Potassium Status of Soils in Relation to Land use Types in Ngor-Okpala, Southeastern Nigeria

B.U.Uzoho*, C.Ekeh
Department of Soil Science and Technology, Federal University of Technology, P.M.B 1526
Owerri, Imo-State, Nigeria
E-mail: betheluzoho@yahoo.com; chizobaeke78@yahoo.com

Abstract

Study of the potassium status of soils provides useful information needed for rational K fertilizer management and for environmental control against K pollution. Potassium status of soils of cassava, fallow, oil palm and pineapple land use types in Ngor-Okpala, Southeastern Nigeria was evaluated. This involved determination of the total K, structural or mineral K, non-exchangeable or fixed K, available K, exchangeable K and solution K. Also intercorrelationship between K forms, correlation between K forms and soil properties as well as regression models of available K and selected K forms were determined. Equally K fixation and exchange capacities were evaluated. Total, structural or mineral, non-exchangeable or fixed, available, exchangeable and solution K ranged from 11.65-20.35, 11.52-19.65, 0-2.25, 0.07-0.92, 0.05-0.90 and 0.002-0.022 cmol (+) kg^{-1} respectively, with distributions varying with soil depths for each land use type. Intercorrelationship amongst the K forms was significant ($P \leq 0.05$) between available K and exchangeable K and structural K with total K but none distinct ($P \leq 0.05$) between the other K forms. The regression model showed that non-exchangeable, exchangeable, structural and total K accounted for 39, 51, 96 and 97% of soil available K. Soil K forms correlated with selected soil properties especially OM, pH, ECEC, %BS, Na, Ca, Mg, H, clay, silt/clay ratio, sand and silt. Potassium exchange and fixation capacities ranged from 1.33-7.83 and 0.03-2.23cmol (+) kg^{-1} respectively with pattern of distribution irregular for the former but increased with rates of added K for the later. In general, variations in soil K forms suggests the imperative for regular K evaluation to guide against environmental K pollution and for promotion of sustainable K fertilizer use in soils of varying land use types.

Keywords: Potassium, Soils, Landuse, Ngor-Okpala and Southeastern Nigeria

1.0 Introduction

Potassium is the third most essential nutrient element after nitrogen and phosphorus for plant nutrition. It plays significant roles in the physiological processes of protein formation, transportation of water, nutrients and carbohydrates, photosynthesis, N utilization, stimulation of early growth and in insect and disease resistance (Rehm and Schmitt, 2002; Lakudzala 2013). Also, it promotes the transportation of assimilates, control of stomata opening, enzyme activation in plants especially those responsible for energy transfer and formation of sugars, starch and protein as well as promotion of microbial activities and the nutrition and health of man and livestock (Lauchli and Pfluger, 1979; Al-Zubaidi et al., 2008;Yawson et al., 2011).

Potassium exists in four forms in the soil. These include the solution, exchangeable, non-exchangeable or fixed and mineral or structural K forms (Sparks and Huang, 1985; Sparks, 1987; Sparks, 2000). Solution K constitutes about 2-5 mg L^{-1} except in recently K amended soils and is the form directly taken up by plants and microbes or subject to leaching losses (Sparks, 2000). Exchangeable K is the form that is electrostatically bound to the outer surface of clay minerals and humic substances and which is readily exchangeable with cations and available to plants. Non-exchangeable or fixed K represents the portion held between adjacent tetrahedral layers of dioctahedral and trioctahedral micas, vermiculites, and intergrade clay minerals such as chloritized vermiculite and which is sparingly or moderately available to plants (Rich, 1972; Sparks and Huang, 1985; Sparks, 1987) while mineral or structural K consists of about 98% of total soil potassium and constitutes the portion that is bonded within crystal structures of soil mineral particles (Sadusky et al. (1987).

Equilibrium and kinetic reactions exist between potassium forms in the soils and this affects their solution concentration and availability to plants (Ano, 1991; Ndukwu et al., 2012). Thus as soil solution potassium concentration is depleted through leaching and plant uptake, it is immediately replenished by the other forms especially the exchangeable and non-exchangeable fractions (Yawson et al., 2011). Availability of potassium in soil solution could therefore be influenced by the solution-exchangeable K dynamics, rate of K exchange in soils, K fixation and release from soil minerals and leaching (Sadusky et al., 1987; Sparks, 2000).

Soil potassium distribution and availability could be altered due to changes in soil management and land use practices. For instance, it has been reported that increased addition of organic manures, yielded a corresponding increase in exchangeable K content of an Ultisol (Mbah, 2008). Also, variations in available K distribution have been indicated in soils of varying land use systems (Raheb and Heidari 2011; Ayele, 2013). These variations in soil K status could be associated with factors imposed by certain soil physicochemical properties as have been reported for soils of selected parent materials in Southeastern Nigeria (Ndukwu et al.

2012). Earlier, Uzoho et al. (2007) have reported variations in soil characteristics due to differences in land use types.

Few studies of K status of most tropical and indeed Nigerian soils are presently concerned with their relationships with the parent materials (Adepetu et al., 19888; Ndukwu et al., 2012). There appears to be a dearth of information on the relationship between soil K status and the land use types. The objectives of this study were therefore to evaluate the K status of soils in relation to selected land use types in Ngor-Okpala, Southeastern Nigeria, correlate the K forms with selected soil physicochemical properties and predict K availability from selected soil K forms.

2.0 Material and Methods

2.1 Study Location

The study location was Ngor-Okpala situated between Latitudes 5^o 02^1 and 5^{o}07^{1}N and Longitudes 7^{o}10^1 and 7^{o}13^{1}E. Ngor-Okpala has a land area of about 635.73 km^2 with a mean annual rainfall range of 2202.3-2206.2 mm, relative humidity of 70.62-81.08% and temperature of 27.81-39.22 ^{o}C (IPEDC, 2006). The geology of the area is Coastal Plain Sands (Orajiaka, 1975) and the soil types Ruptic Hapludult (Pineapple) and Typic Paleudult (Oil palm, Cassava and Fallow land uses) (Soil Survey Staff, 1999). Major economic activities of the area include farming, trading and artisanry.

2.2 Sample Collection and Preparation

Soil samples were randomly collected from two depths (0-15 and 15-30 cm) at two locations of each land use (Pineapple, Cassava, Fallow and Oil Palm), giving a total of 16 samples. Samples from the 0-15 cm depth represented the top soil while those from the 15-30 cm depth constituted the sub soil. The pineapple land use consisted of more than a year old pineapple orchard that has received some hog manure amendments. Oil palm land use consisted of a 10 year old oil palm plantation that has received some inorganic fertilizer treatments especially NPK 20:10:10 and muriate of potash (MOP). Cassava land use was a year old farm that has received liberal fertilizer amendments while the fallow land use consisted of about 2 year old fallow cover with multiple outcrops of different species. The collected soil samples were air dried, sieved using a 2 mm diameter sieve and the fine earth fractions stored ready for analysis.

2.3 Laboratory Analyses

Routine soil properties and potassium forms were analyzed using sub samples of the fine earth soil fraction. Conducted routine analysis included particle size determination using calgon and water as dispersing agents (Gee and Or, 2002), pH in 1: 2.5 soil/water ratio using the glass electrode of the pH meter, organic carbon using the method described by Nelson and Sommers (1996) and the organic carbon converted to organic matter by multiplication using a factor of 1.724 (Van Bemmelen factor), total nitrogen (Bremner, 1996) and exchangeable cations (Thomas, 1996). The K forms determined included:

2.3.1 Total K

This was determined using the method described by Jackson (1958). In this about 0.1 g ground fine earth soil sample was weighed into a 30 ml platinum crucible and wetted with few drops of distilled water before the addition of 5 ml. of HF and 0.5 ml $HCLO_4$. The crucible was then placed on sand bath, with about nine-tenths of it covered with platinum lid and heated to between 200-225^o till the content was evaporated to dryness. The crucible was cooled and 2 ml. of distilled water and few drops of $HCLO_4$ added. It was again placed on the sand bath and the contents evaporated to dryness. The sample was transferred into a 50-ml. volumetric flask and diluted to volume before the content was filtered into a 100-ml. volumetric flask. The flask was then diluted to volume and K in the filtrate was determined using a flame photometer.

2.3.2 Non-exchangeable K

It was determined using the method by Pratt (1965). Ten (10 g) soil sample was weighed into a 30 ml platinum crucible and heated with 25 ml 1 M HNO_3 solution in an oil bath (118^o) for 25 mins. The extract was decanted by filtration into a 50 ml volumetric flask. The K in the extract was determined in a flame photometer.

2.3.3 Solution and Exchangeable K

Solution K was extracted using distilled water while the exchangeable K was with 1N NH_4OAc solution and K in the extracts determined using a flame photometer (Thomas, 1996).

2.3.4 Available K

This was obtained as a summation of solution K and exchangeable K

2.3.5 Mineral or Structural K

This was obtained as a difference between total K and the summation of all other K forms (non-exchangeable K + exchangeable K + solution K).

2.3.6 Potassium Fixation and Exchange Capacity

Fixed K was determined as described by Jackson (1979). For replacement of exchangeable K, 0.5 M $CaCl_2$ solution was used instead of 1N NH_4OAc after treating the soil samples with KCL solutions to avoid the extraction of fixed K (Martin and Sparks,1983). About 0, 4, 8 and 16 mgs KCl were added to 5g of soil in a 50 ml centrifuge tubes and 10 ml of distilled water added and the tube shaken for 3 hrs. The suspension was then allowed to stand for 72 hrs for equilibration before centrifugation at 5200 x g for 15 mins. The K in the clear supernatant was determined and the fixed K calculated as:

Fixed K = added K + K in extract of zero KCL treatment – K in extract of each treatment

Amount of K extracted at various levels of added KCl was taken to represent the K exchange capacity.

2.4 Statistical Analysis

All data generated were subjected to Analysis of Variance and treatment means separated using the least significant difference (LSD) at 5% probability level with a Genstat statistical package (Buyse et al., 2004). Also correlation and regression analysis were conducted using the same statistical package (Genstat).

3.0 Results and Discussion

3.1 Soil Physicochemical Properties

Physical properties of the soils are presented in Table 1. Sand, silt and clay contents of calgon and water dispersed soils ranged from 821-870 and 890-945, 30-96 and 21-53 and 72-125 and 28-59 g kg^{-1} respectively. Whereas, sand content was higher than the other soil fractions and decreased distinctly (LSD 0.05) with soil depths, distribution of the clay fraction seriously increased while silt content was irregular with depth. The high sand content signifies the coarseness of the soils attributable to the parent materials which is Coastal Plain Sands (Orajiaka, 1975). Silt/clay ratios ranged from 0.26-1.04 and 0.32-1.11for calgon and water dispersed soils respectively and increased none significantly (LSD 0.05) with depth exception being cassava land use in the former and irregularly with depth in the later, with their means less than unity indicating that the soils are old and highly weathered (Essoka and Esu, 2005). According to Nwaka and Kwari (2000), high silt/clay ratio of sandy soils is related to the coarse texture or resistant skeletal composition of the parent materials and youthfulness of the soils. Dispersion ratios (DR), aggregated silt and clay (ASC), clay flocculation index (CFI) and clay dispersion index (CDI) ranged from 316-723, 43-125, 378-671 and 329-622 g kg^{-1} respectively and differed distinctly (LSD 0.05) and irregularly with depths amongst land uses. Similar ranges and patterns of distribution of DR, ASC, CFI and CDI, indicative of irregularity in aggregate stability of soils of the varying land uses have been reported (Oguike and Mbagwu, 2009).

Soils were acidic (pH ranges of 5.05-5.40), with the degree depressed seriously (LSD 0.05) with depths in most land use types (Table 2). The high acidity of the soils has been ascribed to intense base leaching by the high tropical rainfall (Enwezor et al., 1990). Low pH values of less than 5.50 indicate that the soils may suffer from aluminium toxicity. It has been indicated that aluminium toxicity occur in soils with pH values less than 5.50 and increases in intensity as the pH decreases below 5.0 (Opara-Nadi, 1988; White et al., 2006). Soil OM, available P, total N, exchangeable Ca, Mg and K, ECEC and percent base saturation ranged from 11.70-43.30g kg^{-1}, 0.77-2.87mgkg^{-1}, 0.6-2.20g kg^{-1}, 0.56-2.10cmol (+) kg^{-1}, 0.40-1.08cmol (+) kg^{-1}, 0.01-0.02cmol (+) kg^{-1}, 1.74-3.54cmol(+)kg^{-1} and 63.30-89.90% respectively, with all decreased none significantly (LSD 0.05) with soil depths in most land use types (Table 2). Mean values of about 0.88-3.77mg kg^{-1} P, 0.80-1.50 g kg^{-1} N, 15.30-29.40 g kg^{-1}OM, 0.64-1.68 cmol (+) kg^{-1} Ca, 0.39-0.75cmol (+) kg^{-1}Mg, 0.01-0.02cmol(+) kg^{-1}K and 1.73-3.10 cmol(+)kg^{-1}ECEC in the soils is below critical limits for soils of southeastern Nigerian (Enwezor et al., 1990; Uzoho et al.,2007), suggesting poor fertility status of soils of the various land use types. Mean values of less than 16 cmol (+) kg^{-1} ECEC in the soils suggests that they are dominantly of low clay activity (Opara-Nadi et al., 1988).

3.2 Soil Potassium

Total K content of the soils ranged from 11.65 to 20.35 Cmol (+) kg^{-1}(Table 3) equivalent to 4.50-7.90 g kg^{-1}or 4543.50- 7936.50 mg kg^{-1}. This is low relative to values of 15,107.14-15,300 mg kg^{-1} reported for sedimentary and basement complex soils of southwestern Nigeria (Adepetu et al., 1988) but high compared to values of 12-1700 mg kg^{-1} for tropical savannah Thailand soils (Ngwe et al., 2012) and 550.0-4700.0 mg kg^{-1} for savannah soils of southwestern Nigeria (Agboola and Omueti, 1983). According to the authors, the low values for savannah soils of southwestern Nigeria has been attributed to the incomplete digestion by the weak reagents (a mixture of perchloric, nitric and sulphuric acids) used. The low total K content of the soils studied relative to some southwestern Nigeria soils could be ascribed to the low content of the parent materials and the intensity of weathering. It has been indicated that acid sands derived from sand stones and Coastal plain sands parent materials of southeastern Nigeria have low total K content due to the low concentrations of the parent materials and high intense weathering (Unamba-Oparah, 1985; Adepetu et al., 1988; Enwezor et al., 1990). Except pineapple, concentration of total K decreased none distinctly (LSD 0.05) with soil depth in other land uses, with mean values being13.25, 15.10, 17.73 and 19.48 Cmol (+) kg^{-1} for fallow, cassava, pineapple and oil palm respectively indicating that fallow had the least concentration. Highest weatherability indicated by the low silt/clay ratio (Essoka and Esu, 2005) could be responsible for the least total K content in fallow relative to the other land uses.

Structural or mineral K ranged from 11.52-19.65 Cmol (+) kg^{-1} (Table 3) equivalent to 4492.80-

7675.20 mg kg^{-1} and representing about 89.23-93.30% of total K in the soils. This range reported is low compared with ranges of about 5000-25000 mg kg^{-1} for soils of K bearing minerals in Lebanon (Yawson et al., 2011) and 14531.1-14861.9 mg kg^{-1} for sedimentary and basement complex soils of southwestern Nigeria (Adepetu, 1988). The percent mineral or structural K to the total K content reported is consistent with a range of 90-98% noted for soils (Sparks, 2000). Mineral or structural K consists of K fraction that is bonded within the crystal structures of soil minerals especially feldspars and micas particles that are usually only slowly available to plants, with the degree depending on the levels of K in the other K fractions and the degree of weathering (Sparks and Huang, 1985; Sparks, 1987). Thus, the low content of this K fraction in the soils studied indicates that these minerals particularly, feldspars and micas may be absent. Concentrations of mineral K in the top (0-15 cm) and sub soil (15-30 cm) consisted of 86.25 and 95.59, 93.80 and 98.88, 96.71 and 95.91 and 84.86 and 93.48% of total K, with means equivalent to 90.60, 90.08, 93.30 and 89.23% of total K for cassava, fallow, oil palm and pineapple respectively. Distribution of this fraction with soil depth was similar as the total K, with least mean concentration also in fallow land use.

Non-exchangeable K ranged from 0-2.25 cmol (+) kg^{-1} equivalent to 0-877.5 mg kg^{-1} or 0-0.09% of total K in the soils. This range is within values of about 10-570 mg kg^{-1} obtained for sedimentary and basement complex rocks in southwestern Nigeria (Adepetu et al., 1988), 139.8-696.9 mg kg^{-1} for paddy and non paddy soils of Iran (Raheb and Heidari 2011) and 50-750 mgkg^{-1} for mineral soils (Yawson et al., 2011) but high relative to a range of 0.05-0.44 cmol (+) kg^{-1}) obtained for soils of varying lithologies (shale, upper coal measure and lower coal measure) in southeastern, Nigeria (Ndukwu, et al., 2012). Non-exchangeable K represents K held between adjacent tetrahedral layers of dioctahedral and trioctahedral micas, vermiculites, and intergrade clay minerals such as chloritized vermiculite (Rich, 1972; Sparks and Huang, 1985; Sparks, 1987) and contributes significantly to K supplying capacity of soils (Adepetu et al., 1988). Its concentration in the top and sub soils included about 8.05 and 3.91, nil and nil, 1.23 and 1.61 and 12.86 and 3.62% of total K in cassava, fallow, oil palm and pineapple land use types respectively (Table 3) with sub soil concentrations non significantly (LSD 0.05) lower than the top soil in most land uses. Decreased non-exchangeable K with soil depth has been reported (Ngwe et al., 2012). Mean concentrations amongst land uses included 0, 0.28, 0.93 and 1.45 cmol (+) kg^{-1}for fallow, oil palm, cassava and pineapple land uses respectively indicating that fallow land use is devoid of non-exchangeable K in the soils.

Concentrations of exchangeable K ranged from 0.12-0.91 cmol (+) kg^{-1} equivalent to 0.05-0.35 g kg^{-1} or 46.8-354.9 mg kg^{-1} in the soils and consistent with a range of 45. 0-223.5 mg kg^{-1} (Adepetu et al., 1988) but high compared with ranges of -7.1-186.7 mg kg^{-1} (Agboola and Omueti, 1983), 26.13-164.90 mg kg^{-1} (Raheb and Hendari, 2011) and 19.32-130.53 mg kg^{-1} (Ngwe et al., 2012). Percentage exchangeable to total K varied as 5.63 and 0.40, 5.86 and 1.03, 2.01 and 2.47 and 2.17 and 2.79% in the top and sub soils respectively, with mean values of 3.18, 3.77, 2.26 and 2.48% for cassava, fallow, oil palm and pineapple land uses respectively (Table 3) and indicating a significant (LSD 0.05) decrease with depth in cassava and fallow and a non distinct (LSD 0.05) increase with depth in pineapple and oil palm land use types, with mean concentrations higher in fallow compared to the other land uses. Also exchangeable K constituted about 98.91 and 71.43, 100.0 and 92.31, 97.62 and 100.0 and 95.0 and 96.15% of available K in the top and sub soils respectively, with means of 96, 100, 100 and 95.65% available K in cassava, fallow, oil palm and pineapple land uses respectively. This showed that exchangeable K constituted a significant proportion of the soils available K as have been indicated by others (Ngwe et al., 2012). Critical exchangeable K value of 0.2 Cmol kg^{-1} (0.078g kg^{-1} or 78 mg kg^{-1}) has been reported for southeastern Nigeria soils (Enwezor et al., 1990). This indicates that apart from sub soils of cassava and fallow land uses, K deficiency may not be a major problem in the soils studied.

Solution K concentrations ranged from 0.002-0.022 Cmol (+) kg^{-1} equivalent to 0.001-0.009 g kg^{-1} or 0.78-8.58 mg kg^{-1} in the soils. Other workers have reported values of 0.24 Cmol kg^{-1} for west African soils (Juo, 1981), 35.2-229.7 mg kg^{-1} for soils of savanna zone of Western Nigeria (Agboola and Omueti, 1983), 1-11.2 mg kg^{-1} for major Lebanese agricultural soils (Al-Zubaidi et el., 2008) and 1.56-17.94 mg kg^{-1} for paddy and non paddy rice soils in Iran (Raheb and Heidari, 2011). These values are high relative to those reported for the soils studied, indicating that solution K constitutes an insignificant fraction of K available for plant uptake or leaching in the various land use types. Also compared to the critical K value of 0.5 Mml^{-1} proposed by the International Potash Institute (IPI, 2000), values reported for the soils are very low to appreciably support crop growth (Al-Zubaidi et el., 2008). Percentage solution to total K in the soils included 0.06 and 0.16, 0.013 and 0.06, 0.059 and 0.054 and 0.091 and 0.095% in the top and sub soil depths respectively, and with mean values equivalent to 0.11, 0.05, 0.06 and 0.10 % for cassava, fallow, oil palm and pineapple land uses respectively, indicating that the least concentration was in fallow land use type. Compared to the other soil K fractions, solution K concentration was the lowest (Table 3). It has been indicated that levels of solution K is generally low except in soils that have been recently amended with K fertilizers (Sparks and Huang, 1985; Sparks 2000). The forms of soil K in the order of their availability to plants and microbes has been reported to decrease in the order solution > exchangeable > fixed (non-exchangeable) > mineral (Sparks and Huang, 1985; Sparks, 1987; Sparks, 2000).

Available K consisted of the summation of solution K and exchangeable K and ranged from 0.40-0.92 Cmol (+) kg^{-1} equivalent to 0.16-0.36 g kg^{-1} or 156.00-358.80 mg kg^{-1}(Table 3). These values are consistent with a range of 38.3-380 mg kg^{-1} for savanna soils of western Nigeria (Agboola and Omueti, 1983) but low relative to ranges of about 132.74 to 546.59 mg kg^{-1} for soils under banana land use in Ethiopia (Ayele, 2013) and 49.70-803.14 for low land vertisols under rice in tropical savanna climate of Thailand soils (Ngwe et al., 2012). Percentage available K to total K content of the soils varied as 5.70 and 0.50, 5.89 and 1.12, 2.06 and 2.47 and 2.29 and 2.90% and means of 3.31, 3.77, 2.29 and 2.59% in the top and sub soils of cassava, fallow, oil palm and pineapple land uses respectively. Mean available K content of soils of the various land use types were 0.50, 0.50, 0.44 and 0.46 Cmol(+)$kg^{-1}$for cassava, fallow, oil palm and pineapple and increased sequence in the order oil palm < pineapple < fallow = cassava.

3.3 Intercorrelationship Amongst various K forms and between K forms with soil Available K

Relationships amongst the various K forms (Table 4), showed that available K was highly significantly ($P \leq 0.01$) correlated with exchangeable K (r = 1.00) and not seriously ($P \leq 0.05$) correlated with non-exchangeable K (r = 0.24), solution K (r = -0.36), total K (r = 0.16) and structural K (r = -0.06). Also exchangeable K was not distinctly ($P \leq 0.05$) correlated with non-exchangeable K (r = 0.23), solution K (r = -0.37), total K (r= 0.16) and structural K (r = -0.06). There was equally no distinct ($P < 0.05$) relationship between non-exchangeable K with solution K (r = 0.34), total K (r = 0.11) and structural K (r=-0.20).Furthermore, whereas solution K was none significantly ($P \leq 0.05$) correlated with total K (r = 0.08) and structural K (r = 0.04), there was serious ($P \leq 0. 01$) correlation between total K and structural K (r = 0.94). The poor relationships amongst most K forms indicate that they probably do not have serious influence on one another. Other workers have reported significant (($P \leq 0.05$) correlation between soil available K and exchangeable K (Ayele 2013) and between $HN0_3$ extractable K with non-exchangeable, exchangeable and total K (Ngwe et al., 2012).

Regression models explained the relationship between available K and most soil K forms (Table 4). A regression equation of the form Y = 0.014 + 0.99 X indicated that exchangeable K accounted for about 51% of the soil available K. Also a regression equation of the form Y = 0.39 + 0.13 X explained that 39% of the soil available K was due to non-exchangeable K. Equally a regression model of the form Y = 0.08 + 0.02 X showed that total K was responsible for 97% of the available while that of the form Y = 0.62 – 0.01X showed that 96% of available K was accountable by structural K. The slope of the regression models confirmed the importance exchangeable K (+ 0.99), none-exchangeable K (+0.13), total K (+ 0.02) and structural K (- 0.01) to the soil available K status. The negative relationship with structural or mineral K could be due to the absence of K in the mineralogy of the soils or losses due to intense weathering or the tenacity with which mineral K was held and which made them sparingly available in the soils. It has been noted that soil K status and availability depends on the degree of soil and mineral weathering (Al-Zubaidi et al., 2008).

3.4 Correlation between Selected Soil Properties and Soil K forms

Simple correlation between selected soil properties and soil K forms are presented in Table 5. Total K was seriously ($P \leq 0.05$) correlated with % BS (r = 0.38), exchangeable Na (r = -0.43), exchangeable Ca (r = 0.48), clay content (r = -0.59), silt/clay ratio (r = 0.52) and silt content (r = 0.42) but none distinctly ($P \leq 0.05$) with soil OM (r = -0.12), pH (r = 0.22), ECEC(r = 0.21), Mg (r = 0.12), H (r = -0.20) and sand (r = -0.01). Besides exchangeable Na (r = -0.50), exchangeable Ca (r = 0.45), clay content (r = -0.47) and silt/clay ratio (r = 0.39) that correlated distinctly ($P \leq 0.05$) with structural K, there was no serious relationship between OM (r = -0.02), pH (r = 0.13), ECEC (r = 0.16), % BS (r = 0.32), Mg (r = 0.06), H (r = -0.20), sand (r = 0.19) and silt (r = 0.33) with structural K. Non-exchangeable K correlated significantly with sand content (r = -0.48) only but not with OM (r =-0.21), pH (r = 0.29), ECEC (r = 0.07), % BS (r = 0.36), Na (r= 0.30), Ca (r = 0.15), Mg (r = 0.06), H (-0.17), clay (r = -0.35), silt/clay ratio (r = 0.23) and silt (r = 0.09). Correlation between exchangeable K with silt/clay ratio (r = 0.39) and silt content (r = 0.39) were significant whereas that with OM (r = -0.29), pH (r = 0.02), ECEC (r = 0.17), % BS (r = -0.27), Na (-0.08), Ca (r = -0.08), Mg (r = 0.29), H (r = 0.28), clay (r = -0.13) and sand (r = -0.37) were none distinct ($P \leq 0.05$). Also apart from silt/clay ratio (r = 0.40) and silt contents (r = 0.39) that correlated seriously with available K there was no serious relationship between soil OM (r = -0.29), pH (r = 0.02), ECEC (r = 0.18), %BS (r = -0.27), Na (r = -0.09), Ca (r = -0.08), Mg (r = 0.29), H (r = 29), clay (r = -0.16) and sand (r = -0.11) with available K. Equally, solution K was significantly ($P \leq 0.05$) correlated with ECEC (r =0.38) and Ca (r = 0.40) but not with OM (r = 0.15), pH (r = 0.30), Na (r = 0.32), Mg (r = 0.20), H (r = 0.04), clay (r = -0.20), silt/clay ratio (r = 0.27), sand (r = -0.18) and silt (r = 0.21). Relationship between soil properties and K forms has been reported by other workers. Strong ($P \leq 0.05$) relationship has been reported between available K and soil pH, electrical conductivity, silt, exchangeable Mg but not with soil OC, total nitrogen, available P, clay, Ca and CEC (Ayele, 2013). Also significant ($P \leq 0.05$) correlation has been reported between fixed K with clay content, silt/clay ratio and CEC (Al-Zubaidi et al., 2008). Furthermore, distinct ($P \leq 0.05$) correlationship has also been reported between soil organic matter and exchangeable K and between silt content with non-exchangeable and $HN0_3$ extractible K (Ngwe et al., 2012).

3.5 Potassium Exchange and Fixation Capacity

Potassium exchange and fixation capacity of the soils varied with added K for the various land use types (Table 6). Potassium exchange capacity ranged from 1.55-3.30, 0.45-2.90 and 3.75-9.75 Cmol (+) kg^{-1} with the addition of 4, 8 and 16 mgs KCl respectively. Variation in K exchange capacity was an increased concentration with depth at 4 mg KCl rates in all but oil palm land use, increased concentration with depth at 8 mgs KCl in all but fallow and increased content in fallow and pineapple and a reverse decrease in cassava and oil palm at 16 mgs KCl. Mean K exchange capacity at 4 and 8 mgs KCl was higher in pineapple while that at 16 mgs KCl was in cassava. Best K exchange capacity was at the highest application rate (16 mgs KCl). Averaged over K application rates, capacity for K exchange decreased in the order cassava (4.07 Cmol (+) kg^{-1}) > pineapple (3.66 Cmol (+) kg^{-1}) > fallow (3.50 Cmol (+) kg^{-1}) > oil palm (2.59 Cmol (+) kg^{-1}) indicating that best K exchange capacity was in cassava and the least in oil palm land use types. Variation in K exchange capacity with land use types could be due to factors imposed by the soil properties. It has been indicated that soil properties vary with land use types (Uzoho et al., 2007).

Soil K fixation capacity ranged from 0-1.15, 0.30-2.10 and 0-2.35 Cmol (+) kg^{-1} at 4, 8 and 16 mgs KCl application rates respectively. Potassium fixation capacity decreased with depth in fallow and pineapple but increased with depth in cassava and oil palm land uses at 4 mgs KCl. Distribution at the 8 mgs KCl rate was a reverse trend of the 4 mgs KCl application rate while that at 16 mgs KCl was increased concentration with depth in cassava and pineapple and a decrease in fallow and oil palm land uses. Mean K fixation capacity varied as 0.08, 0.25, 0.03 and 0.58, 0.65, 0.85, 0.80 and 1.98 and 0.93, 2.23, 0.95 and 1.95 Cmol (+) kg^{-1} at 4, 8 and 16 mgs KCl in cassava, fallow, oil palm and pineapple land uses respectively. This showed that K fixation was better at 4 and 8 mgs KCl rates in pineapple and at 16 mgs KCl rate in oil palm land use type. Averaged over K application rates, K fixation capacity decreased in the order pineapple (1.36) > fallow (1.11) > oil palm (0.59) > cassava (0.55) with pineapple being the best and cassava the least capacity for K fixation. Variation in K fixation capacity has been reported to depend on the type of clay mineral and its charge density, degree of interlaying, moisture content, concentration of K ions as well as concentration of competing cations and the pH of the ambient solution bathing the clay or soil (Sparks and Huang, 1985).

4.0 Conclusions

Soils of the various land use types varied with respect to their properties but generally, coarse textured, acidic, low OM and nutrient (N, P, Ca, Mg and K) contents, poorly aggregated and of low clay activity. Concentrations of total and K forms were low and varied with soil depths, with fallow land use having the least. Potassium availability in the soils was influenced in the order exchangeable > non-exchangeable > total > structural or mineral K. Soil K forms were poorly intercorrelated with each other exceptions being that between exchangeable K with available K and structural K with total K. Potassium status of the soils was affected by soil properties especially sand, silt, clay, silt/clay ratio, OM, pH, total N, P, Ca, Mg, ECEC, % BS, Na and H contents. Addition of K fertilizer increased K fixation capacity with increased rates but with pattern for K exchange capacity irregular, though highest at the highest application rate. In general, periodic evaluation of soil K status is necessary in planning for rational K fertilizer management and for the control of K pollution of the environment.

5.0 References

Adepetu,J.A, M.T.Adetunji, J.C.Aguiyi and S.A.Alubankudi 1988. Contribution of non-exchangeable K to the K supplying capacity of south western Nigeria, soils. Nigeria Journal of Soil Science 8:47-62.

Agboola, A.A and J.A.I. Omueti, 1983. Potassium status in soils of the savannah zone of western, Nigeria. Nigerian Journal of Soil Science 4:12-21.

Al-Zubaidi, A S. Yanni1, and I. Bashour 2008. Potassium status of some Lebanese soils. Lebanese Science Journal, 9 (1): 81-97

Ano, A.O. 199. Potassium status of the Nigerian Coastal Plain Sands. Journal of Potassium Research 7:247-254.

Ayele, T 2013. Potassium Availability under Banana- Based Land Use Systems in Ab Chamo Lake Basin, South-west Ethiopia. International Journal of Scientific Research and Reviews 2(2): 94-108

Bremner J.M, 1996. Nitrogen-total, in Methods of Soil Analysis. Part 3. Chemical Methods, Vol. 5 of Soil Science Society of America Book Series, ed. by Sparks DL. Soil Science Society of America/American Society of Agronomy, Madison, WI, pp. 1085–1122.

Buysse, W, R.Stern and R.Coe 2004. Genstat Discovery Edition for everyday use. ICRAF Nairobi, Kenya 114 pp.

Enwezor, W.O, A.C.Ohiri, E.E.Opowaribo and E.J.Udo1990. A review of soil fertilizer use for crops in southereastern zone of Nigeria (in five volumes). Produced by the Federal

MinistryofAgricultureand Natural Resources Lagos.

Essoka, A.N and I.E.Esu 2000. Profile distribution of sesquioxides in the inland valley soils of Central Cross River State, Nigeria. Proceedings of the 26th Annual Conference of the Soil ScienceSocietyof Nigeria, Ibadan, Oyo State, 30th Oct-4th November, 2000.pp24-31.

Gee, G.W and D. Or. 2002. Particle size distribution. In Dane, J/H and G.C.Topp (eds). Methods of soil analysis. Part 4. Physical and mineralogical methods. Soil Science Society of America book series. No.5 ASAS and SSA. Madison, Wisconsin. p 255-293.

IPEDC (Imo State Planning and Economic Development Commission) 2006. Imo state of Nigeria statistical year book. Published by Imo State Planning and Economic Development Commission, State Secretariate, Portharcourt road, 282pp.

IPI (International Potash Institute) 2001. Potassium dynamics and its availability. International Fertilizer Correspondent, pp. 1 – 5.

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice Hall Inc. Englewood Cliffs, N.J.

Jackson, M.L. 1979. Soil Chemical Analysis. Advanced course, 2nd. Published by the author, Madison, Wisconsin.

Juo, A.S.R. 1981. Chemical characteristics. p. 51-79. In D. J. Greenland (ed.). Characterization of soils in relation to their classification and management for crop production: Examples from some areas of the humid tropics. Clarendon Press, Oxford, UK.

Lakudzala, D.D 2013. Potassium response in some Malawi soils. International Letters of Chemistry, Physics and Astronomy 8(2) (2013) 175-181.

Lauchli, A and R. Pfluger 1979. Potassium transport through plant cell membranes and metabolic role of K in plants. Potassium Research, Review and Trends, Int. Potash Institute, Berne, Switzerland. p. 33.

Martin, H.W. and Sparks, D.L. 1983. Kinetics of non-exchangeable potassium in soils. Communication in Soil Science and Plant Analysis 16: 133 – 162.

Mbah, C.N 2008. Contributions of organic amendments to exchangeable potassium percent and soil nitrate concentration in an Ultisol and their effect on maize (Zea mays L) grain yield. Agro-Science Journal of Tropical Agriculture, Food, Environment and Extension 7(3): 206 – 210.

Nelson DW and LE Sommers 1996.Total carbon, organic carbon and organic matter, in Methods of Soil Analysis. Part 3. Chemical Methods, Vol. 5 of Soil Science Society of America Book Series,ed. by Sparks DL. Soil Science Society of America/American Society of Agronomy, Madison, WI, pp. 96–101.

Ndukwu B. N. M. C. Chukwuma, C. M .Idigbor and S. N. Obasi 2012. Forms and distribution of potassium in soils underlain by three lithologies in southeastern, Nigeria. International Journal of Agriculture and Rural Development 15 (2): 1104 – 1108

Ngwe, K, Irb K and A. Suddhiprakarn 2012. Potassium Status and Physicochemical and Mineralogical Properties of Lowland Vertisols in a Rice-Based Cropping System under Tropical Savanna Climate. Kasetsart Journal (Natural Science.) 46: 522 – 537

Nwaka, G.K and J.J. Kwari 2000. The nature and properties of the soils of Jere Bowl in Bornu State. Samaru Journal of Agriculture and Natural Resources 16: 25-40.

Oguike,P. C and J.S.C. Mbagwu 2009 Variations in Some Physical Properties and Organic Matter Content of Soils of Coastal Plain Sand under Different Land Use Types. World Journal of Agricultural Sciences 5 (1): 63-69, 2009

Opara-Nadi, O.A 1988. Liming and organic matter interactions in two Nigerian Ultisols on soil pH, organic matter and early growth of maize (Zea mays)

Orajiaka, S.O 1975. In Ofomata G.E.K (ed), Nigeria in maps; Eastern states. Ethiope Publishing house, Benin City. Pp 5-7

Pratt, P.F. 1965. Potassium. In C.A. Black et al. (ed). Methods of soil analysis, part 2. Agronomy 9: 1023 – 1031. American Society of Agronomy, Madison, Wisconsin.

Raheb, A and A. Heidari 2011. Clay mineralogy and its relationship with potassium forms in some paddy and non-paddy soils of northern Iran. Australian Journal of Agricultural Engineering 2(6):169-175 (2011) Rehm, G and M. Schmitt 2002. Potassium for crop production. University of Minnesota Extension. http://www. extension.umn.edu/distribution/crop systems/DC6794.html.

Rich, C.I. 1972. Potassium in minerals. Proceedings of Colloquim of International Potash Institute 9: 15-31.

Sadusky, M.C, D.L. Sparks, M.R. Noll and G.J. Hendricks, G. 1987. Kinetics and mechanisms of potassium release from sandy soils. Soil Science Society of America Journal 51: 1460-1465.

Sparks, D.L. 1987. Potassium dynamics in soils. Advances in Soil Science 6: 1-63.

Sparks, D.L. 2000. Bioavailability of soil potassium, D-38-D-52. In M.E. Sumner (ed.) Handbook of Soil Science, CRC Press, Boca Raton, FL.

Sparks, D.L. and Huang, P.M. 1985. Physical chemistry of soil potassium. p. 201-276. In R.D. Munson (ed.) Potassium in agriculture. American Society of Agronomy, Madison, WI.

Soil Survey Staff 1999. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. 2nd Edition. USDA-NRCS Agric. Handbook 436. U.S Govt. Printing Office, Washinton, DC. Thomas 1996,G.W. Soil pH and soil acidity, In D.L.Sparks, A.L.Page, P.A.Helmke, R.H.Loeppert, P.N.Soltanpour, M.A.Tabatabai, C.T.Johnson and M.E.Summer (eds.). Methods of soil analysis. Part 3. Chemical Methods. Soil Science Society of America, Inc,and American Society of Agronomy, Maidson, WI.USA, PP 475-490.

Unamba-Oparah, I.1985. The potassium status of sandy soils of Northern Imo State, Nigeria. Soil Sciences. 139 (5): 437- 445.

Uzoho, B.U, N.N.Oti and A. Ngwuta 2007. Fertility status under Land use Types on Soils of Similar Lithology. Journal of American Science 3 (4): 20-29.

White, J.R, M.J.Bell and N.W.Marzies 2006. Effect of subsoil acidity treatments on the chemical properties of a ferrosol. Proceedings of Agronomic Conference of Australia, 10th-15th September, 2006pp10-15.

Yawson, D. O, P. K. Kwakye, F. A. Armah and K.A. Frimpong 2011. The dynamics of potassium (K) in representative soil series of Ghana. ARPN Journal of Agricultural and Biological Science 6(1): 48-55.

Table 1.Selected Physical Properties of the studied Soils

Land uses	Soil Depth	$Sand_c$	$Sand_{H20}$	$Silt_c$	$Silt_{H20}$	$Clay_c$	$Clay_{H20}$	Si/Cl ratio$_c$	Si/Cl ratioH$_20$	DR	ASC	CFI	CDI
	cm			g kg^{-1}							g kg^{-1}		
Cassava	0-15	870	937	46	30	85	28	0.54	1.11	444	73	671	329
	15-30	844	890	30	53	125	59	0.26	0.92	723	43	524	476
	Mean	**857**	**913**	**38**	**41**	**105**	**44**	**0.40**	**1.02**	**596**	**58**	**583**	**417**
Fallow	0-15	842	940	45	23	107	37	0.42	0.32	397	92	651	349
	15-30	862	932	50	26	87	42	0.61	0.62	495	69	514	486
	Mean	**852**	**936**	**48**	**24**	**97**	**40**	**0.52**	**0.47**	**444**	**80**	**590**	**410**
Oil Palm	0-15	855	935	51	30	90	38	0.63	1.03	488	72	572	428
	15-30	821	932	96	23	87	35	1.04	0.66	316	125	594	406
	Mean	**838**	**933**	**73**	**26**	**88**	**37**	**0.84**	**0.85**	**390**	**99**	**583**	**417**
Pineapple	0-15	832	930	46	26	72	45	0.66	0.61	599	47	378	622
	15-30	832	945	81	21	87	35	0.90	0.69	331	112	600	400
	Mean	**832**	**937**	**63**	**23**	**80**	**40**	**0.78**	**0.65**	**441**	**80**	**499**	**501**
	LSD 0.05	10.69	3.14	7	1.3	3.78	2.64	0.83	0.83	3.67	6.84	3.02	6.98
	% CV	5.3	1.4	53.4	19.1	17.3	27.9	55.7	47.5	66.48	23.7	61.27	16.1

C = Calgon, Si/ Cl ratio= Silt/ Clay ratio, DR = Dispersion ratio, ASC = Aggregated silt, clay, CFI = Clay flocculation index and CDI = Clay dispersion index

Table 2. Selected Chemical Properties of the Studied Soils

Land use	Soil Depth cm	pH (H_20)	Avail P mg Kg^{-1}	TN g Kg^{-1}	OM	Ca	Mg	K	Na	H	ECEC	BS %
						Cmol(+)Kg^{-1}						
Cassava	0-15	5.37	0.91	0.90	18.70	1.22	0.40	0.02	0.10	0.18	1.92	89.9
	15-30	5.32	0.84	0.80	16.70	1.12	0.37	0.01	0.06	0.26	1.82	87.7
	Mean	**5.35**	**0.88**	**0.85**	**17.70**	**1.17**	**0.39**	**0.02**	**0.08**	**0.22**	**1.87**	**88.8**
Fallow	0-15	5.16	4.66	1.10	22.70	0.71	0.54	0.01	0.10	0.38	1.74	76.2
	15-30	5.05	2.87	1.10	21.00	0.56	0.39	0.01	0.15	0.64	1.75	66.3
	Mean	**5.11**	**3.77**	**1.10**	**21.85**	**0.64**	**0.47**	**0.01**	**0.13**	**0.51**	**1.73**	**71.3**
Oil Palm	0-15	5.15	1.89	1.00	18.90	1.40	0.76	0.01	0.06	0.28	2.51	82.4
	15-30	5.07	0.77	0.60	11.70	1.13	0.74	0.01	0.08	0.20	2.16	88.9
	Mean	**5.11**	**1.33**	**0.80**	**15.30**	**1.27**	**0.75**	**0.01**	**0.07**	**0.24**	**2.35**	**85.7**
Pineapple	0-15	5.40	2.00	2.20	43.30	2.10	1.08	0.02	0.12	0.22	3.54	89.0
	15-30	5.33	1.93	0.80	15.50	1.25	0.41	0.02	0.10	0.88	2.66	80.9
	Mean	**5.37**	**1.97**	**1.50**	**29.40**	**1.68**	**0.75**	**0.02**	**0.11**	**0.55**	**3.10**	**85.0**
	LSD 0.05	0.54	1.56	0.17	3.47	1.01	1.44	0.01	0.19	0.68	2.49	29.9
	% CV	4.40	33.30	69.70	69.70	36.00	103.5	23.50	84.0	75.9	46.4	15.3

Avail P = Available P, TN = Total nitrogen, OM = Organic matter, ECEC = Effective cation exchange capacity and BS = Base saturation

Table 3. Potassium Forms of the Studied Soils (Cmol(+)kg^{-1}

Land use	Soil Depth (cm)	Total K	Structural K	Non-exch. K	Exch. K	Available K	Solution K
Cassava	0-15	16.15	13.93	1.30	0.91	0.92	0.009
	15-30	14.05	13.43	0.55	0.05	0.07	0.022
	Mean	**15.10**	**13.68**	**0.93**	**0.48**	**0.50**	**0.016**
Fallow	0-15	14.85	13.93	0.00	0.87	0.87	0.002
	15-30	11.65	11.52	0.00	0.12	0.13	0.009
	Mean	**13.25**	**12.73**	**0.00**	**0.50**	**0.50**	**0.006**
Oil Palm	0-15	20.35	19.68	0.25	0.41	0.42	0.012
	15-30	18.60	17.84	0.30	0.46	0.46	0.01
	Mean	**19.48**	**18.76**	**0.28**	**0.44**	**0.44**	**0.011**
Pineapple	0-15	17.50	14.85	2.25	0.38	0.40	0.016
	15-30	17.95	16.78	0.65	0.50	0.52	0.017
	Mean	**17.73**	**15.82**	**1.45**	**0.44**	**0.46**	**0.017**
	LSD 0.05	3.84	5.13	1.36	1.22	1.22	0.01
	% CV	9.90	14.20	86.90	112.10	109.40	23.5

Exch = Exchangeable

Table 4. Simple Correlation between K Forms and Regression Equation of Available K and K forms

A. Correlation Coefficient of K forms

	Available K	Exch. K	Non-Exch.	Solution K	Total K	Structural K
Available K	-					
Exch. K	1.00	-				
Non- Exch. K	0.24	0.23	-			
Solution K	-0.36	-0.37	0.34	-		
Total K	0.16	0.16	0.11	0.08	-	
Structural K	-0.06	-0.06	-0.20	0.04	0.94	-

B. Regression Equation of Available K and K forms

Parameter	Regression Equation	r^2
Available K vs. Exch. K	Y = 0.014 + 0.99 X	0.51
‘’ vs. Non-Exch.	Y = 0.39 + 0.13 X	0.39
‘’ vs. Total K	Y = 0.08 + 0.02 X	0.97
‘’ vs. Structural K	Y = 0.62 - 0.01X	0.96

Table 5. Correlation Coefficient of Selected Soil Properties and K Forms

Parameters	Total K	Structural K	Non exch. K	Exch. K	Available K	Solution K
OM	-0.12ns	-0.02ns	-0.21ns	-0.29ns	-0.29ns	0.15ns
pH	0.22ns	0.13ns	0.29ns	0.02ns	0.02ns	0.30ns
ECEC	0.21ns	0.16ns	0.07ns	0.17ns	0.18ns	0.38*
%BS	0.38*	0.32ns	0.36ns	-0.27ns	-0.27ns	0.32ns
Na	-0.43*	-0.50*	0.30ns	-0.08ns	-0.09ns	-0.03ns
Ca	0.48*	0.45*	0.15ns	-0.08ns	-0.08ns	0.56*
Mg	0.12ns	0.06ns	0.06ns	0.29ns	0.29ns	0.20ns
H	-0.20ns	-0.20ns	-0.17ns	0.28ns	0.29ns	0.04ns
Clay	-0.59*	-0.47*	-0.35ns	-0.13ns	-0.16ns	-0.20ns
Silt/Clay ratio	0.52*	0.39*	0.23ns	0.39*	0.40*	0.27ns
Sand	-0.01ns	0.19ns	-0.48*	-0.37ns	-0.11ns	-0.18ns
Silt	0.42*	0.33ns	0.09ns	0.39*	0.39*	0.21ns

Exch. = Exchangeable,
ns = Non significant,
* = Significant P <0.05

Table 6. Potassium Exchange and Fixation Capacities (Cmol (+) kg^{-1})

Land use	Soil depth (cm)	K Exchange Capacity			K Fixation Capacity		
		4	8	16	4	8	16
Cassava	0-15	1.60	1.65	9.75	0.00	0.35	0.00
	15-30	2.95	2.55	5.90	0.15	0.95	1.85
	Mean	**2.28**	**2.10**	**7.83**	**0.08**	**0.65**	**0.93**
Fallow	0-15	2.70	2.30	5.95	0.40	1.40	2.35
	15-30	2.80	0.95	6.30	0.10	0.30	2.10
	Mean	**2.75**	**1.63**	**6.13**	**0.25**	**0.85**	**2.23**
Oil Palm	0-15	2.65	0.45	4.95	0.00	0.70	1.20
	15-30	1.55	2.20	3.75	0.05	0.90	0.70
	Mean	**2.10**	**1.33**	**4.35**	**0.03**	**0.80**	**0.95**
Pineapple	0-15	2.50	2.25	4.35	1.15	2.10	1.40
	15-30	3.30	2.90	6.60	0.00	1.85	1.65
	Mean	**2.90**	**2.58**	**5.48**	**0.58**	**1.98**	**1.53**
	LSD 0.05	3.50	1.74	7.59	0.30	1.17	1.16
	% CV	59.00	38.60	54.00	0.71	46.40	34.90