VERTICAL DISTRIBUTION OF FERTILITY INDICES AND TEXTURAL PROPERTIES OF A SANDY CLAY LOAM UNDER SHORT AND LONG-TERM FALLOW

Mabel Chinenye Onah[1], Sunday Ewele Obalum[1] and Ifeyinwa Monica Uzoh[1, *]
[1]Department of Soil Science, University of Nigeria, Nsukka
[*] Corresponding author: ifeyinwa.uzoh@unn.edu.ng, ifeyinwa.okpara@unn.edu.ng

ABSTRACT
Deviant from shifting cultivation prevalent in tropical ecosystem has constituted a challenge in sustainability of the farming system. Shortening of the fallow period could be an alternative. This research evaluated the vertical distribution of fertility indices and textural separates of an Ultisolin Nsukka under short and long-term fallow. The result showed that short-term fallow had better fertility indices (pH, available phosphorus (AvP), total nitrogen (TN) and organic matter (OM)) than the long-term fallow. These indices were higher at 0 -20 cm depth than at other depths. For textural separates, clay, fine sand and total sand were higher under short-term fallow(260.5 mg kg^{-1}, 320.9 mg kg^{-1}, 710.8 mg kg^{-1}) than under long-term fallow (239.2 mg kg^{-1}, 298.1 mg kg^{-1}, 695.1 mg kg^{-1}). Correlation matrix shows that despite the fallow type, AvP and OM had significant positive relationship, while TN and OM (0.58^{*}), AvP and pH (0.71^{**}) had significant positive relationship under long-term fallow. In addition, coarse sand separate had positive relationship with most fertility indices for both fallow type. In conclusion, based on this research, short-term fallow could sustain the fertility parameters of an Ultisol, though there is need to proffer a management system to reduce eroding of the fine textured materials.

KEYWORDS: Soil profile, soil depth, horizon, soil nutrients, pH

INTRODUCTION
Soil Profile properties determine soil resilience, potentials and management strategies for sustainable productivity (Singh et al., 2016). Soil, as an interface between the atmosphere, biosphere and lithosphere, undergoes vertical exchange of materials.With resultant steep chemical and physical gradients, soil nutrient stratification occurs within the soil depth. Soil stratification results from the above exchange, which forms the basis for soil study and classification (Buol et al. 1989;Jobbagy and Jackson, 2001). This vertical distribution of soil nutrients gives insights into nutrient dynamics and cycling processes (Jobbagy and Jackson, 2001), as well as the vegetation type. Biogeochemical processes at the horizonsof soil profile are essential for the global soil development. They are the principal drivers of ecological functions such as plant productivity and water quality (Totsche et al., 2010). Spatial distribution physiognomies of soil nutrients in relation toland use,offer basis for restoration of ecosystem (Xiao-Yin et al., 2015). Therefore, the dynamic equilibrium among the physical, chemical and biological properties determines the productivity and sustainability of soils (Azuka and Obi, 2012).

Several factors especially soil and crop management, influences the variability of these soil properties, which in turn determines soils resilience and sustainability.Land degradation caused by unsuitable land management poses a great threat toagricultural productivity in all agro-climatic regions. According to Ezeaku et al. (2015), land use system influences soil quality and determines their sustainability. This exerts influence on variability in soil properties, since it affects soil processes such as erosion, oxidation, mineralization andleaching of nutrients. In addition, Qiu et al. (2000) stated that land use history and topography are the dominant controlling factors affecting the distribution of soil properties at smaller scale such as catchment level. This variation in soil properties may differ among the different soil horizons due to the transport and storage of water and nutrient across and within the soil profile. It is an essential characteristic because it serves as basis for soil nutrient management including fertilization and other location-specific applications (Ezeaku et al., 2015). Land managementoption corrects nutrient deficiencies, land degradation and other anomalies in soils.
Fallow system is one of such management system employed in rejuvenating the soil after some years of continuous cultivation. In southeastern Nigeria, shifting cultivation was widely practiced by smallholder farmers. Increased population pressure and the need to cultivate greater land area have resulted in reduced fallow periods (Grogan et al, 2013). Fallows are of ecological, economic and social importance to rural people and to the nation at large. A majority of farmers depended on fallowing, using little or no fertilizers to improve impoverished soils. In present scenario, fallow is no longer the order of the day. This implies that farm production (and income) will consistently decline over the years. Studieswith respect to vertical distribution of soil nutrient as a result of fallow durationare limited (Cardinale et al., 2011). Therefore, studies to ascertain the vertical distribution of physicochemical properties is indispensable for sustaining agricultural productivity. Such studies are very useful in understanding the inherent capacity of the soil to supply required nutrient to the plant. Based on the above, the objective of this work was to compare the effect of short-term and long-term fallow management practices on vertical distribution of

some selected fertility indices and soil textural properties and to examine the relationship between themwith the aim to improve soil productivity and sustainability.

MATERIALS AND METHODS

SITE DESCRIPTION

The study took place at the University of Nigeria, Nsukka research and teaching farm. It lies within the co-ordinates of 6^o 44 and 6^o55 N and 7^o11 and 7 25 ^{o} E in the derived savannah zone of southeastern Nigeria. Its elevation is 447 m above sea level. The climatic condition of the area is generally tropical, characterized with sub-humid weather. The rainy season extends from March to November with mean annual rainfall of about 1600mm, which shows marked monthly pattern with the highest peak in July and October. Average minimum and maximum temperatures are 22^o and 30^o, respectively, withrelative humidity of 60%.

The research took place in two locations within University of Nigeria, Nsukka research farm based on length of fallow. The two locations originatefrom the same parent material. One comprised of conventionally tilled arable crop land with shrubs and grasses cover under three years' fallow located around the metrological station of the University of Nigeria, Nsukka and another one sited on a plot under fifteen years fallow system with vegetation cover (mango tree) and grasses located at the piggery unit of animal science farm of the university.

SOIL SAMPLING

Profile pits of about 2m x1.5m, to a depth of >1m were dug on each of the locations. The sampling was done, as disturbed soilin triplicate was collected, each from pre- determined depths of 0-20, 20-40, 40-70, 70-100, and >100cm.Fifteen (15) soil samples per location and thirty (30) soil samples for the two locations were air-dried and sieved with 2-mm sieve for analysis.

LABORATORY ANALYSIS

The particle size distribution was determined using the Bouyoucos hydrometer method as described by Gee and Or (1982). The pH of the soil was measured in water and potassium chloride (1N KCl) solution in a 1:2.5 (soil: liquid ratio) using a Beckman's zeromatic glass electrode pH meter according toMcLean (1982). Soil available phosphorus (P) was extracted with Bray (II) solution and measured using a colorimeter following the principles of light. Soil organic carbon was obtained by the wet dichromate acid oxidation method (Nelson and Sommers, 1982). Total Nitrogen (N) was determined using Kheldahl digestion distillation and titration method as described by Bremner and Mulvaney, (1982) by oxidizing the organic matter in 0.1N concentrated sulphuric acid (H_2SO_4).

STATISTICAL ANALYSIS

Data generated from the laboratory analysis were subjected to two-way analysis of variance (ANOVA) using linear model of Genstat discovery edition. In this analysis, fallow type and soil depths were considered as factors and this enabled the study of the interaction. The least significant difference was used to separate means at 5% probability level. Correlation analysis was used to determine the relationship between the chemical and physical soil parameters.

RESULTS AND DISCUSSION

Main effect of fallow and soil depth on selected soil fertility indices

Table 1 shows the effect of fallow and soil depth on some fertility indices. Fallow significantly affected pH and TN, while all the measured fertility indices significantly differed in soil depth. For the fallow system, long-term fallow had lower OM, TN and AvP(7.68g kg^{-1}, 0.36%, 2.94 mg kg^{-1}) but higher pH than the short-term fallow (7.68 g kg^{-1}, 0.381%, 4.43 mg kg^{-1}). Accumulation of crop residues, organic and inorganic fertilization during cultivation probably have increased fertility parameters in the short-term fallow. In addition, increase in organic carbon cum organic matter content increases available phosphorus during decomposition by the enzyme phosphatase and total nitrogen when mineralized. This finding is in contrast to some other studies, which reported that long fallowed plots had higher nutrient concentration due to minimal mechanical disturbances

Table 1: Effect of fallow and soil depth on soil fertility indices

Fallow type	Soil Chemical properties			
	pH in H_2O	OM (g/kg)	TN (%)	AV.P (mg/kg)
SFL	4.9	7.68	0.381	4.43
LFL	5.1	7.56	0.336	2.94
LSD	0.1	NS	0.068	N S
Soil depth				
0-20	5.1	14.10	0.443	12.43
20-40	4.8	10.55	0.373	3.13
40-70	4.9	6.26	0.373	2.50
70-100	4.9	4.04	0.280	2.20
>100	4.9	3.15	0.323	1.90
LSD	0.2	1.576	0.108	1.510

and nutrient mining by annual crops (Mishra et al 2015; Ezeaku et al., 2015 and Franzluebbers (2002) but is in agreement with the studies by Nwite (2015) on distribution of soil nutrient on forest and cultivated land.Soil depth had decreasing soil fertility indices down the profile, with 0 -20cm depth having highest values than other depths. This higher values of the analyzed chemical properties obtained at the surface layers (0-20) is because all the inputs both organic and inorganic fertilizers and plant residues are applied on the soil surface. This decrease in soil nutrient with increasing depth compliments the research work by Alvarieiz et al., (2002) and Nwite (2015). The decrease of pH with depths shows that pH is directly proportional to nutrient depletion, since nutrients in this experiment also decreased with depth. In addition, this is conventionally true because nutrient uptake or depletion is one of the sources of positive ions in the soil, which inadvertently decreases pH (Nwite, 2015). This also conforms to the work by Asadu and Nweke, 1999; and Nwite (2015)

Main effect of treatments on soil textural separates

Soil textural separates as influenced by fallow and soil depth are shown on Table 2.Clay, silt and fine sand were significantly affected by fallow, with short term fallow having higher silt content and lower clay and fine sand. The lower clay content in short-term fallow could have resulted from leaching and erosive forces, which possibly occurred during the non-fallow period, at time of cultivation. The long fallow system has been there for over 15 years. Depth significantly affected all the soil textural separates, while clay increased down the profile, coarse and total sand decreased down the profile. Silt increased from 0 -20 cm to 20 – 40 cm, then decreased down the depth.Sand dominates over all other particle sizes analyzed along the various depths which shows the effect of parent material (false bedded sand stone) as stated earlier and decreased with increasing depth while clay, silt and fine sand on the other hand, increased significantly as depth increased.According to Akamigbo and Igwe (1990) and Idoga and Azagaku (2005), the result depicts the washing down offine earth materials from the upper coal measure formation and their translocation vertically and laterally including those weathered in-situ. Coarse sand was highest at 0-20cm and decreased with depth.

Table 2: Effect of treatments on soil textural separates

Fallow type	Clay	Silt	F.Sand	C Sand	T Sand
			g kg^{-1}		
SFL	239.2	52.3	298.1	397.0	695.1
LFL	260.5	40.3	320.9	389.9	710.8
LSD	12.67	10.69	17.14	Ns	Ns
Soil depth					
0-20	135.9	42.3	275.5	543.1	818.6
20-40	202.5	65.6	322.7	409.2	731.9
40-70	275.9	45.6	301.2	377.3	678.4
70-100	319.2	38.9	327.4	312.7	640.1
>100	315.9	38.9	320.7	325.0	645.7
LSD	20.03	16.90	27.11	36.70	22.56

Interaction effect of fallow and soil depth on fertility indices and textural separates of the soil

Interaction of fallow type and soil depth (Table 3) significantly affected only AvP among the chemical properties. Top soil 0 -20 cm depth had highest AvP, both at short and long-term fallow. It decreased down the soil depth, irrespective of the fallow type. Also in Table 4, interaction of fallow and soil depth significantly affected all soil textural separates except silt content. Irrespective of the fallow type, clay contentincreased down the soil depth, which was reverse for coarse and total sand. Clay content was generally higher in all the soil depth of long fallow land than short fallow except at 0 – 20 cm depth, in which clay content was higher in short fallow(145.9 g kg^{-1}) than long fallow (125.9 g kg^{-1}). This means that in short fallow, which consisted of three-year fallow sandwiched with cultivation, the fine clay particles were lost to erosion. Long fallow, which had consistent cover for, at least fifteen years had higher clay content. The higher content of clay on the surface of short fallow possibly because long fallow had higher aggregation than short fallow, thereby had lower clay content.

Fine sand was higher at 0 – 20 cm soil depth of long fallow (326.3) than at 0 – 20 cm depth of short fallow (224.6 g kg^{-1}). Coarse and total sand were higher at the top 0 – 20 cm depth of short fallow (610.6, 835.2) than long fallow (475.5, 801.8).

Table 4: Interaction effect of fallow duration and soil depth on fertility indices

Fallow type	Depth (cm)	pH H_2O	OM (g/kg)	TN (%)	Av.P (mg/kg)
SFS	0-20	4.9	14.00	0.467	12.43
	20-40	4.9	11.24	0.420	3.13
	40-70	4.9	6.28	0.420	2.50
	70-100	4.9	3.94	0.233	2.20
	>100	5.0	2.96	0.367	1.90
LFS	0-20	5.3	14.20	0.420	5.30
	20-40	4.9	9.86	0.327	2.20
	40-70	5.0	6.24	0.327	2.20
	70-100	4.9	4.14	0.327	2.80
	>100	5.2	3.35	0.280	2.20
LSD		NS	NS	NS	2.14

Table 4: Interaction effect of fallow duration and soil depth on

Fallow system		**Textural separates**				
	Depth (cm)	**Clay ($g\ kg^{-1}$)**	**Silt ($g\ kg^{-1}$)**	**F Sand ($g\ kg^{-1}$)**	**C Sand ($g\ kg^{-1}$)**	**T Sand ($g\ kg^{-1}$)**
SFS	0-20	145.9	52.3	224.6	610.6	801.9
	20-40	179.2	85.6	340.6	388.0	721.9
	40-70	272.5	45.6	280.9	394.3	675.2
	70-100	292.5	38.9	310.5	291.0	675.2
	>100	305.9	38.9	334.0	301.2	656.2
LFS	0-20	125.9	32.3	326.3	475.5	835.2
	20-40	225.9	45.6	304.9	430.3	728.5
	40-70	279.2	45.6	321.5	360.4	675.2
	70-100	345.9	38.9	344.2	334.3	601.9
	>100	325.9	38.9	307.4	348.8	635.2
LSD		28.32	Ns	38.34	51.90	33.86

Relationship amongst soil fertility indices for either short fallow or long fallow

From the correlation analysis done (Table 5), under short fallow, organic matter and AvP had highly significant relationship (0.78^{**}), other relationships were not significant while under long fallow (Table 6), there were significant positive relationship between OM and TN (0.58^{*}), OM and AvP (0.58^{*}) and AvP and pHin water (0.71^{**}). The relationship between OM and AvP were consistent for both fallow periods because organic matter determines the availability of phosphorus. Although soil pH might not influence the mineralization processes of SOM, the decomposition and nitrification processes of SOM are quite sensitive to soil pH (Curtin et al., 1998; Kemmitt et al., 2006). Soil pH regulates a series of soil processes, such as SOM turnover, nutrient bioavailability and microbial activity, through which soil pH greatly affects the decomposition of SOM (Bååth et al., 1995).

Table 5: Correlation matrix of soil fertility indices under short fallow

Soil Fertility indices	pH in Water	pH in KCl	OM (%)	TN (%)
pH in KCl	0.40			
OM	-0.27	0.12		
TN	-0.3 3	-0.04	0.45	
AV.P	0.01	-0.10	0.78**	0.29

Table 6: Correlation among the soil fertility indices under long fallow

	pH in water	pH in KCl	OM (%)	TN (%)
pH in KCl	0.62*			
OM	0.36	0.31		
TN	0.25	0.04	0.58*	
Av.P	0.71**	0.77**	0.58*	0.44

Relationships between fertility indices and textural indices of the soil

Table 7 shows the correlation coefficient between textural separates and soil fertility indices. Under short fallow, coarse sand and silt had significant positive relationship with OM (0.87^{**} and 0.59^{*} respectively). Coarse sand also had positive significant relationship with AvP (0.91^{**}), while clay had significant negative relationship AvP (-0.75^{**}) and positive relationship with OM (0.95^{**}). Under long-term fallow (Table 8), total sand had positive significant relationship with pH in water (0.55^{*}), OM (0.91^{**}) and AvP (0.59^{*}). Clay had positive relationship with OM (0.92**) and negative correlation with TN (-0.56*) and AvP (-0.63*). Coarse sand had positive relationship with OM (0.78^{*}), TN (0.61^{*}) and AvP (0.67^{**}).

The distributions of SOC and SON are results from many factors, including soil pH and soil texture (Zhon et al., 2020). Soil texturerefers to the soil particle size distributions (including clay, silt and sand) and is believed to be essential for understanding soil physicochemical properties in the terrestrial ecosystems (Zhao et al 2016). Generally, clay and fine silt particles because of their large surface area and activity can safeguard SOM from being lost through chemical or physical means. However, the effects of these fine particles on the accumulation and decomposition of SOM are different in different ecosystems, making it necessary to explore the specific influence of clay on SOM in different regions (Hassink, 1994). In short-term fallow, silt had positive significant relationship with organic matter while positive relationship between organic matter and clay occurred in the long-term fallow.

Table 7: Correlation between textural separates and fertility indices under short fallow

	pHW	pHKCl	OM (%)	TN (%)	Av.p (mg/kg)
C. Sand	-0.13	-0.11	0.87**	0.35	0.91**
Silt	-0.233	0.30	0.59*	0.22	0.06
Clay	0.15	-0.16	-0.95**	-0.434	-0.75**
F.sand	0.30	0.53*	-0.47	-0.33	-0.73**

Table 8: Correlation between textural separates and fertility indices underLong-term fallow

	pH in water	pH in KCl	OM (%)	TN (%)	Av.p (mg/kg)
Total Sand	0.53*	0.31	0.91**	0.46	0.59*
Silt	-0.22	-0.03	-0.20	0.14	-0.10
Clay	-0.52*	-0.30	-0.92**	-0.56*	-0.63*
F.sand	-0.15	-0.04	0.02	-0.16	-0.13
C. sand	0.41	0.33	0.78**	0.61*	0.67**

CONCLUSION

Vertical distribution of soil properties is relevant in the study of soils, its classification and suggesting proper management practices for its sustainability. In addition, shifting cultivation was an intricate part of farming culture in southeastern Nigeria and in most tropical regions. Elimination of fallow and lack of high input agriculture puts sustainability of the farming system at a crossroad. This research evaluated fertility indices and textural separates of short-term fallow of three years and long-term fallow of fifteen years and their vertical distribution. The result shows that most of the fertility indices improved under short-term fallow than under long-term fallow. This could be because of fertilization and other good management practices employed during cultivation. These fertility indices were also better at 0 -20 cm depth. The effect of fallow on textural separates shows that clay and fine sand were lower in short-term fallow, where possibly erosive forces must have washed them away. In depth distribution, only coarse and total sand were higher at 0 -20 cm depth, while clay, silt and fine sand were least at 0 – 20 cm and increased to some extent down the profile. Concerning correlation analysis, soil organic matter had significant positive relationship with available phosphorus in both short and long-term fallow. Coarse sand had significant positive relationship with organic matter, available phosphorus under short term and with organic matter, available phosphorus and pH under long fallow. This shows that coarse sand controls the fertility indices of the soils of the research area.

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