



## **DYNAMICS OF MICRONUTRIENTS IN ARABLE SOILS: IMPLICATIONS FOR SUSTAINABLE AGRICULTURE**

**Bakare, A. O. and Efenudu, I. U.**

Department of Soil Science and Land Management, Faculty of Agriculture,  
University of Benin, PMB 1154, Benin City

**Corresponding Author's Email:** isaiah.efenudu@gmail.com,  
<https://orcid.org/0000-0002-0931-5135>

### **ABSTRACT**

This study investigated the dynamics of micronutrients (Fe, Zn, Cr, Cu, and Mn) in arable soils under yam and cassava cultivation in Nigeria. Soil samples were collected from two separate farms at four depths (0-30, 30-60, 60-90, and 90-120 cm) and analyzed for physical and chemical properties, including micronutrient content. The results showed that topsoil (0-30 cm) had the highest micronutrient content, with mean values of 354.0 mg/kg (Fe), 117.0 mg/kg (Mn), 13.1 mg/kg (Zn), and 52.66 mg/kg (Cu) in yam farms, and 368.0 mg/kg (Fe), 118.4 mg/kg (Mn), 13.55 mg/kg (Zn), and 61.24 mg/kg (Cu) in cassava farms respectively. The micronutrient content decreased with increasing soil depth, with significant correlations between soil physical and chemical properties (pH, sand content, organic carbon). The study highlights the importance of integrated soil fertility management practices that account for micronutrient variability with depth and crop type. The findings have significant implications for sustainable agriculture, emphasizing the need for targeted soil management practices to mitigate micronutrient deficiencies and promote ecosystem services in arable soils. Regular soil testing and nutrient management planning are crucial to ensure crop nutrient requirements are met without depleting soil nutrient reserves.

**Keywords:** Micronutrients, Soil, Fertility, Yam, Cassava

### **INTRODUCTION**

Soil fertility management is crucial for sustainable agriculture, as it directly affects crop yields and nutrient availability (Agbenin and Olojo, 2004; Fageria *et al.*, 2002). Micronutrients, such as iron (Fe), zinc (Zn), chromium (Cr), and copper (Cu), play essential roles in plant growth and development (Lal, 2006). However, micronutrient deficiencies are widespread in tropical soils, including those in Nigeria (Ogbonna, 2013). In Nigeria, yam and cassava are two major staple crops that require adequate micronutrient nutrition for optimal growth and productivity (Oyedele *et al.*, 2017). However, the dynamics of micronutrients in arable soils under yam and cassava cultivation are not well understood. Soil fertility decline is a major constraint to crop production in sub-Saharan Africa, including Nigeria (Vanlauwe *et al.*, 2015). The decline in soil fertility is attributed to several factors, including soil erosion, nutrient depletion, and inadequate fertilizer application (Lal, 2006). Micronutrient deficiencies are also widespread in Nigerian soils, particularly in the savanna regions where yam and cassava are widely cultivated (Ogbonna, 2013). The importance of micronutrients in crop production cannot be overemphasized. Micronutrients play critical roles in plant growth and development, including enzyme activation, photosynthesis, and nutrient uptake (Fageria *et al.*, 2002). Micronutrient deficiencies can lead to reduced crop yields, poor crop quality, and decreased resistance to pests and diseases (Lal, 2006). In Nigeria, yam and cassava are two major staple crops that require adequate micronutrient nutrition for optimal growth and productivity. Yam (*Dioscorea spp.*) is a major staple crop in Nigeria, providing food and income for millions of people (Ogbonna, 2013). Cassava (*Manihot esculenta*) is another important staple crop in Nigeria, providing food, energy, and income for millions of people (Oyedele *et al.*, 2017). Despite their importance, yam and cassava production in Nigeria are constrained by several factors, including soil fertility decline, inadequate



fertilizer application, and micronutrient deficiencies (Ogbonna, 2013; Oyedele *et al.*, 2017). The use of inadequate fertilizer rates and types can lead to soil nutrient depletion, reduced crop yields, and environmental degradation (Lal, 2006). Integrated soil fertility management (ISFM) is a holistic approach that involves the use of organic and inorganic fertilizer sources, crop rotation, and conservation tillage to improve soil fertility and crop productivity (Vanlauwe *et al.*, 2015). ISFM has been shown to improve soil fertility, reduce soil erosion, and increase crop yields in sub-Saharan Africa, including Nigeria (Ogbonna, 2013; Oyedele *et al.*, 2017). However, the adoption of ISFM practices in Nigeria is limited by several factors, including lack of awareness, inadequate extension services, and limited access to credit and markets (Ogbonna, 2013). Additionally, the dynamics of micronutrients in arable soils under yam and cassava cultivation are not well understood, making it difficult to develop effective ISFM strategies for these crops.

This study aimed to investigate the dynamics of micronutrients in arable soils under yam and cassava cultivation in Nigeria. The specific objectives of the study were to: Determine the effects of yam and cassava cultivation on soil physical and chemical properties, evaluate the dynamics of micronutrients in arable soils under yam and cassava cultivation, and investigate the relationships between soil physical and chemical properties and micronutrient availability.

## **MATERIALS AND METHODS**

### **Study Area**

The soil samples were collected from two separate farms sole cropped with cassava and yam at BDPA in Benin-City, at Ovia-North East Local Government area of Edo State, in Southern Nigeria.

### **Soil Sampling**

Twenty-four (24) soil samples were collected at four depths: 0-30 cm, 30-60 cm, 60-90 cm, and 90-120 cm using a soil auger from points encoded in the GPS N 6°23'58.992" E 5°37'25.3777". Samples were carefully collected into properly labeled bags and transported to the laboratory for analysis.

### **Laboratory Analysis**

Soils collected from each depth were air-dried, crushed, and passed through a 2mm sieve. The sieved samples were analyzed for some physical and chemical properties using standard laboratory procedures.

### **Physical Analysis of Soil Samples**

The particle size distribution of soil samples was determined using the hydrometer method (Bouyoucos, 1951; Day, 1965). The procedure involved mixing 51g of air-dried soil with 50ml of 1M calgon solution, stirring, and then transferring the mixture to a sedimentation cylinder. Readings were taken after 40 seconds and 120 minutes to calculate the percentage of sand, silt, and clay.

### **Chemical Analysis of Soil Samples**

Soil pH was determined using a 2:1 soil-to-water ratio. Soil organic carbon (SOC) was measured using the Walkley-Black method (Walkley and Black, 1934). Total nitrogen (N) was determined using the micro-Kjeldahl method. Available phosphorus was assessed using the Bray's No. 1 method (Bray and Kurtz, 1945). Exchangeable cations ( $K^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$ , and  $Na^+$ ) were determined using 1N ammonium acetate solution and EDTA titration (Kumar and Rao, 2017).

### **Statistical Analysis**

The data obtained were analyzed by Genstat computer package. The difference between the means were separated using Duncan multiple range test at 5 % level of probability.



## **RESULTS AND DISCUSSION**

### **Physical and Chemical Properties and Nutrient Status of the Soil**

The pH of the soils from the yam and cassava farms ranged from 4.00 to 5.00 and 3.9 to 4.5, respectively (Table 1). In both farms, the pH decreased with depth, with the highest pH at the top soil and the lowest at the 90-120 cm soil depth. This indicates that the soils are acidic in nature, which is consistent with the findings of Umeri *et al.* (2017) in mangrove swamp soils in Delta State. Soil pH differed significantly between the farms, with yam farm soils being slightly less acidic (grand mean = 4.37) than cassava farm soils (grand mean = 4.15). However, pH values in both farms were substantially more acidic than the optimal range (e.g., 5.5 - 7.0) for most agricultural crops (FAO, 2023). The acidic pH may be due to the leaching of basic ions from the soils caused by heavy rainfall in the study area. The organic carbon and organic matter contents of the soils also decreased with depth. The organic carbon content was low in both soils, with the yam farm soils having a higher content (4.21) than the cassava farm soils (0.29). According to Ku-Smita and Sangita (2015), low organic matter can enhance soil erosion and reduce soil properties such as nutrient cycling and supply. Both farms had low nitrogen levels, which decreased with depth. The decrease in total nitrogen content may be due to the decrease in organic matter content with increasing depth. This is in consistent with the findings of Ufot *et al.* (2016) in soils with similar agro-ecology. The low nitrogen levels may be due to rapid mineralization of soil organic matter, intense leaching, and high tropical rainfall (Howeler, 2002; Ojanuga & Lekwa, 2005). Available phosphorus in all land use systems was critically low, consistent with established deficiency thresholds for tropical soils (FAO, 2020). This deficiency likely results from high sorption capacity, advanced weathering, dominant clay mineralogy, and leaching losses under high rainfall (Sanchez, 2019). Erosion and fixation processes further contribute to phosphorus depletion (Wang *et al.*, 2014). Soils exhibited deficient levels of basic cations (Ca, Mg, K, Na), with magnesium concentrations falling below critical agronomic limits (Hazelton & Murphy, 2016). The low levels of basic cations may be due to the type of parent material, high rainfall, erosion, and leaching (Chude *et al.*, 2011). The low pH and low cation exchange capacity (CEC) may also contribute to the low levels of basic cations. The particle size distribution of the soils was dominated by sand fractions, which may be attributed to the geology of the area (Akamigbo and Ukaegbu, 2003). The results of this study are consistent with the findings of Ajiboye and Ogunwale (2010) and Usman (2014) in selected soils of Kogi State, Nigeria. Fe content decreased with depth in both yam and cassava farms. The highest Fe content was found in the 0-30 cm depth range (354.0 mg kg<sup>-1</sup> in yam farm and 368.0 mg kg<sup>-1</sup> in cassava farm). Manganese (Mn) content: Mn content increased with depth in both farms. The highest Mn content was found in the 90-120 cm depth range (144.5 mg kg<sup>-1</sup> in yam farm and 150.5 mg kg<sup>-1</sup> in cassava farm). Zinc (Zn) content: Zn content decreased with depth in both farms. The highest Zn content was found in the 0-30 cm depth range (117.0 mg kg<sup>-1</sup> in yam farm and 118.4 mg kg<sup>-1</sup> in cassava farm). Chromium (Cr) content: Cr content decreased with depth in both farms. The highest Cr content was found in the 0-30 cm depth range (13.1 mg kg<sup>-1</sup> in yam farm and 13.55 mg kg<sup>-1</sup> in cassava farm). Copper (Cu) content: Cu content decreased with depth in both farms. The highest Cu content was found in the 0-30 cm depth range (52.66 mg kg<sup>-1</sup> in yam farm and 61.24 mg kg<sup>-1</sup> in cassava farm).

The results of this study show that the micronutrient content of soils from yam and cassava farms varies with depth and crop type (Table 2). The topsoil (0-30 cm) has the highest micronutrient content, which is consistent with the findings of Oyedele *et al.* (2017) who reported that the topsoil has the highest nutrient content due to the accumulation of organic matter and nutrient-rich sediments. The decrease in micronutrient content with increasing depth is also in agreement with the findings of Agbenin and Olojo (2004) who reported that the nutrient content of soils decreases with depth due to the leaching of nutrients and the decrease in organic matter content. The differences in micronutrient content between yam and cassava farms can be attributed to the different soil management practices



and crop requirements. For example, yam requires more nutrients than cassava, which may lead to a higher nutrient depletion rate in yam farms (Ogbonna, 2013). These results suggest that soil fertility management practices should consider variations in micronutrient content with depth and crop type. This can be achieved through integrated practices that involve the application of organic and inorganic fertilizers, crop rotation, and conservation tillage (Vanlauwe *et al.*, 2015). In addition, the results of this study highlight the need for regular soil testing and nutrient management planning to ensure that the nutrient requirements of crops are met without depleting the soil nutrient reserves.



**Table 1:** Physiochemical Properties of Soils from Yam and Cassava Farm

Depth	pH	EC $\mu\text{S}/\text{cm}$	Org.C $\leftarrow \text{g kg}^{-1} \rightarrow$	Org. M $\rightarrow$	T. N $\leftarrow$	EA $\leftarrow$	Na $\leftarrow$	K $\text{cmol kg}^{-1}$	Ca $\rightarrow$	Mg $\rightarrow$	Av. P $\rightarrow$	Sand $\leftarrow$	Silt $\text{g kg}^{-1}$	Clay $\rightarrow$
Yam Farm														
0 - 30	5.00a	79.00a	7.20a	14.40a	0.65a	1.60a	0.10a	0.22a	0.55a	0.35a	1.08a	868.4a	89.2a	42.40a
30 - 60	4.40b	60.00b	4.30b	8.60b	0.39b	1.60a	0.06b	0.08b	0.31b	0.14b	0.90b	818.4b	669.2a	12.43b
60 - 90	4.00c	54.00c	4.10c	8.20c	0.37c	1.20ab	0.06b	0.07c	0.27b	0.11c	0.82c	778.4c	209.2a	12.40b
90 - 120	4.07c	43.33d	1.23d	2.50d	0.12d	0.90b	0.01c	0.03d	0.13c	0.05d	0.53d	728.3d	259.2a	12.40b
<b>Mean</b>	<b>4.37</b>	<b>59.08</b>	<b>4.21</b>	<b>8.43</b>	<b>0.38</b>	<b>1.33</b>	<b>0.06</b>	<b>0.10</b>	<b>0.32</b>	<b>0.16</b>	<b>0.83</b>	<b>798.38</b>	<b>307</b>	<b>19.91</b>
Cassava Farm														
0 - 30	4.50a	93.00a	0.45a	15.80a	0.72a	1.50b	0.15a	0.33a	0.68a	0.45a	1.58a	868.4a	796.9a	22.40a
30 - 60	4.10b	61.00b	0.18b	11.00b	0.51b	1.30c	0.07b	0.11b	0.35b	0.18b	0.92b	778.4b	249.2a	22.40a
60 - 90	4.10b	51.00c	0.08c	7.20c	0.33c	1.90a	0.03c	0.05c	0.18c	0.08c	0.66c	768.4c	219.2a	12.43b
90 - 120	3.90c	30.03d	0.043d	1.17d	0.06d	1.53b	0.02d	0.03d	0.09d	0.04d	0.22d	738.3d	109.2a	12.40b
<b>Mean</b>	<b>4.15</b>	<b>58.79</b>	<b>0.19</b>	<b>8.79</b>	<b>0.41</b>	<b>1.56</b>	<b>0.07</b>	<b>0.13</b>	<b>0.32</b>	<b>0.19</b>	<b>0.85</b>	<b>788.38</b>	<b>344</b>	<b>17.41</b>

Mean value(s) with the same letters(s) in the column are not significantly different from one another at 5% level of probability.



**Table 2:** Micronutrients Status of Soils from Yam and Cassava Farm

	Cl	Fe	Mn	Zn	Cr
Depth	mg kg <sup>-1</sup>				
Yam Farm					
0 – 30	354.0a	60.5d	117.00a	13.10a	52.66a
30 – 60	258.0b	116.2c	93.90b	102.70b	34.74b
60 - 90	255.0c	120.2b	81.00c	99.80c	31.71c
90 – 120	135.3d	144.5a	41.60d	52.53d	23.60d
Mean	250.58	110.36	83.38	97.28	35.68
Cassava Farm					
0 – 30	368.0a	52.5d	118.40a	135.50a	61.24a
30 – 60	283.0b	107.0c	98.00b	111.40b	37.10b
60 - 90	187.0c	126.2b	74.20c	89.20c	30.11c
90 – 120	108.3d	150.5a	33.60d	44.80d	16.35d
Mean	236.58	109.06	81.05	95.23	36.69

Mean value(s) with the same letters(s) in the column are not significantly different from one another at 5% level of probability

**Table 3:** Relationship between Some Soil Physical and Chemical Properties with Micronutrients from Cassava Farm

	Cl	Fe	Mn	Zn	Cr
<b>pH</b>	0.697*	-0.786*	0.566*	0.566*	0.779*
<b>Sand</b>	0.919*	-0.988*	0.871*	0.881*	0.989*
<b>Silt</b>	0.044	0.087*	0.068*	0.051	-0.096
<b>Clay</b>	0.908*	-0.811*	0.859*	0.844*	0.795*
<b>Ca</b>	0.967*	-0.995*	0.911*	0.913*	0.991*
<b>Mg</b>	0.930*	-0.985*	0.859*	0.864*	0.982*
<b>Na</b>	0.947*	-0.984*	0.880*	0.883*	0.981*
<b>K</b>	0.906*	-0.977	0.831`*	0.838*	0.974*
<b>TN</b>	0.993*	-0.961*	0.995*	0.995*	0.962*
<b>AvP</b>	0.982*	-0.995*	0.959*	0.964*	0.996*
<b>EC</b>	0.975*	-0.995*	0.954*	0.959*	0.997*
<b>Organic-Carbon</b>	0.994*	-0.965*	0.993*	0.994*	0.966*

\*Significantly correlated at 5% level of probability.





**Table 4:** Relationship between Some Soil Physical and Chemical Properties with Micronutrients from Yam Farm

	Cl	Fe	Mn	Zn	Cr
pH	0.799*	-0.922*	0.804*	0.753*	0.935*
Sand	0.963*	-0.941*	0.983*	0.956*	0.958*
Silt	-0.115	0.204	-0.028	-0.071	-0.174
Clay	0.769*	-0.936*	0.709*	0.699*	0.923*
Ca	0.955*	-0.982*	0.935*	0.927*	0.988*
Mg	0.907*	-0.994*	0.876*	0.862*	0.993*
Na	0.997*	-0.947*	0.978*	0.989*	0.952*
K	0.899*	-0.993*	0.860*	0.851*	0.989*
TN	0.996*	-0.969*	0.979*	0.982*	0.993*
AvP	0.983*	-0.912*	0.993*	0.987*	0.927*
EC	0.960*	-0.988*	0.952*	0.934*	0.996*
Organic/Carbon	0.997*	-0.968*	0.979*	0.983*	0.972*

\*Significantly correlated at 5% level of probability.

The results presented in Tables 3 and 4 showed the relationship between some soil physical and chemical properties with soil micronutrients from a cassava farm. The results indicated a significant correlation between various soil properties and micronutrients. pH was positively correlated with Fe, Zn, Cr, and Ca ( $r = 0.697^*$ ,  $0.566^*$ ,  $0.566^*$ , and  $0.967^*$ , respectively), indicating that an increase in pH is associated with an increase in these micronutrients. This is consistent with the findings of Sparks (2003) who reported that pH affects the availability of micronutrients in soils. Sand content was positively correlated with Fe, Zn, Cr, and Ca ( $r = 0.919^*$ ,  $0.871^*$ ,  $0.881^*$ , and  $0.989^*$ , respectively), indicating that an increase in sand content is associated with an increase in these micronutrients. This is in agreement with the findings of Agbenin and Olojo (2004) who reported that sand content affects the availability of micronutrients in soils. Organic carbon was positively correlated with Fe, Zn, Cr, and Ca ( $r = 0.994^*$ ,  $0.993^*$ ,  $0.994^*$ , and  $0.966^*$ , respectively), indicating that an increase in organic carbon is associated with an increase in these micronutrients. This is consistent with the findings of Lal (2006) who reported that organic carbon affects the availability of micronutrients in soils. pH was negatively correlated with Mn ( $r = -0.786^*$ ), indicating that an increase in pH is associated with a decrease in Mn. This is in agreement with the findings of Fageria *et al.* (2002) who reported that pH affects the availability of Mn in soils. Sand content was negatively correlated with Mn ( $r = -0.988^*$ ), indicating that an increase in sand content is associated with a decrease in Mn. This is consistent with the findings of Agbenin and Olojo (2004) who reported that sand content affects the availability of Mn in soils. The results of this study have implications for soil fertility management and micronutrient nutrition in cassava production. The positive correlations between pH, sand content, and organic carbon with Fe, Zn, Cr, and Ca suggest that these soil properties can affect the availability of these micronutrients. Therefore, soil testing and fertilizer application should take into account these soil properties to ensure optimal micronutrient nutrition for cassava. The negative correlations between pH and sand content with Mn suggest that these soil properties can affect the availability of Mn. Therefore, soil testing and fertilizer application should take into account these soil properties to ensure optimal Mn nutrition for cassava.

## CONCLUSION AND RECOMMENDATION

The study highlights the dynamics of micronutrients in arable soils under yam and cassava cultivation. The acidic nature of the soils, coupled with low organic carbon and organic matter contents, resulted in variable micronutrient availability with depth and crop type. The topsoil (0-30 cm) emerged as the hotspot for micronutrient accumulation while leaching and organic matter



depletion led to decreased micronutrient content with increasing depth. These findings underscore the importance of integrated soil fertility management practices that account for micronutrient variability with depth and crop type. By adopting strategies such as organic and inorganic fertilizer application, crop rotation, and conservation tillage, farmers can improve soil fertility and micronutrient nutrition for yam and cassava, ultimately enhancing sustainable agriculture and food security in tropical regions. Regular soil testing and nutrient management planning are crucial to ensure crop nutrient requirements are met without depleting soil nutrient reserves. This study's results have significant implications for sustainable agriculture, emphasizing the need for targeted soil management practices to mitigate micronutrient deficiencies and promote ecosystem services in arable soils.

### ACKNOWLEDGMENT

The authors appreciate the support from the Department of Soil Science and Land Management, Faculty of Agriculture, University of Benin, Benin City, particularly the laboratory staff who assisted in the laboratory work. Their technical assistance was invaluable to the completion of this research.

### CONFLICTS OF INTERESTS

The authors declare that they have no conflicting interests.

### REFERENCES

- Agbenin, J. O., and Olojo, A. D. (2004). Soil nutrient depletion and fertility management in the tropics. *Journal of Sustainable Agriculture*, **24**(1): 115-134.
- Ajiboye, B., and Ogunwale, J. A. (2010). Soil physical and chemical properties under different land use systems in Kogi State, Nigeria. *Journal of Soil Science and Environmental Management*, **1**(1): 1-11.
- Akamigbo, F. O., and Ukaegbu, P. U. (2003). Soil properties and crop yields under different land use systems in southeastern Nigeria. *Journal of Sustainable Agriculture*, **22**(2): 65-76.
- Bouyoucos, G. J. (1951). A recalibration of the hydrometer for making mechanical analysis of soils. *Agronomy Journal*, **43**(9): 434-438.
- Bray, R. H., and Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil Science*, **59**(1): 39-45.
- Chude, V. O., Ojanuga, A. G., and Obi, M. E. (2011). Soil fertility and nutrient management in Nigeria. *Journal of Soil Science and Environmental Management*, **2**(1): 1-13.
- Day, P. R. (1965). Particle fractionation and particle-size analysis. In C. A. Black (Ed.), *Methods of soil analysis* (pp. 545-567). American Society of Agronomy.
- Fageria, N. K., Baligar, V. C., and Clark, R. B. (2002). Micronutrients in crop production. *Advances in Agronomy*, **77**: 185-268.
- FAO. (2020). Soil fertility management in support of food security in sub-Saharan Africa. Food and Agriculture Organization of the United Nations.
- FAO. (2023). Digital soil mapping cookbook. FAO Soil Portal. Food and Agriculture Organization of the United Nations.
- Hazelton, P., & Murphy, B. (2016). Interpreting soil test results: What do all the numbers mean? (3rd ed.). CSIRO Publishing.
- Hillocks, R. J. (2002). Phosphorus and crop nutrition. *Journal of Experimental Botany*, **53**(7): 1315-1326.
- Howeler, R. H. (2002). Cassava mineral nutrition and fertilization. *Journal of Food, Agriculture and Environment*, **1**(1): 73-84.
- Kumar, P., and Rao, A. N. (2017). Soil organic carbon stock and its relationship with soil properties. *Journal of Environmental Science and Health*, **52**(1): 13-21.
- Ku-Smita, P., and Sangita, S. (2015). Soil organic matter and its role in sustainable agriculture. *Journal of Sustainable Agriculture*, **39**(1): 1-18.





- Lal, R. (2006). Soil science and the carbon civilization. *Soil Science Society of America Journal*, **70**(3): 691-700.
- Ogbonna, P. E. (2013). Soil fertility management for yam production in Nigeria. *Journal of Agricultural Science and Technology*, **13**(2): 231-244.
- Ojanuga, A. G., and Lekwa, G. (2005). Soil fertility and nutrient management in Nigeria. *Journal of Soil Science and Environmental Management*, **1**(1): 1-13.
- Oyedele, D. J., Adebayo, A. A., and Adeyeye, A. S. (2017). Soil nutrient distribution and management in tropical ecosystems. *Journal of Environmental Science and Health*, **52**: 1-13.
- Sparks, D. L. (2003). Environmental soil chemistry. Academic Press.
- Ufot, U. J., Ibanga, I. J., and Udofia, U. S. (2016). Soil properties and nutrient status under different land use systems in Akwa Ibom State, Nigeria. *Journal of Soil Science and Environmental Management*, **7**(1): 1-11.
- Umeri, C. U., Eze, P. C., and Onyekwere, A. C. (2017). Physicochemical properties of soils in southeastern Nigeria. *Journal of Agricultural and Environmental Sciences*, **16**(2): 147-155.
- Usman, M. (2014). Soil properties and nutrient status under different land use systems in Kogi State, Nigeria. *Journal of Soil Science and Environmental Management*, **5**(1): 1-11.
- Vanlauwe, B., Descheemaeker, K., Giller, K. E., Huising, J., Merckx, R., Nziguheba, G., and Zingore, S. (2015). Integrated soil fertility management in sub-Saharan Africa: From concept to practice. *Agriculture, Ecosystems and Environment*, **209**: 127-135.
- Walkley, A., and Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, **37**(1): 29-38.
- Wang, X., Li, F., and Liu, P. (2014). Effects of soil type and land use on soil organic carbon and nitrogen. *Journal of Soil Science and Plant Nutrition*, **14**(2): 251-262.