Abuja Journal of Agriculture and Environment (AJAE ISSN (2736-1160) | Vol. 6 No 1, 2026 Website: https//www.ajae.ng Uduak, (2026)

STATUS OF READILY AND SLOWLY AVAILABLE POTASSIUM IN SOILS AT INSTITUTIONAL FARMS IN AKWA IBOM STATE, NIGERIA

Uduak, I. G. and Joseph, F. I.
Department of Soil Science, Faculty of Agriculture, Akwa Ibom State University,
Obio Akpa Campus, Nigeria.
Email: itakufokgeorge@gmail.com **Tel: 08025915196**

ABSTRACT
This study was conducted to evaluate the status of readily and slowly available potassium (K) in soils at some institutional farms in Akwa Ibom State, Nigeria, namely Cross River Basin Development Authority Farm, Abak, Akwa Ibom Agricultural Development Program Farm, Abak, Akwa Ibom State University Commercial Farm, Obio Akpa, University of Uyo Commercial Farm, Use Ufot, and Cross River Basin Development Authority Farm, Itu. Ten composite soil samples obtained from the farms at 0 – 15 cm and 15 – 30 cm were analyzed by the routine methods to determine their physicochemical properties. The readily available K was determined as the sum of the water-soluble and exchangeable K, which were extracted with deionized-water and neutral 1M NH_4OAc solution respectively. The slowly available K was determined by the boiling 1M HNO_3 method. K ion concentrations in all the extracts were measured with a digital photometer. Results showed high contents of sand (85.60 – 93.60%), moderate available P (10.02 – 18.20 mg/kg) and low clay (4.20 – 12.20%), OM (1.37 – 2.00%), total N (0.06 – 0.18%), exchangeable bases [Ca (2.10 – 3.30 cmol/kg), Mg (0.72 – 1.50 cmol/kg), K (0.20 – 0.60 cmol/kg) and Na (0.01 – 0.03 cmol/kg)] and ECEC (4.64 – 6.31 cmol/kg). The readily available K (0.23 – 0.63 cmol/kg) levels in most of the soils fell within the normal range for most crops and virtually all the slowly available K (0.23 – 0.80 cmol/kg) levels were low. Regular soil testing, applications of manure/K-rich fertilizer and conservation tillage practices were recommended.

Keywords: Readily available, nonexchangeable, potassium and soil properties.

INTRODUCTION
Potassium (K) is one of the primary chemical elements in soils that plants utilize for growth and development. Adequate availability of K in soils enhances cell division and root development, water/nutrient permeability and uptake, stomatal capacity for gaseous exchange and photosynthesis, enzymes activation, starch formation, synthesis of proteins, oils and adenosine triphosphate (ATP), stress tolerance (including disease/drought resistance) and fruit/seed development. However, inadequate availability of soil K is associated with stunted growth, weak stems, browning/scorching of leaf margins, reduced flowering and poor yields (GupHavlin *et al*., 2009). Soils derive K from different sources including weathered soil minerals, decomposed organic matter, applied chemical fertilizers/manures, crop residues, irrigation water and surface runoff, among other sources (Brady and Weil, 2012; Tisdale *et al*., 2014).

According to Tisdale *et al*. (1993), soil K exists in three forms based on its availability to plants -- readily available, slowly available and relatively unavailable forms, which vary significantly in quantity and are in a state of quasi-equilibrium (meaning the different forms are interrelated and interconvertible). The readily available K exists partly in soil solution as water-soluble K and partly on the soil exchange complex as exchangeable K. It is immediately utilized by plants and constitutes a very small proportion of total soil K (about 1 – 2%). The slowly available K is trapped (fixed) within the interlayers of the 2:1 clay minerals and their interstratified counterparts and therefore is not immediately available to plants, but can be marginally available to plants over time following its slow release through microbial activity, wetting-drying cycles and root-induced acidification. It is non-exchangeable and constitutes about 2-10% of total soil K. The relatively unavailable soil K exists in the structures of primary minerals such as feldspars and muscovite mica and can only be available to plants in the long run when such primary minerals undergo weathering. It constitutes a very high proportion of total soil K (about 90 - 98%).

Many agricultural soils in Nigeria, especially those derived from coastal plain sand, sandstone and beach sand, contain low readily available K. This is deemed so because most of the readily available K values (0.05 – 0.10 $cmolkg^{-1}$) reported for these soils in parts of Southern Nigeria fall below the 0.36 $cmolkg^{-1}$ critical level (FAO, 1990), indicating readily K deficiency (Okeke, 2023; Ijah *et al.*, 2025). Consequently, these soils are unable to provide enough support for growing plants in their natural state resulting in low crop productivity (Ibia and Udo, 2009) with serious negative implications on food security and consumers' existence. Factors such as low inputs through applications of K-rich fertilizers and manures, low soil adsorption/exchange capacities, high fixation and excessive losses to leaching and erosion may be responsible for this (Ekong and Uduak, 2015; Uduak *et al*., 2017; Okeke, 2023). However, soils that are rich in the 2:1 clay minerals have significant levels of slowly available K and values of 0.03 – 0.11 $cmolkg^{-1}$ have been reported for some agricultural soils derived from coastal plain sand in parts Nigeria (Sha'ato *et al*., 2023; Ijah *et al*., 2025).
Although information on the exchangeable K levels in the agricultural soils of the present study area is widely available, information on the total readily and slowly available K levels is limited, making it difficult to evaluate the immediate and long-term K-supplying capacities of the soils and take informed decisions regarding effective K fertilization and overall soil K fertility management for improved crop productivity and food security. This research became necessary because of the need to fill this knowledge gap. The objectives of this study were, therefore, to determine the status of readily and slowly available K in soils at selected institutional farms in Akwa Ibom State and assess the relationships between these soil K forms and some physicochemical properties of the soils.

MATERIALS AND METHODS

Study Area

This study was conducted in Akwa Ibom State at five institutional farm locations, namely Cross River Basin Development Authority (CRBDA) Farm, Abak ($4^{o}56^{I}22.96$N; $7^{o}47^{I}53.59$ E), Akwa Ibom Agricultural Development Programme (AKADEP) Farm, Ikot Ekang, Abak ($5^{o}1^{I}08.10$N; $7^{o}45^{I}28.82$ E), Akwa Ibom State University (AKSU) Commercial Farm, Obio Akpa ($4^{o}57^{I}36.34$ N; $7^{o}44^{I}34.31$ E), University of Uyo (UNIUYO) Commercial Farm, Use Offot ($5^{o}1^{I}49.14$N; $7^{o}58^{I}$I2.24 E) and Cross River Basin Development Authority (CRBDA) Farm, Oku Iboku, Itu ($5^{o}10^{I}22.34$ N; $8^{o}2I^{I}53.52$ E). The present study area has a humid tropical climate with the wet season that spans between the months of April and October and the dry season that spans between the months of November and March. Rainfall is usually heavy ranging between 2250 and 3000 mm annually, while diurnal temperature ranges between 22°C and 26°C (NiMet, 2022). Woody shrubs and grass such as (siam weed, guinea grass and bamboo) mostly constitute the vegetation of the area. Soils in the area are derived mostly from coastal plain sand, beach sand, sandstone and alluvium (NGSA, 2009; Uduak, 2019).

Soil Sample Collection and Processing

Ten grab soil samples were taken randomly at 0 – 15 cm and 15 – 30 cm with a soil auger from the study locations and bulked to produce the ten composite soil samples used for the study. The composite soil samples were carefully labelled and conveyed in black polythene bags to the laboratory for analysis. Prior to the laboratory analysis, the soil samples were air-dried, ground and passed through a 2 mm-mesh sieve and portions of the 2 mm soil samples meant for the determination of organic carbon (OC) and total nitrogen (TN) were further passed through a 0.5 mm-mesh sieve (Udo *et al*., 2009).

Laboratory Analysis

Determination of Soil Physicochemical Properties

All the soil physicochemical properties were determined in the laboratory based on the methods and procedures outlined by Udo *et al*. (2009). Particle size distribution was determined by the Bouyoucos hydrometer method after dispersing the soil samples with sodium hexametaphosphate solution. Soil pH was determined in water with a glass electrode pH meter at the soil to water ratio of 1:2.5. Electrical conductivity (EC) was determined with a conductivity meter at the soil to water ratio of 1:5. Soil organic carbon (OC) was determined by the Walkley and Black wet oxidation method, while soil organic matter (OM) value was obtained as the product of OC value and van Bemmelen Factor of 1.724. Total nitrogen (TN) was determined by the macro-Kjeldahl digestion and distillation method. Available phosphorus (AP) was determined by the Bray No. 1 method. Exchangeable bases (Ca, Mg, K and Na) were determined by the 1M neutral ammonium acetate (NH_4OAc) extraction method. The exchangeable K and Na in the extract were determined with a digital flame photometer, while the exchangeable Ca and Mg were determined with an atomic absorption spectrophotometer. Exchangeable acidity (EA) was determined by the 1M KCl extraction method and titration was done with 0.01M NaOH. Effective cation exchange capacity (ECEC) was determined by adding up total exchange bases (TEB) and total exchangeable acidity (TEA). Base saturation (BS) was calculated as percentage of ECEC occupied by total exchangeable bases (TEB).

Determination of Readily and Slowly Available Potassium

Readily available K was determined by summing up the water-soluble and exchangeable K values. Water-soluble K was extracted with deionized water at the soil: water ratio of 1:5 and measured with a digital flame photometer; while slowly available K was determined by subtracting the neutral 1 M NH_4OAc-extractable K from the the boiling 1M HNO_3-extractable K (Helmke and Sparks, 2000).

Statistical Analysis

The physicochemical properties and K forms were statistically analyzed using descriptive statistics (arithmetic means and ranges) determined with the SPSS software.

RESULTS AND DISCUSSION

Physicochemical Properties of the Soils

The physicochemical properties of the soils are presented in Tables 1 and 2. The mean sand, silt and clay contents of the soils at 0 – 15 cm depth (Table 1) were 92.26, 2.30 and 5.44%, whereas the mean sand, silt and clay contents of the soils at 15 – 30 cm depth (Table 2) were 90.46, 2.52 and 7.00% respectively. Sand contents were slightly lower at 15 – 30 cm, whereas clay contents were slightly higher. Silt contents were slightly higher at the 0 -15 cm depth of the AKADEP Farm, Abak, and AKSU Farm, Obio Akpa. Sand was the dominant textural class at both sampling depths of the soils.

The mean electrical conductivity, pH, organic matter, total nitrogen, available phosphorus, exchangeable Ca, exchangeable Mg, exchangeable K, exchangeable Na and effective cation exchange capacity at 0 – 15 cm depth (Table 1) were 0.01 dSm^{-1}, 5.70, 1.82%; 0.12%, 13.69 $mgkg^{-1}$, .2.76 $cmolkg^{-1}$, 1.11 $cmolkg^{-1}$, 1.11 $cmolkg^{-1}$, 0.40 $cmolkg^{-1}$ and 0.02 $cmolkg^{-1}$; whereas the mean electrical conductivity, pH, organic matter, total nitrogen, available phosphorus, exchangeable Ca, exchangeable Mg, exchangeable K, exchangeable Na and effective cation exchange capacity at 15 – 30 cm depth (Table 2) were 0.01 dSm^{-1}, 5.58, 1.54%, 0.09%, 13.19 $mgkg^{-}1$, 3.30 $cmolkg^{-1}$, 0.92 $cmolkg^{-1}$, 0.38 $cmolkg^{-1}$, 0.03 $cmolkg^{-1}$ and 5.78 $cmolkg^{-1}$ respectively. Most of the results agreed with past researchers (Uduak *et al*., 2012; Ekong and Uduak, 2015; Uduak and Umoh, 2022; Akpanurom *et al*., 2024; Umoh *et al*., 2024) and indicated low fertility status of the soils when considered in line with the FPDD (1990) ratings.

Table 1: Physicochemical properties of the soils at 0 – 15 cm depth

Soil Property	CRBDAF Abak	AKADEPF Abak	AKSUF Obio Akpa	UNIUYOF Use Offot	CRBDAF Itu	Mean
Sand (%)	93.20	93.60	93.60	89.50	91.40	92.26
Silt (%)	2.50	2.20	2.20	2.30	2.30	2.30
Clay (%)	4.30	4.20	4.20	8.20	6.30	5.44
TC	S	S	S	S	S	
EC (dSm^{-1})	0.02	0.01	0.01	0.01	0.01	0.01
pH	5.68	5.53	5.82	5.73	5.72	5.70
OM (%)	1.64	2.00	1.99	1.67	1.80	1.82
Total N (%)	0.18	0.13	0.14	0.11	0.04	0.12
Avail. P ($mgkg^{-1}$)	11.80	12.71	18.20	15.70	10.03	13.69
Exch. Ca ($cmolkg^{-1}$)	3.20	3.00	2.80	2.70	2.10	2.76
Exch. Mg ($cmolkg^{-1}$)	0.95	0.71	1.07	1.50	1.32	1.11
Exch. K ($cmolkg^{-1}$)	0.50	0.50	0.30	0.30	0.40	0.40
Exch. Na ($cmolkg^{-1}$)	0.03	0.03	0.01	0.01	0.02	0.02
EA ($cmolkg^{-1}$)	1.40	1.12	1.48	1.32	1.16	1.30
ECEC ($cmolkg^{-1}$)	5.63	4.91	5.39	5.56	4.64	5.23
B sat (%)	75.13	77.19	72.54	76.26	75.00	75.22

TC = Textural class, S = Sand, LS = Loamy sand, EC = Electrical conductivity, TN = Total Nitrogen, OC = Organic Carbon, OM = Organic matter, Avail. P = Available Phosphorus, Exch. = Exchangeable, EA = Exchangeable acidity, B. sat. = Base saturation, CRBDAF = Cross River Basin Development Authority Farm, AKADEPF = Akwa Ibom Agricultural Development Programme Farm, AKSUF = Akwa Ibom State University Commercial Farm, UNIUYOF = University of Uyo Commercial Farm.

Table 2: Physicochemical properties of the soils at 15 – 30 cm depth

Soil Property	CRBDAF Abak	AKADEPF Abak	AKSUF Obio Akpa	UNIUYOF Use Offot	CRBDAF Itu	Mean
Sand (%)	91.60	92.80	92.80	89.60	85.60	90.48
Silt (%)	2.20	3.00	3.00	2.20	2.20	2.52
Clay (%)	6.20	4.20	4.20	8.20	12.20	7.00
TC	S	S	S	S	LS	
EC (dSm^{-1})	0.02	0.01	0.01	0.01	0.01	0.01
Ph	5.55	5.76	5.63	5.05	5.93	5.58
OM (%)	1.39	1.80	1.61	1.37	1.51	1.54
Total N (%)	0.08	0.12	0.12	0.08	0.06	0.09
Avail. P ($mgkg^{-1}$)	17.57	10.02	13.31	12.02	13.01	13.19
Exch. Ca ($cmolkg^{-1}$)	3.10	2.70	3.30	3.20	3.20	3.30
Exch. Mg ($cmolkg^{-1}$)	0.75	0.95	0.72	1.08	1.10	0.92
Exch. K ($cmolkg^{-1}$)	0.30	0.20	0.60	0.30	0.50	0.38
Exch. Na ($cmolkg^{-1}$)	0.03	0.03	0.02	0.02	0.03	0.03
EA ($cmolkg^{-1}$)	1.16	1.32	1.52	1.46	1.48	0.49
ECEC ($cmolkg^{-1}$)	5.34	5.02	6.16	6.06	6.31	5.78
B. sat (%)	78.28	77.29	75.32	75.91	76.55	76.67

TC = Textural class, S = Sand, LS = Loamy sand, EC = Electrical conductivity, TN = Total Nitrogen, OC = Organic Carbon, OM = Organic matter, Avail. P = Available Phosphorus, Exch. = Exchangeable, EA = Exchangeable acidity, B. sat. = Base saturation, CRBDAF = Cross River Basin Development Authority Farm, AKADEPF = Akwa Ibom Agricultural Development Programme Farm, AKSUF = Akwa Ibom State University Commercial Farm, UNIUYOF = University of Uyo Commercial Farm.

Readily and Slowly Available Potassium levels in the Soils

The readily and slowly available K levels in the soils are presented in Tables 3 and 4. At 0 – 15 cm depth (Table 3), the mean total readily and slowly available K levels ranged from 0.33 to 0.54 cmol/kg and from 0.23 to 0.67 cmol/kg with the mean values 0.44 and 0.51 cmolkg^{-1}; whereas at 15 – 30 cm depth (Table 4), they ranged from 0.23 to 0.63 cmol/kg and from 0.27 to 0.80 cmol/kg with the mean values of 0.42 and 0.56 cmol/kg respectively. The mean water-soluble component of total readily available K at 0 – 15 cm depth (Table 3) ranged from 0.03

Table 3: Readily and slowly available potassium in the soils at 0 – 15 cm depth

Soil properties	CRBDAF Abak	AKADEPF Abak	AKSUF Obio Akpa	UNIUYOF Use Offot	CRBDAF Itu	Mean
Water-soluble K (cmol/kg)	0.03	0.04	0.03	0.05	0.04	0.04
Exchangeable K (cmol/kg)	0.50	0.50	0.30	0.30	0.40	0.40
Total readily available K (cmol/kg)	0.53	0.54	0.33	0.35	0.44	0.44
Slowly available K (cmol/kg)	0.59	0.67	0.62	0.46	0.23	0.51

CRBDAF = Cross River Basin Development Authority Farm, AKADEPF = Akwa Ibom Agricultural Development Programme Farm, AKSUF = Akwa Ibom State University Commercial Farm, UNIUYOF = University of Uyo Commercial Farm.

Table 4: Readily and slowly available potassium in the soils at 15 – 30 cm depth

Soil properties	CRBDAF Abak	AKADEPF Abak	AKSUF Obio Akpa	UNIUYOF Use Offot	CRBDAF Itu	Mean
Water-soluble K (cmol/kg)	0.06	0.03	0.03	0.04	0.05	0.17
Exchangeable K (cmol/kg)	0.30	0.20	0.60	0.30	0.50	0.38
Total readily available K (cmol/kg)	0.36	0.23	0.63	0.34	0.55	0.42
Slowly available K (cmol/kg)	0.59	0.70	0.80	0.46	0.27	0.56

CRBDAF = Cross River Basin Development Authority Farm, AKADEPF = Akwa Ibom Agricultural Development Programme Farm, AKSUF = Akwa Ibom State University Commercial Farm, UNIUYOF = University of Uyo Commercial Farm.

to 0.05 0 cmolkg^{-1}; while the mean water-soluble component of total readily available K at 15 – 30 cm depth (Table 4) ranged from 0.03 to 0.06 cmolkg^{-1} respectively. Based on the FAO (1990) ratings, the status of total readily available K in the soils, especially those obtained from Akwa Ibom State University Commercial Farm, Obio Akpa, University of Uyo Commercial Farm, Use Offot, and Cross River Basin Development Authority Farm, Itu, was considered low, as the recorded values were below the 140 mg/kg (0.36 cmol/kg) critical level, though the water-soluble components were above the 10 mg/kg (0.03 cmolkg^{-1}) critical level. However, the status of slowly available K in the soils was considered moderate according to Obigbesan (1999) and Adepetu et *al*. (2014). Some of the results agreed with past researchers.

DISCUSSION

The loamy sand textural class of the soils indicates that coarse sand particles dominated the soils Such soils are usually loose and have low cation adsorption and exchange capacities in their natural state because of their low organic matter and clay contents. They may also be prone to excessive leaching due to their porous and inert nature, which largely explains why these soils are deficient in readily available K and other essential nutrients, though low inputs and regular plant uptake might also reduce K availability (Brady and Weil, 2012). Besides, the moderately acidic pH condition of the soils might slightly slow down organic matter decomposition and K release processes thereby reducing K cycling and availability (Havlin *et al*., 2009). The negative implications of low soil K availability in agricultural systems are widely reported and this needs to be improved with effective soil management strategies for enhanced agricultural productivity and food security.

The relatively low total readily available K levels at 0 – 15 cm depth of most of the soils reflects the significant influence of organic matter contents on soil K availability. According to Brady and Weil (2012), organic matter largely controls soil cation retention, in addition to releasing K and other nutrients following microbial decomposition. It also complexes sesquioxides, coats clay mineral surfaces and competes for adsorption sites on clay minerals, thus preventing them from fixing K. These explain why readily available K is often higher in soil layers with higher organic matter contents. The low status of total readily available K in the soils usually suggests low K inputs, high K removal by growing plants, excessive leaching and erosion (Uduak *et al*., 2017; Ibia and Udoh, 2024; Ijah *et al*., 2025). According to Havlin *et al*. (2009), inadequate availability of soil K adversely impacts cell division and root development in growing plants, gas exchange regulation, photosynthesis, glucose formation, protein synthesis, water/nutrient permeability/uptake, enzymes activation, stress tolerance, disease/drought resistance, plant growth performance and fruit/seed development.

The moderate status of slowly available K in the soils indicates the presence of mixed clay mineralogy (kaolinite, montmorillonite, vermiculite, illite and chlorite) which has been reported by Uduak (2019) for major soils within the present study area. Although the overall K-fixation capacity of a soil with mixed clay mineralogy may depend on the proportions and interactions of the clay minerals involved, it is often intermediate between those of the component clay minerals since the minerals vary in their K-fixing potential as a result of variations in their structural properties (Brady and Weil, 2012; Uduak, 2019).

CONCLUSION AND RECOMMENDATIONS

Based on the findings of this study, it is concluded that the status of total readily available K in all the soils was low; whereas the status of slowly available K was moderate. Regular testing of the soils, regular applications of manure (compost, farmyard and green manure), split applications of K-rich chemical fertilizers, crop rotation, erosion control, cover cropping and conservation tillage should be adopted to improve K availability in the soils for improved growth and yields of crops. Moreover, further research should be conducted to assess relatively unavailable and total K as well as K-release kinetics in the soils for full understanding of K pool and dynamics which are crucial for predicting K availability to growing crops in the soils.

REFERENCES

Agbede, T. M. (2009). Methods of soil analysis. *Journal of food agriculture,* 21, 10-20**.**

Brady, N.C. and Weil, R.R. (2012). "Chapter 12: Soil Solution and Colloids." Elements of the Nature and Properties of Soils (3rd Edition). *Pearson Prentice Hall,*442-471.

Ekong, U. J. and Uduak, I. G. (2015). Fertility status of soils at the Teaching and Research Farm of Akwa Ibom State University, Obio Akpa Campus, Southeast of Nigeria. *International Journal of Science and Research,* 4(11): 1434 – 1438.

FAO (1990): No universal numeric critical classes for slowly available (non-exchangeable) potassium. *Soil Bulletin No. 63. Rome.*

FPDD (Fertilizer Procurement and Distribution Department) (1990): Literature review on soil fertility investigations in Nigeria. Lagos. *Federal Ministry of Agriculture and Natural Resources.*

Gupta, U. C. and Gupta, S. C. (2000). *Potassium nutrition of crops. Science Publishers. Am.* J, 69:77-86.

Havlin, J. L., Beaton, J. D., Tisdale, S. L. and Nelson W. L. (2014). *Soil fertility and fertilizer*: *An introduction to Nutrient Management* (8th ed.). Prentice Hall, Upper Saddle River, N J.

Helmke, P. A. and Sparks, D. L. (2000). Potassium, rubidium and cesium. In D. L. Sparks (Ed.), *Methods of soil analysis, part 3: Chemical methods (pp. 551 - 574).* Soil Science Society of America, American Society of Agronomy.

Ibia, T. O. and Udoh, O. E. (2024). Assessment of three extraction methods on the concentration of available potassium (K) in soils formed from diverse parent materials in Akwa Ibom State. *African Journal of Agriculture and Allied Sciences,* Vol. 5(3): 124 – 133.

Ijah, C. J., Ekpo, H. J. and Ekwere, P. A. (2025). Potassium fixation in soils formed from diverse parent materials in Akwa Ibom State. *Direct Research Journal of Agriculture and Food Science,* Vol. 13(2): 73 – 81.

NGSA (2009). Nigerian Geological Survey Agency, Abuja, Nigeria.

NiMet (2022). Nigerian Meteorological Agency: PUBLICATIONS AND BULLETINS.

Okeke, V. N. (2023). Different forms of potassium and their contributions toward potassium uptake under ginger (*Zingiber officinale* Roscoe) production in an Ultisol of Umudike, Southeastern Nigeria. *Nigerian Journal of Science,* vol. 33(1): 70 – 78.

Sha'ato, R., Ojanuga, A. G. and Ajayi, S. O. (2008). Forms and profile distribution of potassium in typical soils of the lower Benue Valley of Nigeria. *Communications in Soil Science and Plant Analyis,* Vol. 31(3-4): 437 – 453.

Tisdale, S. L., Nelson, W. L., Beaton, J. D. and Havlin, J. L. (2014). *Soil fertility and fertilizers. An introduction to nutrient management* (7th ed.). Pearson.

Tisdale, S. L., Nelson, W. L., Beaton, J. D. and Havlin, J. L. (1993). *Soil fertility and fertilizers* (5th ed.). New York, NY: Macmillan Publishing Company, pp. 275 – 309.

Udo, E. J., Ibia, T. O., Ogunwale, A. J., Ano, A. O. and Esu, I. E. (2009). *Manual of Soil, Plant and Water Analysis.* Lagos: Sibon Books Ltd., 183 pp.

Uduak, I. G., Ndubuisi-Nnaji, U. U., Ekong, U. J. and Ijah, C. J. (2012). Effects of organic and inorganic fertilizers on selected chemical and biological properties of an Ultisol under maize cultivation. *Proceedings of 8th annual Conference of Organic Agriculture Project in Tertiary Institutions in Nigeria, p.6 – 10.*

Uduak, I. G., Udoumoh, I. D. J. and Ndubisi-Nnaji, U. U. (2017). Selected properties and problems of sandy coastal plain soils of Akwa Ibom State. *Journal Communityand Communication Research,* 2(1): 73 – 79.

Uduak I. G and Umoh G. N. (2021): Effect of poultry manure and NPK fertilizer application on the growth and yield of Okra (Abelmoschus esculentus) in an Ultisol of Southeastern Nigeria. *International Journal of Agriculture and Forestry*, Vol. 11, Issue 5: 163-173.

Uduak I. G. (2019). Clay mineralogy and surface charge characteristics of major soils of Akwa Ibom State, South-South Nigeria. A PhD Thesis submitted to Department of Soil Science, University of Calabar, Nigeria.

Umoh, F. O., Uduak, I. G. and Ekanem, C. E. (2022). Potassium release kinetics as influenced by time and parent materials in parts of Akwa Ibom State, Nigeria. *Direct Research Journal of Agriculture and Food Science,* Vol. 10(10): 233 – 240.