FORMS, AVAILABILITY AND FIXATION OF POTASSIUM (K) IN THE SOILS OF DERIVED SAVANNAH OF NORTH CENTRAL NIGERIA

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ABSTRACT

The study was carried out to determine the distribution of different forms of K, its availability and K-fixation in the soils of Abuja. To achieve these objectives, seven areas within the six area councils of the FCT were selected and in each area two locations were selected giving a total of fourteen (14) locations sampled. The soil samples were collected at two predetermined depths of 0 – 30 and 30 – 60 cm,s giving a total of twenty-eight (28) samples. The collected soil samples were prepared and analysed in the laboratory following standard laboratory procedures. The result showed that the exchangeable K in the soils ranged from 0.17 – 0.30 cmol/kg. The highest mean content of exchangeable K was observed in the soils of Airport road (0.30 cmol/kg) while the least was observed in the soils of Bwari (0.17 cmol/kg). The range of values for the exchangeable K was interpreted as low to moderate. The distribution in the mean of the exchangeable K in the soils is in the order Airport Road > Abaji area > Kwali area > Karshi area > Gwagwalada area > Kuje > Bwari area. while the mean distribution of H2O extractable K ranged from 0.18 – 1.86 cmol/kg. The trend in the distribution of the hot water extractable K in the soils across the seven locations is as follows: Kwali area > Gwagwalada Area > Abaji area > Bwari area > Karshi area > AirportRroad > Kuje area. The mean value for the soils of Kwali was relatively higher followed by the soils of Gwagwalada while the soils of Airport Road and Kuje area were the least. The status of NH_4OAc extractable K ranged 0.010 – 0.032 cmol/kg. The mean distribution of ammonium extractable K in the soils was in the order: Bwari area > Karshi area > Kwali area > Airport Road > Gwagwalada = Kuje > Abaji. The mean for Gwagwalada area and Kuje soils was the same. The potassium fixation in the soil ranged from 0.010 – 0.24 cmol/kg and was interpreted as low to moderately high. It was concluded that further recommendation for K fertilizer in the soils should take into account the amount of K that is already fixed as a means of curtailing under supply of K Fertilizers to crops in the field.

Keywords: Potassium fixation, forms and availability, Derived Savanna.

INTRODUCTION

Plant nutrition is one of the most important factors that is worth considering. The soil resource is not only finite but also dynamic. Frequent changes in the behaviour of elemental nutrients within the soil has remained one of the limiting factors in crop production and soil sustainability (Ogbodo, 2011). Potassium is one of the major nutrients and also a most abundant element in soils, but the K content of the soil varies from place to place based on physicochemical properties of soil. Potassium exists in soil in different forms viz., water soluble, exchangeable, non-exchangeable (fixed), mineral K, lattice K and total K. But these forms are not homogeneously distributed in soils. Its amount in soil depends on the parent material, degree of weathering, K gains through manures and fertilizers and losses due to crop removal, erosion and leaching. Usually, the amounts of non-exchangeable and total K present in the soil are high compared to water soluble and exchangeable K. The concentration and availability of K in the soil is primarily controlled by inorganic processes. Though K does not pose the potential environmental concerns that nitrogen and phosphorus do, an understanding of K cycling and availability is important for the management of profitable long-term cropping systems (Zhao, *et al.,* 2010). The dynamics of potassium in soil depends on the magnitude of equilibrium among various forms and mainly governed by the physicochemical properties of soil. The bulk of soil potassium (about 98% of total K) usually exists in unavailable form in primary (micas and feldspars) minerals and secondary (illite group) clay minerals. The available K and exchangeable K in general are readily available to plants (Pyo, *et al*., 2010). The availability of K is affected by soil processes including physical, chemical, and biological ones. For example, K is fixed by the 2:1 layer silicates in soils, resulting in a decrease of the use efficiency of K fertilizer, though the amount of fixed K is dependent on the soil type and its property (Conti *et al.,* 2011). As a consequence, the newly fixed K is not available to immediate uptake by crops, but it may be slowly released and is then absorbed by crops in growing season under suitable conditions.

Potassium plays a fundamental role in plant function, especially in water-use efficiency and economy. It plays a particularly crucial role in a number of physiological processes vital to growth, yield, quality, and stress resistance of crops (Srinivasarao and Vittal, 2007). Potassium is required in large amounts for growing crops, but farmers in poor countries often do not fertilize their crops with K due to high costs, which lead to K deficiencies in large areas of farmland across the world (Srinivasarao *et al.,* 2014). It has become a limiting element in intensive agricultural production systems, where inadequate fertilizer K application has led to depletion of available soil K reserves.

Its fixation according to Adetunji *et al* (2014) refers to the process whereby K becomes wedged within the interlayer positions of certain clay mineral lattices. This phenomenon has profound influence on K availability. According to Foth (2006), the fixation of K is almost always associated with collapse of expanding 2:1 layer silicates following K saturation. This collapse will occur at lower solution and K activities and the fixed K will be less available. Agbede (2009) noted that the major clay minerals responsible for K fixation are montmorillonite, vermiculite and weathered micas. In acid soils, the principal clay mineral responsible for K fixation is vermiculite. Weathered micas fix K under moist as well as dry conditions. The degree of K fixation in soils depends on the type of clay mineral and its charge density, moisture content, competing ions, and soil pH. Montmorillonite, vermiculite, and weathered micas are the major clay minerals that tend to fix K (Sparks, 2011). The important forces involved in interlayer reactions in clays are electrostatic attractions between the negatively charged layers and the positive interlayer ions, and expansive forces due to ion hydration. Potassium is subjected to fixation by soil minerals, leading to reduced availability. Fixation involves the adsorption of K ions onto sites in the inter layers of weathered sheet silicates, such as illite and vermiculite. Additionally, soil wetting and drying also significantly affects the K fixation. The fixation process of K is relatively fast, whereas the release of fixed K is very slow due to the strong binding force between K and clay minerals (Oborn *et al.,* 2005). Whether a soil fixes or releases K depends on the K concentration in the soil solution (Schneider *et al.,* 2013).\

Materials and Methods

Study Area

The study was carried out in six area councils of the Federal Capital Territory (FCT), Abuja. The area is geographically situated within latitude 07^{o} $20^{`}$ and $09^{o}15^{I}$ N and longitude 06^{0} 45^{I} to $07^{o}39^{I}$ E. Abuja is the capital city of Nigeria located in the southern Guinea Savanna Agro ecological zone of North Central Nigeria and occupies an area of about 8,000 square kilometres.

The FCT has two main seasons – the rainy season (April to October) and the dry season (November to March). The high altitude and the undulating terrain of the territory act to provide a regulating influence on its weather. The daytime temperature can rise to about $32\text{-}38^{0}C$, while night time temperatures can be as low as 12 to 17^{0}. The rainfall pattern is unimodal and the mean annual rainfall ranges from 120 to 1600 mm. The rainfall is characteristic of the Guinea savannah and increases from north to south (FCT Annual Diary, 2016). Sunshine hours ranges from 6 – 10 hours per day from January to April/May. It drops to a mean of 4 hours per day in July/August largely due to increase in the cloud cover and start to rise again in September as a result of decrease in cloud cover (FCT Annual Diary, 2016).

Relative humidity in the area largely depends on the season; during the dry season, the atmosphere is very dry, with relative humidity ranging between 16 to 30% (November to May). During the rains, the atmosphere is well moist with atmospheric vapour. Relative humidity during the rainy season can be as high as 60 – 80%. The dense cloud cover during the rainy season and the reduced evapo-transpiration accounts for the high relative humidity recorded in the area (FCT Annual Diary, 2016

A visit to the area was carried out to mark sites for soil sampling. Two locations were selected in each area council of the FCT, however, in AMAC, four locations were selected. In all, fourteen (14) sampling locations were carefully selected and marked out during the reconnaissance survey.

Random auger borings were made around to form composite samples for each soil unit selected. The soil units were selected based on geological formation and current land use type. The predetermined depths of the auger borings were 0 – 30 cm and 30 - 60 cm. All collected samples were carefully and adequately labelled. The sites for sample collection were carefully georeferenced by picking coordinates using a Garmin GPS device. The latitudes, longitudes and elevations as well as description of each location were taken and recorded.

Samples preparation

The collected samples for routine analysis of physical and chemical properties were transported to the store room where they were carefully spread on cardboard papers for air-drying at room temperature. The air-dried samples were then gently crushed and passed through 2 mm sieve mesh. All materials that could not pass through the 2 mm sieve apertures were carefully washed and weighed and recorded as gravel. The sieved samples were re-bagged, coded and sent to laboratory for analysis.

Table 1: Location and sites of sample collection

Area Council	**Location**	**Latitude ° N**	**Longitude ° E**	**Geology**	**Parent material**	**Land use**
Abaji	L1 = Kekeshi Toto road	8.46945	6.96792	Basement Complex	Basalts	Arable
	L2 = Abuja-Lokoja road by NNPC, Abaji	8.48784	6.94192	Basement complex	Basalts	Arable
AMAC	L1=Orozo	8.89137	7.58049	Basement complex	Colluvium (granites)	Arable
	L2=Karishi Town	8.85844	7.60071	Basement complex	Granites	Arable
Airport Road	L1=Sauka village	8.96228	7.24046		Granite	Arable
	L2= Bill Clinton Avenue (sauka Airport)	8.98207	7.26645		Granite	Arable
Bwari	L1= Usman Dam Area	N=9.19207	7.39394	Basement complex	Granites	Arable
	L2 Bwari Town (Veritas Uni.) Pagwana bwari	9.28967	7.39141	Undifferentiated basement complex	Granite	Arable
Gwagwalada	L1= Dukpa	8.97075	7.08367	Undifferentiated basement complex	Granites	Arable
	L2=Paiko	8.98507	7.0949	Undifferentiated basement complex	Granites, magmatites	Cashew plantation
Kuje	L1= Chukuku	8.91556	7.13191	Basement Complex	Granites, Magmatities, schist	Fluted Pumpkim
	L2= Chibiri	8.89287	7.18491	Undifferentiated basement complex	Granites	Arable
Kwali	L1=Gada Biyu (flood plain)	8.60629	6.9128	Sedimentary basin	Alluvium	Arable
	L2=Big Sheda (kilankwa rd)	8.87885	7.06701	Basement complex		

Laboratory Analysis

Determination of K fixation (neK) and other K contents in the Soil

The fixed K (neK) content of the soils was determined using 1 $molL^{-1}$ hot HNO_3 extraction method developed by Helmke and Sparks (2000). A 2.5 g of finely ground soil sample was heated gently with 25 ml of 1 $molL^{-1}$ nitric acid (HNO_3) in an Erlenmeyer flask on a hot plate for 15 minutes. After cooling for 5 minutes, the sample was filtrated and the extract was diluted to 100 ml with 0.1 $molL^{-1}$ HNO_3. The K concentration was determined by the atomic absorption spectrophotometer (AA-6200: Shimadu, Kyoto Japan).

As the amount of K in the extract can be regarded as the sum of exchangeable K (exK) and neK, the amount of neK was calculated by subtracting the amount of K extracted with 1 $molL^{-1}$ ammonium acetate (NH_4OAc), i.e. the exK, from the amount of K in the HNO_3 extract.

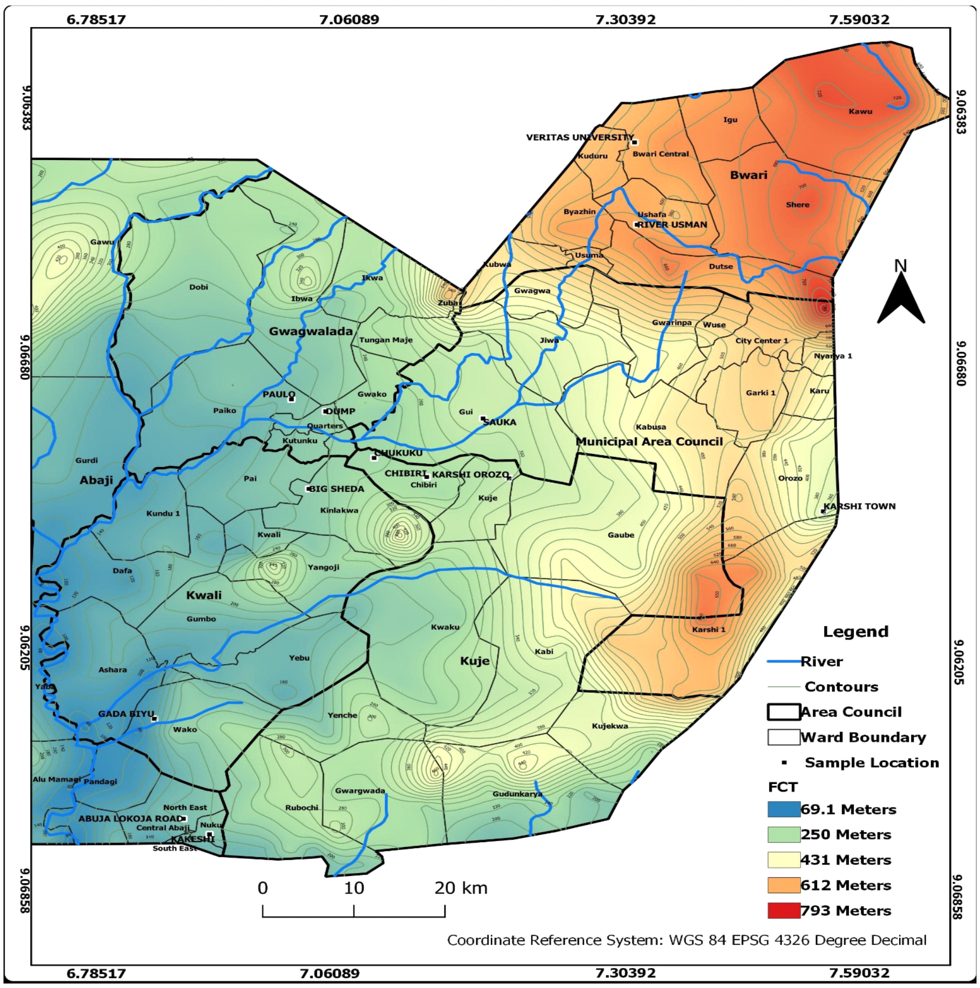

Fig 1: The map of F C T showing Sampling locations

Statistical Analysis

The generated data were subjected to statistical analysis using XLSTAT software (2010). The data was subjected to simple descriptive and mean comparison to determine the mean, standard deviation, standard error and coefficient of variation as described by Wilding *et al*, (1985)

Results and Discussions

Table 2 Forms of Potassium and Potassium Fixation

Area Council	Location	Depth Cm	K	H_2O Ext K	NH_4Ext K cmol/kg	Total K	K-Fixation
Abaji	L1	0-30	0.203	0.180	0.018	0.021	0.003
	L1	30-60	0.210	0.125	0.020	0.021	0.001
	L2	0-30	0.409	0.563	0.020	0.037	0.017
	L2	30-60	0.211	0.170	0.018	0.035	0.017
	Mean		***0.26***	***0.259***	***0.019***	***0.029***	***0.010***
	Sdv.		***0.101***	***0.204***	***0.001***	***0.009***	***0.009***
	C.V.		***38.85***	***78.76***	***5.26***	***31.03***	***90.00***
AMAC Karshi	L1	0-30	0.167	0.200	0.027	0.133	0.086
	L1	30-60	0.251	0.199	0.030	0.125	0.095
	L2	0-30	0.338	0.216	0.028	0.084	0.056
	L2	30-60	0.202	0.220	0.034	0.090	0.056
	Mean		***0.24***	***0.21***	***0.030***	***0.108***	***0.073***
	Sdv.		***0.074***	***0.011***	***0.003***	***0.025***	***0.020***
	C.V.		***30.83***	***5.24***	***10.00***	***25.00***	***27.40***
Airport Road	L1	0-30	0.185	0.164	0.027	0.065	0.038
	L1	30-60	0.218	0.205	0.022	0.096	0.074
	L2	0-30	0.384	0.238	0.023	0.027	0.004
	L2	30-60	0.414	0.188	0.025	0.035	0.007
	Mean		***0.30***	***0.20***	***0.024***	***0.056***	***0.031***
	Sdv.		***0.115***	***0.031***	***0.002***	***0.033***	***0.033***
	C.V.		***38.33***	***15.50***	***8.33***	***58.93***	***106.45***
Bwari	L1	0-30	0.205	0.178	0.025	0.068	0.043
	L1	30-60	0.134	0.251	0.023	0.097	0.074
	L2	0-30	0.184	0.335	0.044	0.199	0.155
	L2	30-60	0.167	0.192	0.036	0.242	0.206
	Mean		***0.17***	***0.24***	***0.032***	***0.15***	***0.12***
	Sdv.		***0.030***	***0.071***	***0.010***	***0.082***	***0.075***
	C.V.		***17.65***	***29.58***	***31.25***	***54.67***	***62.5***
Gwagwalada	L1	0-30	0.192	0.54	0.023	0.096	0.730
	L1	30-60	0.185	0.23	0.021	0.148	0.127
	L2	0-30	0.195	0.67	0.023	0.033	0.010
	L2	30-60	0.211	0.195	0.020	0.037	0.017
	Mean		***0.20***	***0.41***	***0.22***	***0.08***	***0.22***
	Sdv.		***0.011***	***0.233***	***0.002***	***0.055***	***0.344***
	C.V.		***5.50***	***56.83***	***0.91***	***68.75***	***156.36***
Kuje	L1	0-30	0.174	0.136	0.023	0.114	0.091
	L1	30-60	0.18	0.221	0.021	0.131	0.110
	L2	0-30	0.148	0.200	0.021	0.030	0.009
	L2	30-60	0.256	0.162	0.024	0.035	0.011
	Mean		***0.19***	***0.18***	***0.022***	***0.08***	***0.06***
	Sdv.		***0.046***	***0.038***	***0.002***	***0.052***	***0.053***
	C.V.		***24.21***	***21.11***	***10.00***	***65.00***	***88.33***
Kwali	L1	0-30	0.243	0.162	0.023	0.094	0.071
	L1	30-60	0.207	0.154	0.027	0.247	0.220
	L2	0-30	0.185	0.266	0.022	0.025	0.003
	L2	30-60	0.361	6.870	0.026	0.002	0.665
	Mean		***0.25***	***1.86***	***0.025***	***0.09***	***0.24***
	Sdv.		***0.078***	***3.338***	***0.002***	***0.110***	***0.298***
	C.V.		***30***	***166.90***	***10.00***	***110.0***	***74.50***

NB: Sdv = Standard deviation, C.V. coefficient of variation. L1= location 1, L2 = location 2, K = extractable potassium, H_2O K = hot water extractable Potassium, NH_4OAC K = ammonium acetate extracted potassium, Total K = Total potassium

Forms and Fixation of Potassium in Soils of the Study Area

The different forms of K determined and the K-Fixation of the soils across different locations in the federal capital territory Abuja are presented in Table 2.

Exchangeable potassium

The distribution of exchangeable K in the soils of Abaji ranged from 0.210 – 0.409 cmol/kg with a mean of 0.260 cmol/kg while in the soils of Karshi, the exchangeable K ranged from 0.167 – 0.338 cmol/kg with a mean of 0.240 cmol/kg. In the soils of Airport Road, exchangeable K ranged from 0.185 – 0.414 cmol/kg with a mean of 0.300 cmol/kg. For the soils of Bwari, exchangeable K ranged from 0.134 – 0.205 cmol/kg with a mean of 0.170 cmol/kg while in the soils of Gwagwalada, exchangeable K ranged from 0.185 – 0.211 cmol/kg with a mean of 0.190 cmol/kg, and in the soils of Kuje area, the exchangeable K ranged from 0.148 – 0.256 cmol/kg with a mean of 0.190 cmol/kg while in the soils of Kwali area, the exchangeable K ranged from 0.185 – 0.361 cmol/kg with a mean of 0.250 cmol/kg.

The mean content of exchangeable potassium across the different locations ranged from 0.17 cmol/kg – 0.30 cmol/kg. The highest mean content of exchangeable K was observed in the soils of Airport Road (0.30 cmol/kg) while the least was observed in the soils of Bwari (0.17 cmol/kg). The range of values for the exchangeable K was interpreted as low to moderate. The distribution in the mean of the exchangeable K in the soils is in the order Airport Road > Abaji area > Kwali area > Karshi area > Gwagwalada area > Kuje > Bwari area.

Hot Water Extractable K

The distribution of hot water extractable K in the soils of Abaji ranged from 0.1709 – 0.563 cmol/kg with a mean of 0.259 cmol/kg while in the soils of Karshi in AMAC, the hot water extractable K ranged from 0.199 – 0.220 cmol/kg with a mean of 0.210 cmol/kg. In the soils of Airport Road still in AMAC, the hot water extractable K ranged from 0.164 – 0.238 cmol/kg with a mean of 0.200 cmol/kg while in the soils of Bwari area council, the hot water extractable K ranged from 0.178 – 0.335 cmol/kg with a mean of 0.240 cmol/kg. In the soils of Gwagwalada area, hot water extractable K in the soils of the two locations sampled ranged from 0.195 – 0.67 cmol/kg with a mean value of 0.410 cmol/kg while in the soils of Kuje area, the hot water extractable K ranged from 0.136 – 0.221cmol/kg with a mean of 0.180 cmol/kg. In the soils of Kwali area, the distribution of hot water extractable K ranged from 0.154 – 6.870 cmol/kg with a mean of 1.86 cmol/kg. This value was extremely high especially at 30 – 60 cm of the second location of the area.

The mean values hot water extractable K in the soils ranged from 0.18 cmol/kg (Kuje) to 1.86 cmol/kg (Kwali). The trend in the distribution of the hot water extractable K in the soils across the seven locations is as follows: Kwali area > Gwagwalada Area > Abaji area > Bwari area > Karshi area > Airport Road > Kuje area. The mean value for the soils of Kwali was relatively higher followed by the soils of Gwagwalada while the soils of Airport Road and Kuje area were the least.

Ammonium (NH_4) Extractable Potassium

The distribution of ammonium extractable K in the soils of Abaji area ranged from 0.018 – 0.020 cmol/kg with a mean value of 0.019 cmol/kg. In the soils of Karshi area in AMAC of the FCT, ammonium extractable K ranged from 0.027 – 0.034 cmol/kg with a mean of 0.030 cmol/kg while in the soils of Airport Road in AMAC, ammonium extractable K ranged from 0.022 – 0.027 cmol/kg with a mean of 0.024 cmol/kg. In the soils of Bwari area, ammonium extractable K ranged from 0.023 – 0.044 cmol/kg with a mean of 0.032 cmol/kg. In the soils of Gwagwalada area, ammonium extractable K ranged from 0.020 – 0.023 cmol/kg with a mean of 0.022 cmol/kg while in the soils of Kuje, the ammonium extractable K in the soils ranged from 0.021 – 0.024 cmol/kg with a mean value of 0.022 cmol/kg. In the soils of Kwali area, ammonium extractable K ranged from 0.022 – 0.027 with a mean value of 0.025 cmol/kg.

The mean distribution of ammonium extractable K in the soils was in the order: Bwari area > Karshi area > Kwali area > Airport Road > Gwagwalada = Kuje > Abaji. The mean for Gwagwalada area and Kuje soils was the same. The result showed that in all the soils, exchangeable K was very low to moderate in status. Water soluble K was more abundant in the soils but ranged from low to moderate. Ammonium extracted K was lowest in all the soils implying that the actual available K in the soils for plants absorption is low. This should provide the basis for K fertilizer recommendation because it is the most available form of K to plants in the soils. The range of values obtained for the ammonium acetate extraction of K shows that in the soils of Abuja, K is one of the most deficient plant nutrients and for good plant performance, there would be need for supplemental application of K in the soils.

Total Potassium in the soils

The distribution of total K in the soils of Abaji ranged from 0.021 – 0.037 cmol/kg with a mean value of 0.029 cmol/kg. In the soils of Karshi area, total potassium ranged from 0.084 – 0.133 cmol/kg with a mean of 0.108 cmol/kg while in the soils of Airport road, total K ranged from 0.027 – 0.096 cmol/kg with a mean value of 0.056 cmol/kg. In the soils of Bwari area, total K in the soils of the two locations sampled ranged from 0.068 – 0.242 cmol/kg with a mean of 0.15 cmol/kg. In the soils of Gwagwalada, total K across the two sampled locations ranged from 0.033 – 0.148 cmol/kg with a mean total K of 0.080 cmol/kg. In the soils of Kuje area, total K raged from 0.030 – 0.131 cmol/kg with a mean of 0.080 cmol/kg while in the soils of Kwali, total K ranged from 0.002 – 0.247 cmol/kg with a mean of 0.090 cmol/kg.

In terms of mean total K distribution in the soils across the studied area, total K was least in the soils of Karshi (0.025 cmol/kg) and highest in the soils of Bwari (0.15 cmol/kg). The distribution pattern in the mean total K of the soils across the areas was in the order of Bwari area > Karshi > Kwali area > Gwagwalada = Kuje > Airport Road > Abaji area.

Potassium Fixation in the soils

The result of fixed K in the soils of Abaji ranged from 0.001 – 0.017 cmol/kg with a mean fixed K value of 0.010 cmol/kg. In the soils of Karshi in AMAC, the values for fixed 0.056 – 0.095 cmol/kg with a mean of 0.073 cmol/kg. In the soils of Airport Road Fixed K ranged 0.004 – 0.074 cmol/kg with a mean of 0.031 cmol/kg. In the soils of Bwari area, the values for fixed K ranged from 0.043 – 0.206 cmol/kg with a mean of 0.120 cmol/kg, while in the soils of Gwagwalada area, fixed K in the soils ranged from 0.010 – 0.730 cmol/kg with a mean value of 0.220 cmol/kg. In the soils of Kuje area, the fixed K values ranged from 0.009 – 0.110 cmol/kg with a mean value of 0.060 cmol/kg. In the soils of Kwali however, fixed K ranged from 0.003 – 0.665 cmol/kg with a mean value of 0.24 cmol/kg.

The result showed that mean fixed K was highest in the soils of Kwali area (0.240 cmol/kg) and least in the soils of Abaji (0.010 cmol/kg). The distribution of mean fixed K in the soils of the FCT Abuja are in the order Kwali > Gwagwalada > Bwari > Karshi > Kuje > Airport Road > Abaji area.

The level of K fixation was lower in the soils of Abaji but became increasingly more in the soils of other locations especially Gwagwalada, Bwari and to some extent, Kwali and Kuje soils. When K is fixed in soils, its availability to plants is significantly reduced and that means that the K would easily be held tenaciously by the soil lattice as explained by Taiwo et al, (2018).

The other soil units with low K fixation, potassium leaching may be expected because the soils are sandy in texture with high potential to leaching and low water and nutrient holding capacity. The results of this study indicated that all the soils of Abuja have the potential to fix applied potassium. The ability of these soils to fix K can be attributed predominantly to the presence of low activity clay minerals such as kaolinite and low cation exchange capacity of the soils. This also suggests the presence of specific adsorption sites for K in the soils across the area. This implies that fertilizer recommendations involving K must take into cognizance the amount already fixed into the soils, otherwise, even with application of K into the soils as fertilizers, plants may still be underserved.

Conclusion and Recommendation

Available potassium in the soils is low as seen in the status of ammonium acetate extracted K in the soils. The soils total K reserve is low and the soils have high potential to fix K, this makes K to be one of the most deficient elements in the soils of Abuja and its environs. So, any recommendation for K fertilizer applications in the soils of the FCT Abuja should take into account the amount of K already fixed in the soils. This is to avoid the problem of under supply of K in the soils based on the assumption that specific rates should be adequate to meet the crops' K requirement.

References

Adetunji,M.T. Adepetu, J.A., and Ige, D.V. (2014).Soil fertility and crop nutrition. Jumak Publishers, Nigeria Limited, Ibadan.

Agbede, O.A. (2009). Understanding soil and plant nutrition. Salman press limited, Keffi, Nasarawa State, Nigeria. Ist Edition. pp 47-62.

Conti M E, de la Horra A M, Effron D,(2011) Factors affecting potassium fixation in Argentine agricultural soils. Comm Soil Sci Plant Anal, (2011), 32(17-18): 2679—2690 3 *(12) (PDF) Factors affecting potassium fixation in seven soils under 15-year long-term fertilization*.

Foth, H. D., 2006. Fundamentals of soil science. 8Ed. John Wiley and Sons, New York.

Oborn I, Andrist Rangel Y, Askekaard M, Grant CA,Watson CA, Edwards AC (2005) Critical aspects of potassium management in agricultural systems Soil Use Manag 21:102-112.

Ogbodo, E.N. (2011) Assessment of some soil fertility characteristics of Abakaliki urban flood plains of south-East Nigeria, for sustainable crop production. World Journal of Agric sci 7(4):489-495.

Pyo, Y.J., Gierth, M., Schroeder, J.I. & Cho, M.H. (2010) High-affinity K+ 901 transport in 902 Arabidopsis: AtHAK5 and AKT1 are vital for seedling establishment and post 903 germination growth under low-potassium conditions. Plant Physiology, 153, 863- 904 875.

Schneider A, Tesileanu R., Charles R., Sinaj S. (2013). Kinetics of soil potassium sorption-Description and fixation. Commum Soil Plant Anal 44:837-849.

Sparks, D. L. 2011. Dynamics of K in soils and their role in management of K nutrition. In K in Nutrient Management for Sustainable Crop Production in India, pp. 79---101. IPI, PRII New Delhi.

Srinivasarao, CH., Vittal, K.P.R., Tiwari, K.N., Gajbhiye, P.N. and Kundu, S. 2007a. Categorization of soils based on potassium reserves and production systems: Implications in K management. Australian Journal of Soil Research 45, 438-447.

Srinivasarao, CH., Kundu, S., Ramachandrappa, B.K., Reddy, S.B., Lal, R., Venkateswarlu, B., Sahrawat, K.L. and Naik, R.P. 2014b. Potassium release characteristics, potassium balance, and finger millet (Eleusine coracana G.) yield sustainability in a 27-year long experiment on an Alfisol in the semi-arid tropical India. Plant and Soil 374, 315-330

Taiwo, A.A., Adetunji, M.T., Azeez, J.O. (2018) Kinetics of potassium release and fixation in some soils of Ogun State, Southwestern, Nigeria as influenced by organic manure. *Int J Recycl Org Waste Agricul* 7, 251-259

Zhao, H, Zhang X, Xu, S, Zhao, X, Xie, Z and Wang, O (2010). Effect of freezing on soil nitrogen mineralization under different plant communities in a semi-arid area during a non-growing season. Applied Soil Ecology. Volume 45 Pages 187-192.