pedons. The maximum of palygorskite is observed in deeper horizons. It can indicate that palygorskite, weathers and transforms to smectite at soil surface. Similar results are reported in literature (Abtahi, 1980; Khademi and Mermut, 1998; Owliaie et al., 2006).

Increase of Mg/Ca ratio after gypsum crystallization in Tertiary followed by Miocene orogenic activities in arid lands of Iran was reported in the literature (Khademi and Mermut, 1998; Owliaie et al., 2006; Moazallahi and Farpoor, 2009). Farpoor et al. (2002) have reported a close relationship between geomorphic positions and palygorskite morphology and origin in the soils of Rafsanjan area in the south central part of Iran. A close relationship between palygorskite morphology and depth of soil was observed on different landforms in the soils of southwestern Iran (Owliaie et al., 2006).

Traces to minor contents of quartz and interstratified minerals are observed in clay fraction of the studied soils (Table 3). More contents of these minerals are found in clay fraction of the deeper horizon with lower weathering suggesting a lithogenic origin for these minerals.

According to the results (Tables 2 and 3), the relative amount of palygorskite in soils is much more than the parent rock samples (especially in gypsiferous soils). It may suggest that the pedogenic origin for palygorskite formation is more important than lithogenic. It has been stated that palygorskite in soils of arid and semi-arid environment has two main origins: (1) inheritance from parent materials and (2) pedogenic formation (Badraoui et al., 1992; Monger and Daugherty, 1991). Pedogenic palygorskite has been proposed to form by alteration of precursor minerals such as smectite or by precipitation from solution (Singer, 1984). Neoformation of palygorskite seems to need large activities of Si and Mg with a pH of about 8 (Singer, 1989). Figure 5d shows SEM micrographs of palygorskite fibers on gypsum crystals (Bky1 horizon of pedon 4).

A high amount of palygorskite was observed in gypsiferous pedons (pedons 4 and 5) compared with calcareous pedons (Table 3). Owliaie et al. (2006) concluded that calcareous and gypsiferous soils can provide buffered alkaline media with essential anions and cations for pedogenic formation of palygorskite but properties of the gypsiferous soils may result in a more favorable medium for this purpose.

Presence of first (7.1 Å) and second (3.57 Å) order peaks of kaolinite prove the formation of this clay mineral in the soils studied (Dixon and Weed, 1989). Warm and humid climate with good drainage was reported for kaolinite formation (Nadimi and Farpoor, 2013; Khormali and Abtahi, 2003). Since such an environment could not be found in the area at present, kaolinite should have been inherited in the studied soils. Besides, the role of kaolinite-bearing eolian deposits in the arid environment of the present research should not be neglected as a probable source of this mineral.

Abbaslou et al. (2013) in a study in arid regions of Hormozgan Province, southern Iran, concluded that the soil mineralogy did not vary systematically with depth but showed spatial variations, and the relative influence of mineral distribution in topsoils was mainly affected by parent rocks and the geomorphological setting.

Micromorphology

Table 4 shows a brief description of some micromorphological properties of thin sections from selected soils. The overall microstructure of the studied soils ranged between weakly and well separated subangular blocky. The c/f 10µm related distribution is porphyric and ranged from 2/8 in the Bkg horizon of pedon 8 to 6/4 in the Bky2 horizon of pedon 4. Reddish brown groundmass dominated in the soils with gypsiferous parent material (particularly pedons 4 and 5), whereas yellowish brown to bright brown groundmass prevailed in the soils with calcareous parent materials. Since soils are highly calcareous or gypsiferous, the b-fabric is mostly crystallitic (Figures 6a, 6b, 6c, 6g and 6i), except in the soils with argillic horizons (pedons 1 and 2), where it can be speckled b-fabric when calcite depletion occurs (Table 4, Figure 6e). Within the studied soils coating and infilling of gypsum (as lenticular and psedo-hexagonal forms) and calcite crystals in voids and channels (Figure 5a) as well as Fe and Mn oxide nodules were common.

Few large lithogenic calcite nodules are impregnated by Fe oxides (Figure 6d). Calcite has been shown to be an efficient absorber of some impurities such as Mn^{2+}, Fe^{2+}, organic matter, etc (Van Beynen et al., 2001). Few Fe/Mn oxides were observed as dense nodules in the matrix of non-aquic soils, due to less degree of weathering of primary minerals (Figures 6b and 6d). In Bkg horizon of pedon 8 with an aquic condition, Fe/Mn oxides were observed as distributed hypocoating around voids and channels (Figure 6f). In a micromorphological study in southwestern Iran, Owliaie (2014) reported two different distribution patterns of Fe/Mn oxides in aquic and non-aquic soils due to more mobility of these oxides in aquic conditions. In aquic soils, these oxides were observed as hypocoating or quasicoating mostly with concentric internal fabric.

In the Btk horizon of pedon 1 located on a stable surface (plateau), some channels in thin sections, were covered with illuvial-clay coatings (Figure 6e)., however no clay coating was observed in the Btk horizon of pedon 2. More stability of pedon 1 compared to pedon 2 might be a reason for preserving clay skins. The absence of clay coating in thin sections of argillic horizons of highly calcareous soils of arid and semiarid regions is either tied to high shrink–swell potential, caused by the considerable amount of expandable clays (Nettleton et al., 1969; Nettleton and Peterson, 1983) or to the disruption force of growing crystals, such as gypsum or calcite (Khademi and Mermut, 2003) or to engulfment with carbonates (Mahmoodi, 1979). Soil horizons with high extensibility, were mostly missing clay coatings on the faces of peds because of high shrink–swell activity of the groundmass (Griffin and Buol, 1988). As mentioned above, smectite is the major clay mineral of the studied soils, particularly in more stable landforms.

SEM and thin section observations exhibited needle shaped (acicular) calcite as loose infilling in voids and channels of the Bk1 horizon of pedon 6 and Btk horizon of pedon 2 (Figure 5c and 6c). The length and width range of these needles were 20 to 80 µm and 1 to 2 µm, respectively. The origin of needle-shaped calcite has been discussed for a long time and is usually interpreted in two ways: in relation to organic material (roots, root hairs, bacteria, algae, and fungi) and as physicochemical phenomena (Wright, 1984).

Verrecchia and Verrecchia (1994) in a review on the morphology and genesis of needle-shaped calcite showed four types and several subtypes that from which three types are the result of biological methods whereas one is the result of physico-chemical crystallizations related to evaporation and desiccation. Preservation of needle-fiber calcite in soils indicates that the pedogenesis was weak (lack of leaching) and/or the climate of the environment was arid to semiarid (Wright, 1984). However, Strong et al. (1992) reported the occurrence of this form of calcite in cool and wet climate with abundant carbonate and high degree of biological activity.

Specific morphologies of calcite accumulation related to vegetation have been described in calcareous soils. In these soils, roots are responsible for the concentration of sparitic calcite crystals, also called cytomorphic calcite in the root channel (Jaillard et al., 1991). Cytomorphic calcites were observed in the Bk1 horizon of pedons 5 (Figure 5b). According to Monger (2002), biotic processes include CO_2 input into the soil via respiration, Ca^{2+} extraction by roots, and direct precipitation by organisms. The results of a micromorphological study in the soils of Kohgilouye Province, southwestern Iran, showed that cytomorphic calcite pedofeature, was more common in the near-surface horizons of the regions with higher rainfall and denser vegetation (Owliaie, 2012).

Table 4. Thin section description of the pedons studied.

Pedon/ horizon	Microstructure	c/f ratio (10 µm)	Micromass, b-fabric, color	Pedofeatures
1/Btk1	Moderate to well- developed subangular blocky, partly channel structure, porosity (~15%)	4/6	Crystallitic, speckled b-fabric, reddish brown	Dense and loose calcite coating and infilling in voids and channels, few to common clay coatings, dark reddish to black Fe/Mn oxides in matrix and Fe impregnation in calcite nodules.
2/Btk	Moderately developed subangular blocky with interpedal channels, porosity (~20%)	3/7	Crystallitic, speckled b-fabric, reddish brown	Coating of calcite in channels and voids, small calcite nodules, dark reddish to black Fe/Mn oxides in matrix.
2/Bk1	Weak developed subangular blocky, partly channel structure, porosity (~10%)	5/5	Crystallitic, b-fabric, ellowish brown	Loose and dense calcite infilling in voids and channels, coating of calcite along channels, few micritic calcite nodules, few Fe-Mn oxide in ground mass
4/Bw	Moderately developed subangular blocky, porosity (~50%)	4/6	Crystallitic b-fabric, light yellowish brown	Few micritic calcite nodules, few Fe-Mn oxide in ground mass
4/Bky2	Weak developed subangular blocky, porosity (~30%)	6/4	Crystallitic b-fabric, light yellowish brown	Coating of calcite in channels, few medium to large lenticular gypsum crystals in voids, channels and matrix.
5/Bky	Weak developed subangular blocky porosity (~20%) with some planes	3/7	Crystallitic b-fabric, light brown	Infilling of calcite in channels and voids, few fine to medium gypsum crystals in voids and matrix
6/Bk1	Moderately developed subangular blocky with interpedal channels, porosity (~20%)	3/7	Crystallitic b-fabric, yellowish brown	Dense calcite infilling in voids and channels, few needle-like calcite crystals, few Fe-Mn oxide in ground mass
7/Bw1	Weak to moderately developed subangular blocky with some planes, porosity (~20%)	4/6	Crystallitic b-fabric, yellowish brown	Few micritic calcite nodules, few Fe-Mn oxide in ground mass and calcite nodules.
8/Apg	Weak developed subangular, porosity (~25%)	4/6	Crystallitic b-fabric, yellowish red	Very few calcite nodule, oxidized plant residues, Fe-Mn oxide in ground mass
8/Bkg	Weak developed subangular, porosity (~25%)	2/8	Crystallitic b-fabric, reddish brown	Few calcite nodule, calcite infilling in voids and channels oxidized, plant residues, hypocoating of Fe oxide in voids
9/Ap	Weak developed subangular, porosity (~20%)	3/7	Crystallitic b-fabric, yellowish brown	Very few calcite nodule, oxidized plant residues, spheroidal faunal excrements in voids and channels

Faunal excrements were observed in thin section of Ap horizon of pedon 8. These pedofeatures were as organic spheroids (less than 25µm in diameter), and as a vermiform structure with oriented fabric (50 to 150 µm in length), within voids and channels, suggesting high biological activity in this soil (Figure 6j). In addition, plant residues (organs and tissues) in different stages of decomposition, were observed in the thin sections of some surface soils (Figures 6h and 6j). Lenticular, sub-lenticular and pseudo-hexagonal gypsum crystals, are dominant pedofeatures observed in the thin sections of the Bky1 and Bky2 horizons of pedon 4 (Figure 6g) and Bky horizon of pedon 5 (Figures 6i). Gypsum interlocked plates were found mostly in deeper horizons with a larger content of gypsum. SEM observations showed gypsum crystals as individual prismatic crystals (80 to 100 µm in length and 20 µm in width) distributed in soil matrix (Figure 5e), and subhedral crystals (20 to 30 µm) located in large voids (Figure 5f). The lenticular crystals vary in length between 100 and 250 µm and in diameter between 50 and 100 µm. Larger crystals were found in the soils with larger voids. Jafarzadeh and Burnham (1992) believed that lenticular gypsum crystals may form in any environmental condition. However, Amit and Yaalon (1996) have reported ionic impurity and unlimited pore space as the necessary conditions for the formation of lenticular gypsum.

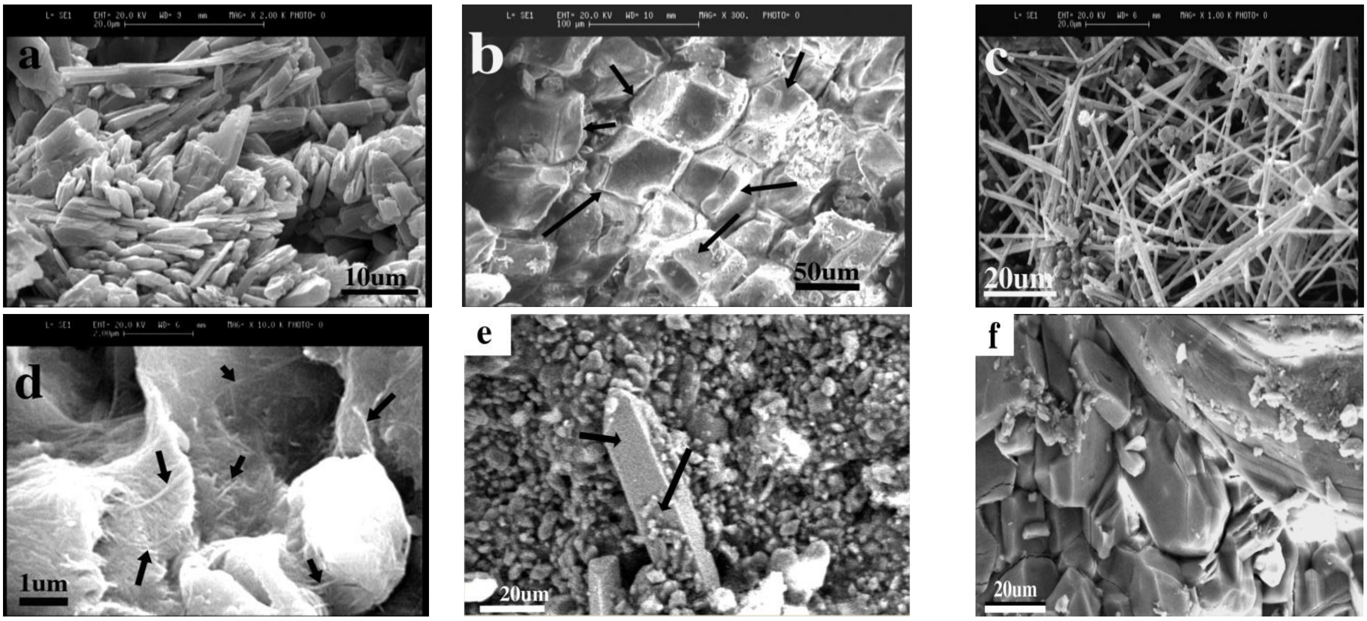
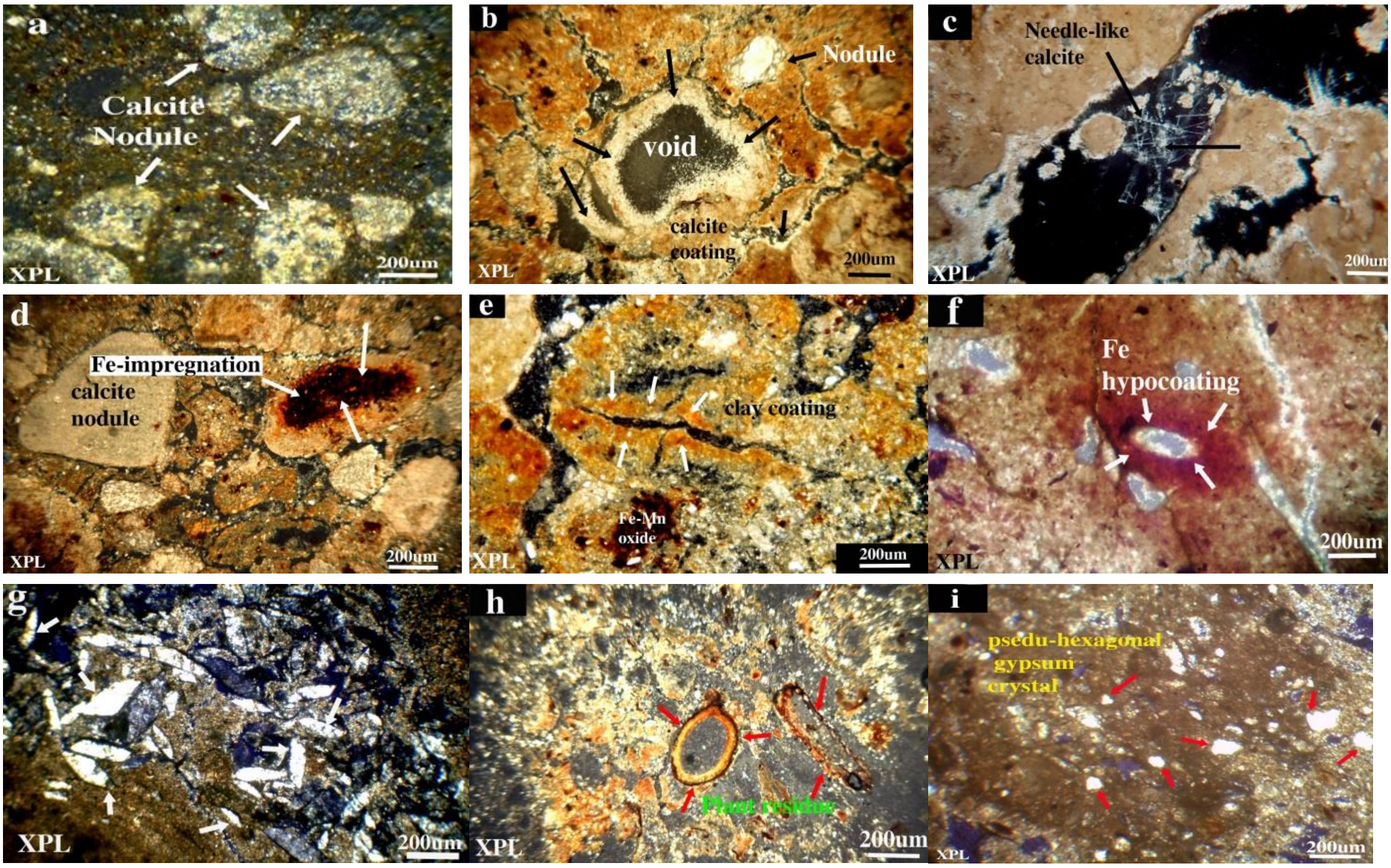


Figure 5. SEM micrographs of (a) euhedral calcite crystal of Bk2 horizon of pedon 6, (b) cytomorphic calcite crystals, Bk1 horizon of pedon 2 (c) needle-like calcite crystals of Btk horizon of pedon 2, (d) palygorskite fibers on gypsum crystal, Bky1 horizon of pedon 4, (e) individual prismatic gypsum crystal, Bky1 horizon of pedon 4, (f) integration of subhedral gypsum crystals, Bky horizon of pedon 5.



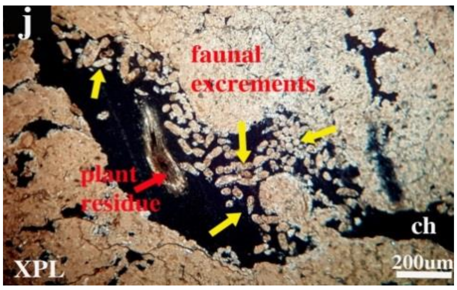


Figure 6. Thin sections of (a) Bk1 horizon, pedon 2 (b) Btk1 horizon, pedon 1 (c) Bk1 horizon, pedon 6 (d) Btk1 horizon, pedon 1 (e) Btk1 horizon, pedon 1, (f) Bkg horizon, pedon 8 (g) Bky1 horizon, pedon 4 (h) Ap horizon, pedon 9 (i) Bky horizon, pedon 5 (j) Ap horizon, pedon 8.

Conclusion

The results of the present study showed that soil formation on different physiographic surfaces and geological strata and its physicochemical, mineralogical, and micromorphological characteristics are closely influenced by landscape position and parent material. More developed soils were found on the stable plateau and piedmont plain; however, the soils formed on the unstable river alluvial plain and alluvial fan showed a minimum of development. Spatial distribution of calcareous and gypsiferous geological strata was responsible for the occurrence of calcic and gypsic horizons in the studied pedons. Mountain runoff water is the main source for the soil gypsum. The depth of calcic and gypsic horizons in the soils was highly related to the amount of precipitation and landscape position. The presence of argillic horizons in the more stable positions of plateau and piedmont plain soils in a semi-arid region indicated a more humid paleoclimate in the history of the area. Smectite, illite, chlorite, palygorskite, kaolinite and quartz clay minerals were identified in almost all landscape surfaces, but more palygorskite and less smectite were found in the soils with gypsiferous parent materials. A large amount of smectite is inherited from the marl formations, although some may be the product of transformation of illite and also palygorskite weathering, particularly at the surface horizons. In the soil with aquic soil moisture regime, neoformation of smectite seems to be the main pathway for the occurrence of this clay mineral. Coating and infilling of gypsum and calcite crystals in voids and channels as well as Fe and Mn oxide nodules and hypocoating (in aquic soil) were common pedofeatures observed in the soils studied. Faunal excrements were observed in the thin section of surface horizons with more biological activity. Co-occurrence of illuvial clay features and pedogenic carbonates were observed in pedons located on the stable physiographic surface suggesting the occurrence of polygenetic soils.

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Can arbuscular mycorrhiza fungi and NPK fertilizer suppress nematodes and improve tuber yield of yam (*Dioscorea rotundata* 'cv' ewuru)?

Gani Oladejo Kolawole [a,*], Tunmise Moses Haastrup [a], Timothy Ipoola Olabiyi [b]

[a] Ladoke Akintola University of Technology, Department of Crop Production and Soil Science, Oyo State, Nigeria

[b] Ladoke Akintola University of Technology, Department of Crop and Environmental Protection, Oyo State, Nigeria

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Abstract

Poor soil fertility and nematodes limit yam tuber yield and quality. Arbuscular mycorrhizal fungi (AMF) and fertilizers may suppress nematodes and improve yam productivity. We evaluated the extent AMF and fertilizer suppressed nematodes and improved yam performance. Tuber weight, mycorrhizal colonization of roots and nematode populations were evaluated with eight treatments; Control (No amendments), 90-50-75, kg N- P_2O_5-K_2O ha^{-1} (NPK), (AMF) (2g/kg soil), nematodes (5000 juvenile/pot), and their combinations. Tuber weight was higher in NPK+AMF and NPK+nematode treatments than AMF+nematode. NPK+AMF improved tuber weight by 17.5% and 32% compared with sole NPK or AMF respectively. Compared with control, nematodes did not reduce tuber weight but, AMF+nematode reduced it by 49.4%. NPK reduced AMF colonization of roots and reduced nematode population on tuber, in roots and soil by 34%, 42.6% and 41% respectively. NPK+AMF treatment was superior to either NPK or AMF in improving tuber yield while NPK was superior to AMF in suppressing nematodes in roots, soil, and tuber.

Keywords: Arbuscular mycorrhizal fungi, nematodes, Nigeria, mineral fertilizer, root colonization, yam tuber weight.

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Introduction

Yams (*Dioscorea* spp) are tropical plants with large reserve of food in their underground tubers (Okoli and Onwueme, 1986). They are important staple food crops in many parts of West Africa, and are prominent during socio-cultural festivals. Yam represents stored wealth, which can be sold all-year-round by the farmer or marketer because they can be stored relatively for longer duration in comparison with other tropical fresh produce (Aidoo, 2009). White yam, *Dioscorea rotundata* is indigenous to West Africa and it is an important economic crop in the yam belt zone of West Africa. Nigeria accounted for more than 70% of the world production of yam (Ekanayake and Asiedu, 2003). Many farm-families depend on the tubers for food, cash, local food security and other traditional uses. In spite of the importance and increased demand for yam tubers, its production and productivity has steadily declined (APMEU, 2001). The steadily declining tuber yields of yam per unit area is caused among other factors by decreasing soil fertility, high labour requirement, problems of pests and diseases. Amongst the various constraints to production of yam, nematode pests are of significant importance (Bridge et al., 2005). Application of fertilizer has been reported to increase yam productivity (Kolawole, 2013). Hence, mineral fertilizer application is considered a quick way of meeting the nutrient requirement of yam.

* Corresponding author.

Ladoke Akintola University of Technology, Department of Crop Production and Soil Science, PMB 4000, Ogbomoso, 210001, Oyo State, Nigeria

Tel.: +234 8037198801

E-mail address: ogkolawole@lautech.edu.ng

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Plant parasitic nematodes have been observed to reduce yield, food quality, market value and sprouting of yam. Reduction of 20-30% in tuber weight at harvest has been reported (Kwoseh, 2000). Although the use of pesticides to control nematode is feasible and effective, but they are costly, scarce or highly toxic for both the user and the environment, constituting serious health hazards (FAO, 2014). Concerns of the environment, crop production and food safety have made researchers to spur many measures to manage nematode pests on crops. For the control of nematodes in yam production, alternative management practices such as hot water treatment of tubers (Coyne et al., 2007), use of cover crops and chemical fertilizers (Kolawole, 2013) have been explored.

Importance of association of arbuscular mycorrhizal fungi (AMF) with yam for natural soil fertility has been demonstrated (Dare et al., 2012). AMFs are important elements of the soil microflora in agroecosystems, which form a mutualistic symbiosis with most plant species. AMFs have been implicated in increasing the availability and uptake of soil phosphorus and trace elements, thereby enhancing host plant growth (Ceballos et al., 2013). Root colonization by AMF, in general, favors plant development by increasing nutrient uptake, hormonal activity, growth rate and consequently yield (Hart et al., 2014), but is also associated with pathogen suppression (Hol and Cook, 2005). Plant parasitic nematodes may enhance or depress colonization of roots and sporulation of mycorrhizal fungus. Likewise, mycorrhizae may decrease or increase nematode penetration, development and reproduction. Previous studies showed the efficiency of indigenous AMF on yam growth (Tchabi et al., 2016).

The present study aimed at determining the effects of NPK mineral fertilizer, AMF inoculation on the performance of yam planted in plant parasitic nematodes infested soil.

Material and Methods

The experiment was conducted at the Teaching and Research Farm, Ladoke Akintola University of Technology, Ogbomoso (Lat. 8^0 10′ N: Long. 4^0 10′E) Oyo State, Nigeria.

Top soil (0-30 cm depth) was collected randomly with soil auger at the Teaching and Research Farm, Ladoke Akintola University of Technology, Ogbomoso. The soil was bulked, mixed thoroughly, air dried, and sieved through 2 mm mesh size sieve. Thereafter, the soil was sterilized by autoclaving at 120^{o}C and 15psi for 30 minutes and later air dried for 72 h. Sub sample of the autoclaved soil was collected and taken to the laboratory for plant parasitic nematode bioassay and chemical analyses. The initial chemical properties of the soil (sandy loam in texture; sand 810 g kg^{-1}, silt 90 g kg^{-1}, and clay 100 g kg^{-1}) are as follows; pH-H_2O) 6.5, total organic carbon 5.3 g kg^{-1}, total nitrogen 0.22 g kg^{-1}, Bray P 6.9 mg kg^{-1}, Exchangeable cations: K 0.22, Ca 1.48 and Mg 0.96 in cmol kg^{-1}.

Thirty kg soil each was weighed into thirty two plastic pots (30-liter volume) perforated at the bottom to prevent water logging and allow good water drainage. The pots were properly labeled.

Eggs of *Meloidogyne incognita* were extracted from galled roots of *Celosia argentea* using the method described by Hussey and Barber (1973).

There were eight treatments namely: 90 - 50 - 75 kg N - P_2O_5 - K_2O ha^{-1} (NPK) which is the recommended rate for yam in the zone; Arbuscular Mycorrhizal Fungi (AMF) at the rate of 2 g/kg soil; Nematodes (5000 eggs and juveniles per pot); AMF + NPK; AMF + Nematode; NPK + Nematode; NPK + Nematode + AMF; and Control (no fertilizer, AMF and nematode). The experiment was arranged in completely randomized design with four replicates.

Healthy white ware yams (cultivar ' ewuru', popular among farmers) were obtained from the local market, steam sterilized at 50-55^{o}C and cut into yam setts under sterile condition. Planting was done by opening holes in the autoclave sterilized soil inside the pots and one 200-300 g yam sett was placed in each hole with the cut surface turned upward at an angle of about 45^0 and covered with soil and capped 2 weeks after planting (WAP). Staking began 5 months after planting with 4 m long bamboo stakes. The pots were manually weeded by hand pulling as at when necessary.

Arbucular Mycorrizal Fungi (AMF) was placed in the planting hole in designated pots at the rate of 60 g/pot. This inoculum contained soil spores, roots of plants used in propagating the inoculum and hyphae. Two weeks after sprouting of yam, each appropriate pot was inoculated with approximately 5000 eggs and juveniles of *Meloidogyne incognita*. Inoculation was done by slowly dispensing 5 ml of the previously prepared nematode suspension into holes around the yam plant. NPK compound fertilizer (15 - 15 -15) (5 g/pot) and the excess N (1.33 g/pot) and K (0.63 g/pot) were met using urea and muriate of potash, respectively. The fertilizers were applied in a ring form and lightly incorporated into the soil about 30 cm away from the growing yam at five months after planting.

At 48 WAP, the pots were upturned over polyethylene sheet. The roots and tubers were gently separated and the adhering soils washed off. The tubers were weighed on weighing balance and weight per treatment was recorded. Post harvest soil samples were collected from individual pots for nematode bioassay.

Pin-pie extraction method (Whitehead and Hemming, 1965) was used for root and soil nematode extractions within 3 hours after harvesting of the yam tubers. Nematodes were extracted within 48 hours after tubers were collected from the pots. Modified Baermann technique was used for extraction. Nematodes species were identified by means of morphology and morphometrics coupled with guide by the identification key for agricultural important plant-parasitic nematodes (Mekete et al., 2012).

At final harvest, galls on the yam root and tuber were assessed following the method of Sasser et al. (1984) on 0 – 5 rating scale where 0 = no gall;1 = 1 – 2% gall; 2 = 3 -30% gall;3 = 31 – 50% gall; 4 = 51 – 70% gall and 5 = 71 – 100% gall.

At twelve weeks after sprouting, root samples were collected from designated plants by digging 30 cm away from the main yam plant to get fine roots. The roots were washed with water and then cut into about 10 cm long pieces, put inside bottles containing ethanol alcohol, and later transferred to the laboratory for mycorrhizal count. Percentage mycorrhizal colonization of roots was determined by gridline-intersect method (Giovanetti and Mosse, 1980), after clearing the root with KOH and staining with chlorazol black E (Brundrett et al., 1984).

Data were subjected to analysis of variance (ANOVA) using SAS software (SAS, 2009) and treatment means compared using least significant difference (LSD) at 5% probability level.

Results

Plant parasitic nematode bioassay of soil after inoculation

There was no nematode found in the soil that was examined immediately after sterilization before yam planting.

Yam tuber weight

Tuber weight was significantly higher in NPK+AMF and NPK+nematode treatments compared with AMF+nematode treatment which had significantly lowest tuber weight (Table 1). The combined application of NPK and AMF improved yam tuber weight by 17.5% and 32% compared with the sole application of NPK or AMF respectively. Inoculation of juvenile nematodes into the soil compared with the control (no nematodes, no fertilizer) had no significant effect on yam tuber weight. However, AMF+nematode treatment reduced tuber weight by 49.4% compared with the control. Compared with the nematode alone treatment, application of NPK fertilizer in nematode infested soil improved tuber weight by 28.4% and combined application of NPK fertilizer and AMF only improved tuber weight by 12%. That is, the effect of combined application of NPK fertilizer and AMF on yam tuber weight in nematode infested soil was neither additive nor synergistic.

Table 1. Effects of NPK fertilizer and arbuscular mycorrhizal fungi (AMF) on tuber weight and AMF colonization of yam roots grown in nematode infested soil

Treatments	Tuber weight (kg/pot)	AMF colonization (%)
Control		Nil
NPK alone	0.85	Nil
AMF alone	0.70	72.5
Nematode (NEM) alone	0.73	Nil
NPK+AMF	1.03	48.5
AMF+NEM	0.40	65.0
NPK+NEM	1.02	Nil
NPK+AMF+NEM	0.83	49.3
$LSD_{(0.05)}$	0.46	4.2

AMF colonization of yam roots

Significantly highest AMF colonization of yam roots was observed in the AMF treatment followed by AMF+nematode treatment, while NPK+AMF and NPK+AMF+nematode treatments had significantly lowest AMF root colonization values (Table 1).

Nematode infestation

Root gall was significantly higher in the AMF+nematode treatment than for the sole nematode treatment (Table 2). Other treatments were not significantly different from each other. All the treatments had no significant effects on yam tuber gall formation (Table 2).

Table 2. Effects of NPK fertilizer and arbuscular mycorrhizal fungi (AMF) on gall index on roots and tuber and nematode population in soil, root and tuber of yam grown in nematode infested soil

Treatments	Root gall index	Tuber gall index	Nematode population (number L^{-1})		
			Root	Tuber	Soil
Nematode alone	1.3	3.7	1677	831	1585
AMF+Nematode	2.8	2.3	1185	727	1421
NPK+Nematode	1.8	3.0	962	548	933
NPK+AMF+Nematode	2.0	3.0	930	664	1139
LSD(0.05)	1.25	ns	380	200	412

Nematode population recorded on yam tuber grown in sole nematode infested soil was significantly more than that recorded for NPK+nematode treatment. That is, application of NPK fertilizer reduced nematode population on yam tuber by 34% (Table 2). Other treatments were not significantly different from each other.

Yam roots harvested from sole nematode infested soil had significantly highest nematode population than the other treatments which were not significantly different from each other (Table 2). Post harvest soil nematode count was the highest in sole nematode infested soil. Inoculation of AMF in nematode infested soil only significantly reduced post harvest nematode population in yam roots, whereas application of NPK fertilizer significantly reduced post harvest nematode populations in the roots, tubers and soil. Combined application of NPK fertilizer and AMF only significantly reduced nematode population in the roots (Table 2).

Discussion

Generally, plants with mycorrhizae and nematode parasites yield less than mycorrhizal plants without nematodes and more than non-mycorrhizal plants with nematodes. This was also true in the present study except that the non-mycorrhizal plants with nematodes out yielded plants with mycorrhizae and nematode parasites. The observation in the present study that AMF did not improve yam tuber weight compared with the control is in contrast with previous reports (Odoh and Oluwasemire, 2015; Tchabi et al., 2016). The observation is however similar to the report of Sidibe et al. (2015) for yam. Banuelos et al. (2014) observed that in fertilized plants single inoculation with AMF and nematodes caused plant growth depressions, which were counteracted when AMF and nematode inoculation were combined in *Impatiens balsamina* plants. This is contrary to what was observed in this study where yam tuber yield of fertilized pots with either AMF or nematode inoculation had the highest weight.

Although AMF generally suppressed nematode population on yam roots, tuber and soil similar to the report of Tchabi et al. (2016), but the effect was not as pronounced as that of the application of NPK mineral fertilizer.

In the present study also, arbuscular mycorrhizal colonization of yam roots was reduced with NPK fertilizer application. This is similar to the observation of Kolawole et al. (2015). High P-supply reduced AMF colonization of maize root (Liu et al., 2016). Isolates of AMF differ in their sensitivity to soil and plant P levels and therefore fertilizer application may alter the activity of the symbiosis (Sylvia and Schenck, 1983). There are contradictory reports on the role of fertilizers in influencing AMF in soil. Many reports indicated a negative influence (Vivekanandan and Fixen, 1991) while a few reported a positive influence of fertilizers on AMF (Kolawole, 2013). Previous studies have however found increased levels of AM fungal inoculum and root colonization rates in low-input as compared with intensive farming systems in the field (Douds et al., 1995).

Conclusion

The effect of combined application of NPK fertilizer and AMF on yam tuber weight in nematode infested soil was neither additive nor synergistic. AMF was less effective in suppressing nematodes compared with NPK fertilizer. NPK fertilizer reduced the negative effect of nematodes on yam tuber weight; significantly reduced nematode populations in the roots, soil, and on the tuber. Nematodes did not reduce yam tuber weight but reduced tuber quality.

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Response of three soils in the derived savanna zone of southwestern Nigeria to combined application of organic and inorganic fertilizer as affecting phosphorus fractions

Abigail O. Ojo [a,*], Michael T. Adetunji [b], Christopher O. Adejuyigbe [b], Ibukun O. Fademi [a]

[a] Institute of Agricultural Research and Training, Moor Plantation, Ibadan, Nigeria

[b] Department of Soil Science and Land Management, Federal University of Agriculture, Abeokuta, Nigeria

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Abstract

Phosphorus inputs to the soil are primarily from the application of fertilizer P and organic resources. A ten week incubation study was carried out to determine the effects of organic and inorganic P sources on phosphorus fractions in three derived savanna soils. Poultry manure was applied at 0, 0.75g, 1.5g, 2.25g and 3g per 300g weight of soil while single superphosphate was applied at 0.0023g, 0.0046g, 0.0069g and 0.0092g per 300g of soil. Sampling was done at two weeks interval. At 0 week of the incubation study, Ekiti series had the largest amount of P fractions i.e. Fe-P, Al-P, residual P, reductant soluble P, occluded P, organic P and occluded P while Ca-P was high in Apomu series. However, increases in Fe-P, Al-P, Ca-P and organic P were observed in the three soil series evaluated and poultry manure was notably effective in reducing P occlusion. In conclusion, it was observed that irrespective of the soil series at different stages of the incubation studies, poultry manure and the combined application of poultry manure and Single superphosphate was highly effective in increasing P fractions.

Keywords: Poultry manure, single superphosphate, phosphorus fractions, derived savanna soils.

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Introduction

Nigeria is located in the tropical zone (between latitude 9.0820°N, and longitude 8.6753°E), with a vast area having savanna vegetation. The soils found in this agroecological zone have coarse-textured surface soil and low in organic matter and the soil chemical properties. The lack of P availability in many agricultural soils has been described as the 'the bottle-neck of world hunger'. Even if P is supplied it may be rapidly and irreversibly fixed in usually strongly P-fixing soils (Brookes, 2001). In Nigeria, most of the soils especially in the southwestern part of the country are limiting in phosphorus (Nziguheba and Bunemann, 2005). Low availability of P is one of the main constraints to agricultural production under wet tropical conditions (Hinsinger, 2001). Manure and inorganic P fertilizers can supply phosphorus to the soil but most farmers in Nigeria are poor and cannot afford the high cost of the inorganic fertilizers. As a result a lot of research work (Omotayo and Chukwuka, 2009, Ayeni, 2010; Usman et al., 2015) has been carried out in Nigeria to find alternative source of P. Such as the use of different animal manures. . Many researchers have found that soil phosphorus availability would increase after long term fertilizer P application (Halvorson and Black;1985, Samadi and Gilkes, 1998; Fan et al., 2003; Lai et al., 2003; Zhang et al., 2004). However, such an effect of fertilizer P application varies with the climatic condition, soil type and soil test method employed as well as the rate of fertilizer P applied (Zhang et al., 2004). Manure on the other hand, contains significant proportion

* Corresponding author.
Institute of Agricultural Research and Training, Moor Plantation, Ibadan, Nigeria
Tel.: +2348033563972
E-mail address: remia_ode@yahoo.com
e-ISSN: 2147-4249
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of organic P fractions and inorganic P forms. Different P fractions differ in mobility, bioavailabilty and chemical behavior (Jalali and Ranjbar, 2010) and the different P fractions could indicate distinct bioavailability to crops. Manure has been shown through incubation studies to have increased soil organic P fraction content (Reddy et al., 2000) and P from manure sources gradually turn into available forms over time (Halajnia et al., 2009). The inorganic P has been observed to be the largest fraction of manure, >75% of total P (Eghball, 2003). However, approximately two-third of inorganic P and one-third of organic P are not available in soil (Yu et al., 2006) while 70-90% of P that enters the soil is fixed, making it difficult for plants to absorb and use (Lei et al., 2004). If soluble fertilizer phosphorus is placed in the soil, it reverts into slowly soluble or insoluble forms, removing soluble phosphorus from the soil solution. This phenomenon is often called "fixation" and these phenomenon is common in most Nigeria soils where continuous fertilization is practiced. Application of organic and inorganic fertilizer affects the distribution of P fractions in soils, which determines the availability of P with reduction in P fixation and this will invariably affect the yield of crops and the order of abundance differs from soil to soil as a result of amendments (Verma et al., 2005; Kolawole and Tian, 2007). Therefore, this study intends to assess the effect of adding poultry manure and single superphosphate to soils in the derived savanna region as affecting soil phosphorus fractions over a period of time.

Material and Methods

Background Information

The study area was located in Oniyo village situated between Ogbomoso and Kishi in the derived savanna region of Oyo, State, of southwestern part of Nigeria. The soils which have already been characterized to the series level were sampled on different farmers field in the region. Arable crops were planted solely and mixed cropped especially the maize/cassava intercrop. Most of the farmers in the locations by interviewing them was discovered to be subsistence farmers and therefore could not really afford buying inorganic fertilizers for use on their farm. However, some areas have received inorganic fertilizer over time while other areas received none.

Soil Characterization

Free survey method was employed to map the soils. Auger soil examinations were carried out on ten (10) farmers' field along different toposequences for soil type identification and boundary placement. Modal soil profile pits were dug based on the most representative auger examination. The soil profiles were described according to the FAO (2014). On the whole six modal soil profile pits (representing three soil types) were dug, described and sampled. The soils were classified into series level using the approaches of Moss (1957) and Murdoch et al. (1976).

Temidire series was described as been grey brown sandy soil, 50-100cm deep over hard iron pan. While Ekiti series was described as blackish sandy soil, stony, 50 cm deep over hard granite rock and Apomu series was described as very sandy in texture to a depth of 20 inches, free of stones and concretions to a similar depth with a pale greyish brown to reddish brown colour.

Table 1. Description of the soils used

Vegetation	Site Location		Soil series	Soil class (USDA)
Derived Savanna	Lat 8^{0}17.66′N	Log 4^{0}10.86′E	Temidire	Ferrudulf
Derived Savanna	Lat 8^{0}17.80′N	Log 4^{0}10.90′E	Ekiti	Ferrudulf
Derived Savanna	Lat 8^{0}17.93′N	Log 4^{0}10.94′E	Apomu	Hapludualf

Soil Chemical Analysis

Soil samples were collected at 0-20cm depth at five (5) different points around each profile pit and bulked into one sample. The soils were air dried and sub-samples were taken from each sampling bag for the various chemical analysis carried out. The pH of the soil was determined in distilled water (1:1 soil water ratio) with a pH meter. Exchangeable cations (K, Na, Ca, and Mg) by extraction, with ammonium acetate (pH= 7). Effective cation exchange capacity by summation of the exchangeable cations and exchangeable acidity. Available P was extracted with 0.03N NH_4F in 0.025N HCl solution (Bray and Kurtz, 1945) and P in the extract was analysed colorometrically by the molybdenum blue method at 660 nm. Soil organic carbon was determined by wet oxidation with sulphuric acid (Walkey and Black, 1934).

Incubation Studies

A ten week incubation study was conducted to determine the effect of fertilizer application i.e. both organic and inorganic fertilizer on phosphorus (P) forms in three different derived savanna soils. Single superphosphate (SSP) and poultry manure (PM) was applied, while P forms was monitored at two week interval. Poultry manure was applied at 0, 0.75g, 1.5g, 2.25g and 3g per 300g weight of soil while single superphosphate was applied at 0.0023g, 0.0046g, 0.0069g and 0.0092g per 300g of soil. Deionized water was added to the soil and the soil was kept moist throughout the period of the incubation studies. At two (2) weeks interval, soil samples were taken from each cup.

Fractionation of Inorganic Phosphorus

The procedure of sequential phosphorus fractionation is given Table 2. A summary of the procedure is as follows:

Table 2. Sequential P fractionation procedures and targeted P forms

Location	Extractants	Equilibration	Washing	Targeted
NH_4Cl-P	IM NH_4Cl	30mins	None	Saloid-bound P
NH_4F-P	0.5M NH_4F	1 hour	None	Al-P
NaOH – P	0.1M NaOH Saturated NaCl + 5 drops of conc. H_2SO_4	15 mins	Saturated NaCl	Fe-P
Sodium + citrate Sodium dithionite P	0.3M sodium citrate + 1g solid Sodium dithionate + sat Nacl	Shake 15mins, preheat 15mins at 85^{0}C after sodium citrate, additional 15 mins after dithionte addition	Saturated NaCl	Reductant – Soluble P
NaOH-P	O.1M NaOH + few drops of conc. H_2SO_4 to remove colour	15 mins	Saturated NaCl	Occluded – P
H_2SO_4-P Residual P	0.25M H_2SO_4 + 25ml Sat. Nacl Conc. HNO_3 + HCl + 30% H_2O_2	1 hour Variable until complete	Saturated NaCl None	Ca-P Organically stable organic and inorganic P

Statistical Analysis

The experimental design was a 5 x 5 factorial experiment replicated three times. Data collected were subjected to analysis of variance (ANOVA) using GenStat Discovery Edition 4,10.3D Estatistical software, and where the F-value was significant, treatment means were separated at $P \leq 0.05$ level of significance using Fisher least significant differences (LSD) (GenStat, 2011).

Results

The pH of the soils varied between 6-6.5, organic matter between 5.16-10.32 g kg^{-1}, total N between 0.08-0.23g kg^{-1}, available phosphorus between 6.74- 14.5 mg kg^{-1}, exchangeable Ca between 0.62-2.06 cmol kg^{-1}, exchangeable Mg between 0.69-0.79 cmol kg^{-1}, exchangeable K between 0.08-0.31cmol kg^{-1} while exchangeable Na ranged between 0.06-0.1cmol kg^{-1}. Initial phosphorus fractions of the different soils are given in Table 3. Like soil properties, initial P fractions showed different values relative to different soil series.

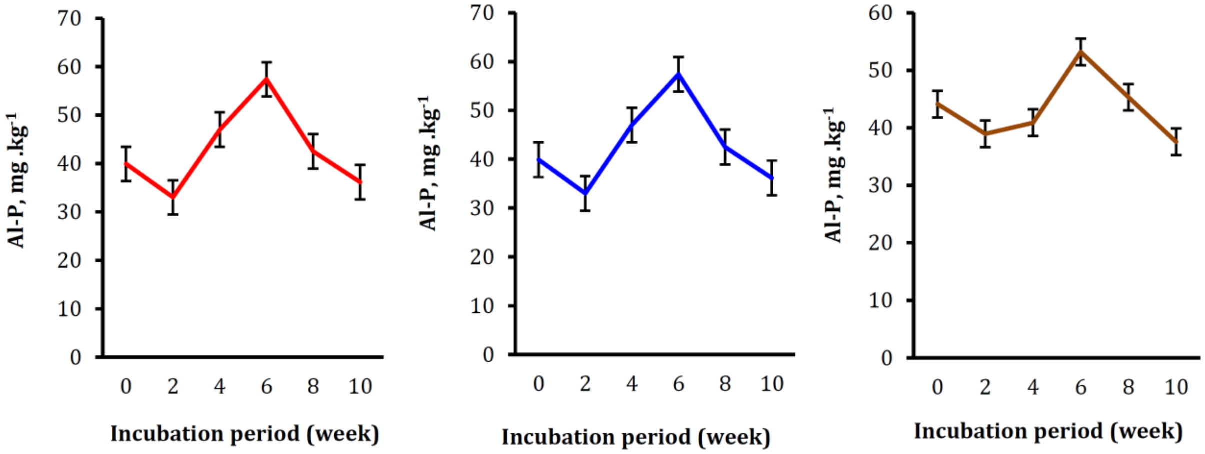
Table 3. Initial soil phosphorus fractions of the different soil series (mg kg^{-1})

	Organic P	Fe-P	Al-P	Ca-P	Occluded P	Reductant Soluble P	Residual P
Temidire Series	52.09	38.96	27.83	22.10	87.83	30.32	33.39
Ekiti Series	68.72	46.87	34.52	24.10	108.39	50.20	55.05
Apomu Series	44.52	7.79	34.52	27.90	94.52	25.70	12.56

Effect of addition of organic manure to P fertilizer followed a similar trend in the three soil series identified. Al-P was initially high at 0 week then decreased at the 2nd week. A gradual increase was observed from the 2nd to the 6th week after which a decrease was observed till the 10th week of incubation (Figure 1).

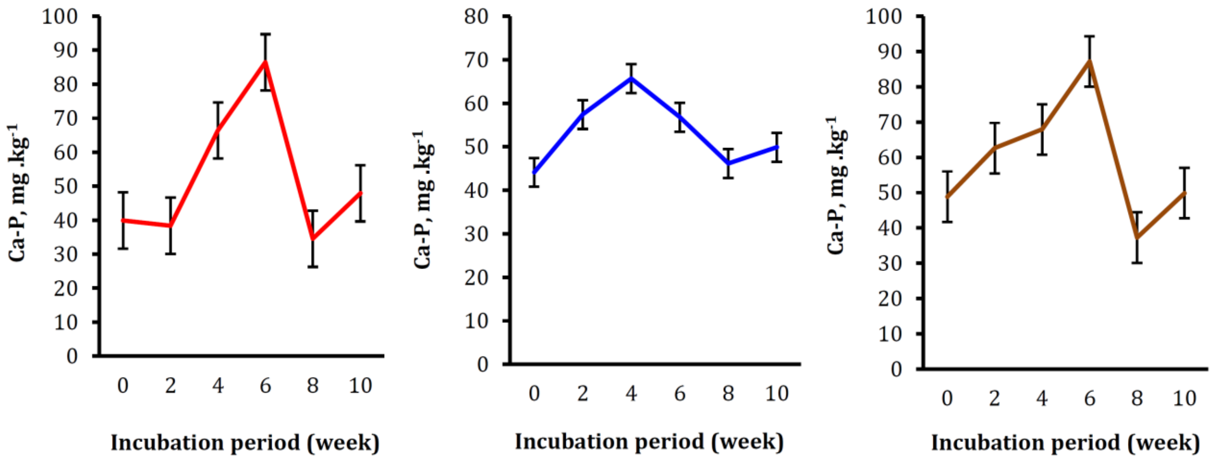
Effect of addition of organic manure to P fertilizer followed a similar trend in Apomu and Ekiti series. Ca-P was low at the beginning of the incubation studies and then increased from the 2nd to the 6th week and later decreased. However, in Temidire series, a steady increase was observed from the 1st week of the incubation studies to the 4th week and later then decreased to the 8th week (Figure 2).

Effect of addition of poultry manure to single superphosphate on Fe-P followed a similar trend in Apomu and Temidire series. The inorganic P fraction was however higher in Temidire series than in Apomu series at the beginning of the incubation studies. Intermittent decrease and increase was observed to the 8th week of incubation and then decreased towards the 10th week of the incubation studies. Fe-P was also higher at the beginning of the incubation studies in Ekiti and Temidire series. A decrease was observed down to the second week after which a steady increase was then observed to the 8th week but later decreased while tending towards the 10th week (Figure 3).



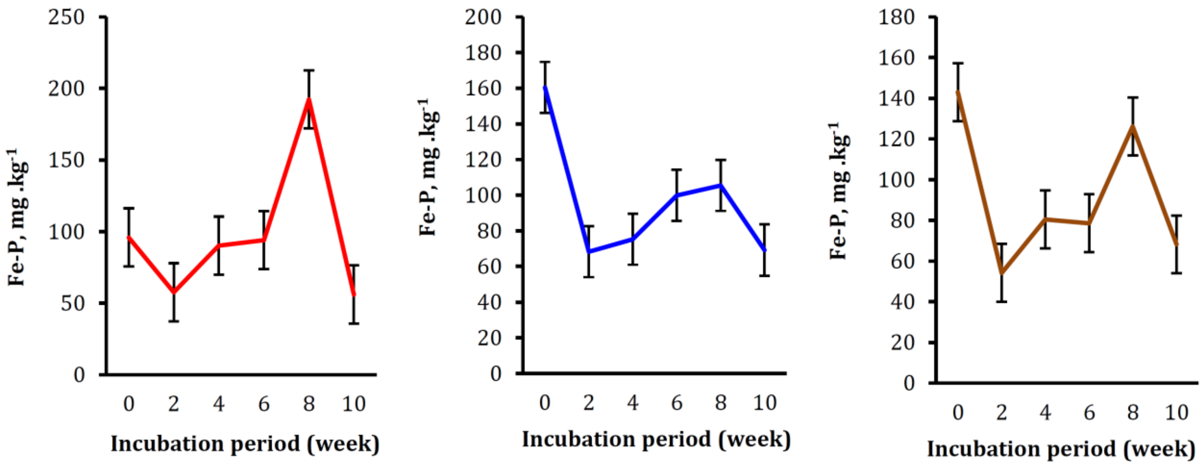
(a) (b) (c)

Figure 1. Al-P as influenced by Single superphosphate (SSP) and poultry manure (PM) on soil series (a) Apomu (b) Ekiti (c) Temidire.



(a) (b) (c)

Figure 2. Ca-P as influenced by Single superphosphate (SSP) and poultry manure (PM) on soil series (a) Apomu (b) Ekiti (c) Temidire.



(a) (b) (c)

Figure 3. Fe-P as influenced by Single superphosphate (SSP) and poultry manure (PM) on soil series (a) Apomu (b) Ekiti (c) Temidire.

A similar trend was observed in the three soil series identified as affected by poultry manure and SSP. A decrease was observed at the 2nd week of incubation and then later increased to the 4th week. A subsequent decrease in occluded P was observed from the 4th week in Temidire and Ekiti series while this observation was noticed at the 6th week in Apomu series (Figure 4).

A steady increase in organic P as affected by the treatments applied was observed in Apomu series from the beginning of the incubation studies to the 6th week of the incubation studies while a decrease was then observed at the 8th week. An increase in organic P was observed to the 4th week in Ekiti and Temidire series and later decreased from the 4th to the 10th week of incubation in Temidire series. However, in Ekiti series, a decrease in organic P was observed from the 6th week to the 10th week (Figure 5).

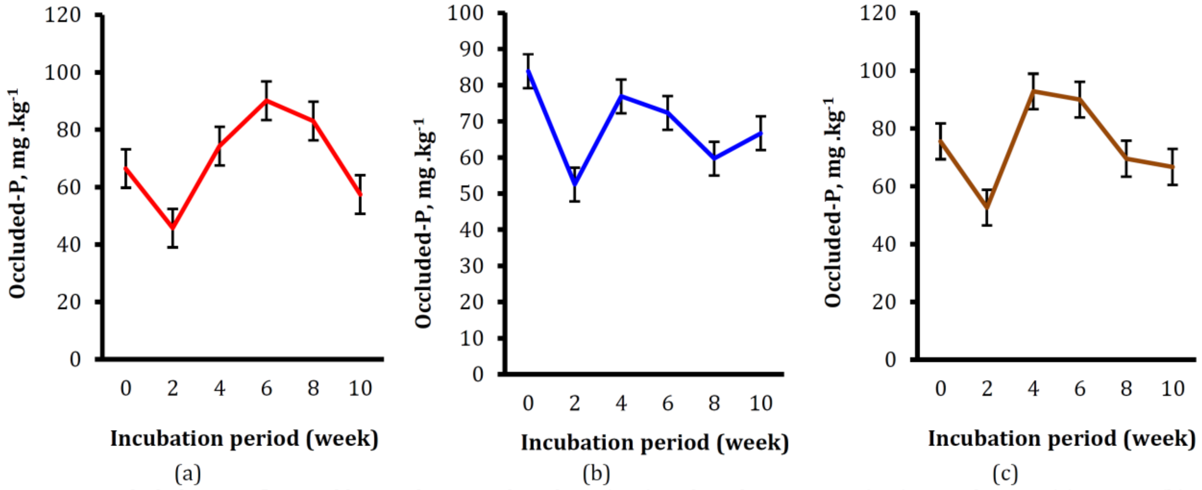


Figure 4. Occluded-P as influenced by Single superphosphate (SSP) and poultry manure (PM) on soil series (a) Apomu (b) Ekiti (c) Temidire.

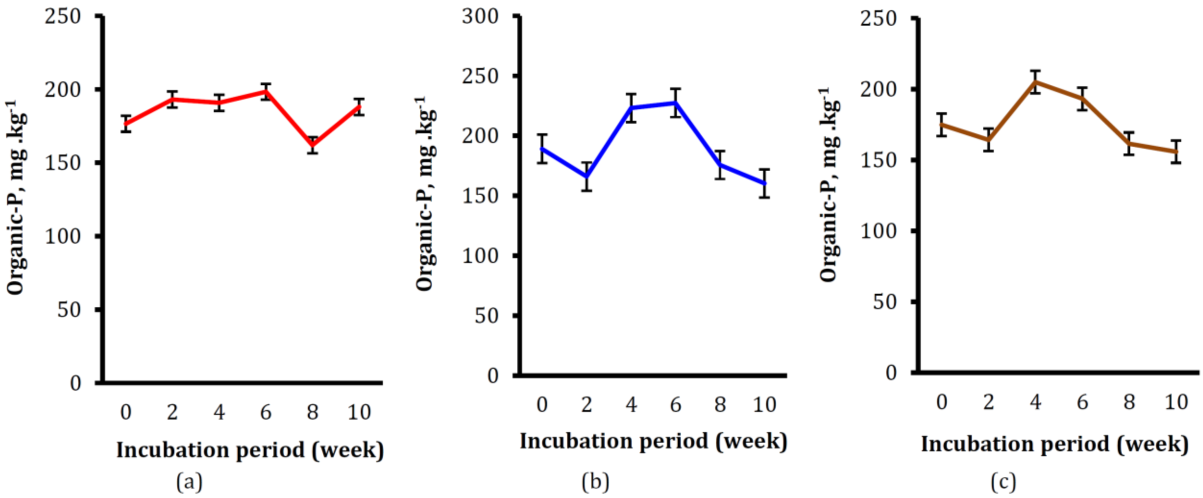
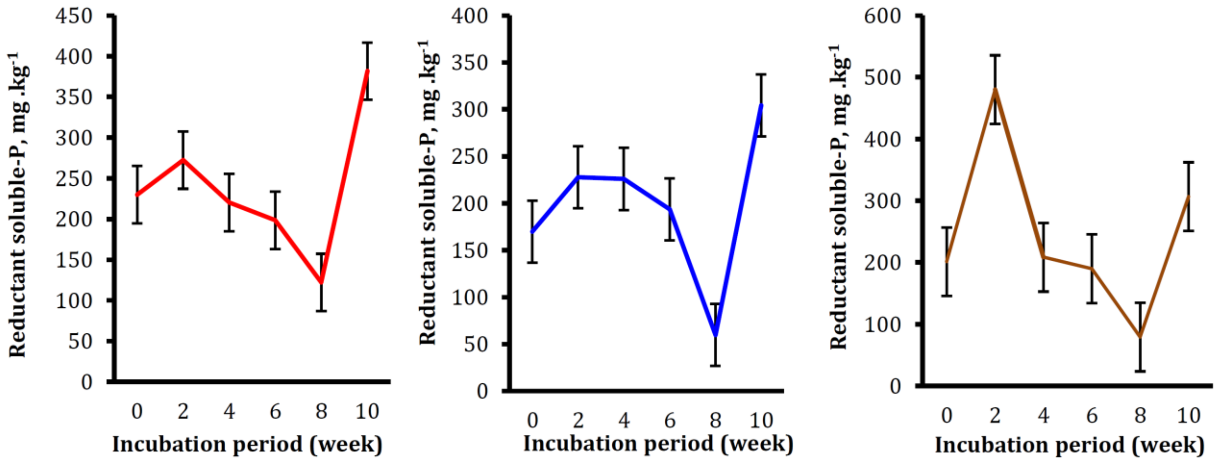


Figure 5. Organic-P as influenced by Single superphosphate (SSP) and poultry manure (PM) on soil series (a) Apomu (b) Ekiti (c) Temidire.

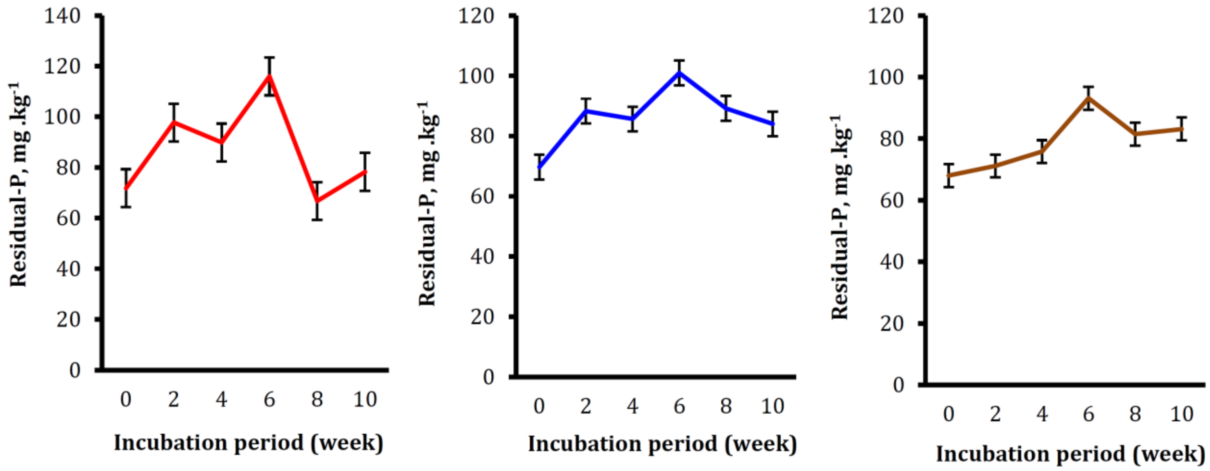
The reductant soluble P fraction was observed to increase from the beginning of the incubation studies to the 2nd week in Apomu and Ekiti series, then a decrease was observed to the 8th week and then an increase from the 8th to the 10th week of the incubation studies. However, in Temidire series, the increase observed at the 2nd week of incubation was higher than what was observed in the two other series. A decrease in organic P was later observed to the 8th week and an increase was then observed from the 8th to the 10th week (Figure 6).

Intermittent increase and decrease in residual P was observed in Apomu series to the 10th week of the incubation studies. A steady increase was however observed in Temidire series to the 6th week and then a decrease to the 10th week. In Ekiti series, an intermittent increase and decrease in residual was observed to the 6th week of incubation and later decreased to the 10th week (Figure 7).



(a) (b) (c)

Figure 6. Reductant soluble-P as influenced by Single superphosphate (SSP) and poultry manure (PM) on soil series (a) Apomu (b) Ekiti (c) Temidire.



(a) (b) (c)

Figure 7. Residual-P as influenced by Single superphosphate (SSP) and poultry manure (PM) on soil series (a) Apomu (b) Ekiti (c) Temidire.

Discussion

Soil phosphorus (P) management requires a more targeted and soil specific approach (Daly et al., 2015). Limited availability of P in many tropical soils can be attributed to dominance of Al-P and Fe-P in the soils evaluated (Kiflu et al., 2017). Presence of Al-P in the soil at 0 week could be attributed to significant amount of Al oxides in soils found in the south western part of Nigeria (Gideon et al., 2016). Increase in Al-P at week two (2) would invariably lead to release of P into the soil solution while the build-up later observed could be attributed to the effect of P fertilizer in the soils (Ibrikci et al., 2005). However, Ca- P was low at the 0 week of the incubation studies due to the acidic nature of the soils evaluated while the increase observed later would probably be due to the liming ability of the poultry manure added to the single superphosphate (Ojo et al., 2015). Effect of added poultry manure was later observed at the 10th week of the incubation studies and this was probably due to the residual effect of the poultry manure added (Amanullah et al., 2010) .This observation was however not seen in Temidire series where an increase in Ca-P was observed from the beginning of the incubation studies to the 4th week and this could have been to the effect of past application of fertilizer that could have increased Ca-P (Song et al., 2017) in Temidire series. High Fe-P at the beginning of the incubation studies could probably be due to the presence of Fe oxides in the soils evaluated (Gikonyo et al., 2011). The intermittent increase and decrease observed in Temidire and Apomu series would have been due to individual effect of poultry manure and SSP at different stages of the incubation studies. However, a decrease in Fe-P was observed at the beginning of the incubation studies in Apomu series and this could probably be due to the characteristic of Apomu series with high sand fraction (Adesanwo et al., 2013) and therefore prone to leaching compared to Temidire and Ekiti series. Effect of poultry manure in reducing P occlusion in soils was observed in the three soil series evaluated (Ojo et al., 2016). However, the increase later observed could be due to the effect of SSP added to the soils. Effectiveness of added poultry manure to P fertilizer was later observed with a decrease in occluded P (Ojo et al., 2016) from the 4th week of the incubation studies. Addition of poultry manure to SSP was more effective in Apomu series and this was evident in the build-up of organic P (Waldrip et al., 2011) from the beginning of the incubation studies to the 6th week. An increase in organic P was observed in Ekiti and Temidire series till the 4th week of incubation while later added poultry manure became less effective with an evident decrease in organic P. A build-up of the reductant soluble P observed in Apomu and Ekiti series would probably be due to the effect of the inorganic fertilizer added (Soremi et al., 2017) while the decrease later observed signified the effectiveness of poultry manure in reducing P fixation in soils. The intermittent increase and decrease in residual P also signifies the individual effect of poultry manure and SSP at different stages of the incubation studies. However, effect of the P fertilizer i.e. SSP added was more evident in Temidire series where a steady build-up of residual P was observed (Sattari et al., 2012).

Conclusion

Effect of combined application of poultry manure and single superphosphate was evident in the increases in the labile P fractions i.e. the NaOH-P fractions notably Al and Fe-P determined. Poultry manure ability to lime and increase Ca was evident in the increases observed in Ca-P and this particular treatment was effective in the reduction of P occlusion and in the build-up of organic P in most of the soils evaluated. Conclusively, irrespective of the soils series, the effectiveness of poultry manure and SSP, solely and in combination was evident in all the P fractions determined.

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