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Potassium Status of Soils under Three Different Parent Materials of the Oil palm (Elaeis guineensis Jacq)

Osayande P. E.[1*] Orhue E. R.[2] Ehigiator J. O.[2] Oviasogie P. O.[1]
1.Soils and Land Management Division, Nigerian Institute for Oil palm Research (NIFOR), P.M.B. 1030, Benin City
2.Department of Soil Science and Land Resources Management, Faculty of Agriculture, University of Benin, Benin City, Nigeria
Email of corresponding author: *pvefosa2001@yahoo.co.uk

Abstract
Potassium quantity/intensity relations were studied in soils of three different parent materials of the oil palm to determine their potassium status and management. This was done by equilibrating 2.5g of the soil samples in 25 ml of 0.01M $CaCl_2$ at room temperature containing known concentrations of K. Potassium saturation was computed over ECEC. The quantity factor (Q) was determined as the difference in concentration between added K and soil solution K after equilibrating. The Q factor was plotted against the intensity factor. Results showed that the soils were generally acidic while organic matter and total nitrogen decreased with increasing soil depths in all the locations. Potassium activity ratio, its activity, its activity coefficient, ionic strength, free energy of replacement and potassium saturation differed due to the influence of the three different parent materials. In soils under alluvium, ECEC was significantly correlated with potassium activity (r = 0.941*), potassium activity coefficient (r = 0.925*), PBC^K (r = 0.953*). In soils under basement complex rocks, ECEC had a significant correlation with potassium activity (r = 0.975**) and calcium activity (r = 0.996**). In soils under shale mixed with sandstone and clay, potassium saturation had a significant correlation with calcium activity coefficient while exchangeable acidity had a significant correlation with potassium activity coefficient. There were high values of potassium activity ratio but low values of ionic strength, free energy of replacement and labile K in all the locations. **Conclusion:** It follows that adequate maintenance of the ECEC status of soils under alluvium and Basement Complex Rocks through deliberate maintenance of cover cropping and frequent K fertilization could suffice in maintaining the soils K and Ca potential in contrast with soils under Shale Mixed with Sandstone and Clay that requires the application of K fertilizers blended with a little bit of lime.
Keywords: Potassium status, potassium activity ratio, ionic strength, potential buffering capacity and labile K.
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1.0 Introduction:

The Oil palm (*Elaeis guineensis* Jacq) is one of the most important oil bearing tree crops in the world today (Kushairi *et al*., 2019). This is because its industry has continued to witness phenomenal growth with growing global demand for fats and oils and biofuels and the versatility of use of palm oil globally (Ikuenobe, 2018). The Oil World Annual Statistics (2018) and MPOB (2009) showed that global production of palm oil doubled in a decade from 20.63 million in 1999 to 43.12 million tonnes in 2008 rising to 68 million MT in 2017. Oil .palm as a tree crop requires large amounts of nutrients for growth and productivity (Tarmizi and Tayeb, 2006; Ng, *et al*., 2011). Consequently fertilizer recommendations for the oil palm made on a broad scale by NIFOR has identified nitrogen, phosphorus, potassium and magnesium as the most important nutrient elements, i.e. NPKMg 12:12:17:2 with potassium having the highest ratio (FMANR, 1990). According to Omoti (1989) nitrogen, potassium and magnesium are the most important nutrient elements required by Oil Palm in the nursery while potassium and nitrogen are more important in the fruiting years. Recent studies have however shown that potassium is the most important nutrient required by oil palm at fruiting. This is because potassium (K) directly affects bunch weight and number (Dubos *et al*., 2019; Osayande *et al*., 2020). This realization by no means undermines the importance of other nutrients such as nitrogen and phosphorus but shows the need for proper assessment of potassium requirement by the oil palm. It has been shown that available K determined by use of neutral ammonium acetate is inadequate in the assessment of K requirements of plants in soils under intensive cropping because soil K exists in three forms that are in a dynamic relationship with one another viz, the readily available form (soluble and exchangeable K); the slowly available (non-exchangeable K), the unavailable form that includes the potassium in the structure of silicate clay minerals (Sparks, 2000). Furthermore, the uptake of K by plants depends not only on its availability but dynamics viz intensity, capacity and renewal rate in soils. The capacity and intensity of K in soil solutions are some of the important factors governing the supply and availability of K to plants. The reserve of the non-exchangeable K is referred to as the capacity of K or the quantity factor (Q) while the immediate available K is referred to as soil solution K and describes the intensity factor of K. The renewal rate is referred to as the buffering capacity. High values of the potential buffering capacity with respect to potassium (PBC^k) implies the availability of K to plants while low value of PBC^k implies that K fertilization is required. Similarly, high value of labile K indicates an increased release of K into the soil solution (Al-Zubaidi *et al*., 2008), probably due to a greater soil potassium pool either from natural sources or potassium fertilization. The dynamics of K in soils can undermine the fertility of the soil if not properly assessed (Lalitha and Dhakshinamoorthy 2015). As important as these factors are in the determination of potassium status and its availability to plants, they have not been applied to the study of soils under oil palm, especially as oil palm can be cultivated on a wide range of soils. As observed by Havlin *et al*., (2005) soils may have the same AR^k_e (intensity) but may not possess the capacity for maintaining AR^k_e when soil K is depleted by crop uptake. This study was undertaken therefore to evaluate the potassium status using quantity/intensity parameters and their relationship with some soil properties of three benchmark soils of the oil palm.

2.0 Materials and Methods:

2.1 Description of study area

Profile pits were sited in soils under three different parent materials namely, Alluvium, Basement Complex Rocks and Shale mixed with Sandstone and Clay. The locations were Agbarho near Warri in Delta state, Onishere in Idanre local Government Area of Ondo state and Ubiaja in Edo state. These locations enjoy a Tropical Equatorial Climate with an average annual temperature and rainfall of 30 ^{0}C and 2500 mm respectively (Akpovwovwo 2014; Oko-Oboh *et al*., 2017).

2.2 Chemical properties of the soils:

Some important chemical properties such as soil pH and electrical conductivity were determined in 1:1 soil to water suspension using a pH and electrical conductivity meter respectively (Hendershot *et al*., 1993). Soil organic carbon was determined by the Walkley and Black method (Nelson and Sommers, 1996) and multiplied by 1.724 to obtain organic matter. Total nitrogen (N) was by micro Kjeldahl (Bremner, 1996) method. Available phosphorus was determined by Bray P-1 (Anderson and Ingram, 1993) while soil exchangeable bases were extracted by the ammonium acetate method buffered at pH 7 (Thomas, 1982). Calcium and magnesium were determined using EDTA titration while potassium and sodium were read with a flame photometer. Exchangeable acidity was extracted using 1 N KCl determined by titration of the soil solution with 0.5M NaOH (Maclean, 1964).

2.3 Potassium saturation index: This was determined as $K\ \% = \frac{K_{ads}(\text{cmol/kg})}{\text{ECEC (cmol/kg)}}$ (Osayande, 2018)

2.4 Quantity/Intensity of potassium:

This was determined by adding 25 ml solution of 0.01M $CaCl_2$ that contained potassium concentrations of 0, 4, 8, 16 and 32 mg/L to 2.5 grams of the soils in bottles and shaken for 6 hours at 25 ± 1 ^{0}C and then left to stand for 24 hours to achieve equilibration and centrifuged 6 at 2000 rpm for 10 minutes. The contents were filtered using Whatman No 42 filter papers. The concentration levels of potassium in the filtrate were measured using a flame photometer (Motsara and Roy, 2006) while calcium and magnesium were determined by titration with ethylene-diamine tetra acetic acid (EDTA) solution. The quantity factor (ΔK) was calculated from the difference in K concentration between the initial and equilibrium solutions while the intensity factor (I) is the K in solution after equilibration. The activity coefficient of the ionic species was measured from the extended Debye Huekel equation given by Al-Zubaidi *et al*., (2008) as

$$\text{Log } f_i = -AZ_i^2 \frac{\sqrt{\mu}}{1+\beta d_i\sqrt{\mu}}$$

Where Z_i = valency of ion, A = 0.508 for water at 298 Kelvin, $\beta = 0.328 \times 10^8$ at 298 Kelvin, d_i = effective size of hydrated ions and μ = ionic strength of cation, computed as the product of 0.0129 and electrical conductivity of the soils. The activity ratio of potassium ions were tabulated as shown below,

$$\text{Activity ratio} = \frac{{}^aK}{\sqrt{{}^aCa + {}^aMg}}$$

The free energy of replacement was calculated by Woodruff (1955) proposed formula as

$$-\Delta F = 2.303RT\log \frac{aK}{\sqrt{{}^aCa + {}^aMg}}$$

Where R = Gas constant = 1.987 Cal/K.mol, T = Absolute temperature at 25^0 C = 298 K and a = activity of the metal ions

2.5 Determination of potential buffering capacity and labile K content of the soils

After equilibration, adsorption isotherms were constructed using the method of (Kenyanyan *et al*., 2013). The amount of K adsorbed was determined as the difference between added K and equilibrated K as $\Delta K = (Ck_i - Ck_f)$

V/M. The K adsorption data were fitted into Freundlich linearized equation given by Log x/m = Log a + b Log C. ΔK is the change in amount of K (Quantity factor (Q)) in solution and represents amount of k adsorbed, CK_i and CK_f are the initial K concentrations added and final equilibrium concentrations of k in solution respectively. V and m are the solution volume and mass of the soil used. The K adsorption data were fitted into the Freundlich linearised adsorption equation as suggested by Pal *et al*., (1999), given by

Log(x/m) = log a + blog C, Where x/m is the mass of adsorbed K per unit mass of soil (mgkg^{-1}, C is the equilibrium K concentrations of solutions (mgL^{-1}), a and b are constants obtained from the intercept and slope respectively and represent the PBC^{-K} and labile–K contents of the soils (Osayande *et al*., 2020).

3.0 Results:

3.1 Chemical properties of the soils:

Soil pH in water, organic matter and total nitrogen decreased with increasing soil depths in all the locations in contrast to phosphorus which increased with increasing soil depth in all the locations (Table 1). Potassium decreased with increasing soil depth only up to 30-45 cm soil depth in all the locations. Sodium and Magnesium were irregular with depth while calcium increased with increasing soil depth in all the locations. Exchangeable acidity (EA) was irregular with depth in all the locations while effective cation exchange capacity (ECEC) increased with increasing soil depth in soils under basement complex rocks but was irregular with soil depth in soils under alluvium and Shale mixed with sandstone and clay. The potassium saturation decreased with increasing soil depths in all the locations (Table 1).

3.2 Thermodynamic properties of the soils:

Potassium activity coefficient and Potassium activity increased with increasing soil depths in all the locations. Similarly, activity of calcium, ionic strength and electrical conductivity increased with increasing soil depths in all the locations while potassium activity ratio, calcium activity coefficient and free energy of replacement decreased with increasing soil depths, a trend also observed with magnesium activity coefficient in soils under basement complex rocks and shale mixed with sandstone and clay (Table 2). Magnesium activity coefficient of soils under alluvium increased with increasing soil depths (Table 2). Potassium activity coefficient, potassium activity, potassium activity ratio, magnesium activity, calcium activity, ionic strength and free energy of replacement were all significantly different due to the influence of the different parent materials (Table 3).

3.3 Potential Buffering Capacity and Labile K Content of the soils:

Potential buffering capacity and labile K contents of the soils are shown in Figures 1 – 17. In soils under Alluvium, PBC^{-K} and labile-K ranged from 0.95 to 2.08 cmol/kg/mol/L and 0.002 to 0.25 cmol/kg respectively (Figures I – V). In the Basement Complex Rocks, PBC^{-K} 116.and labile K

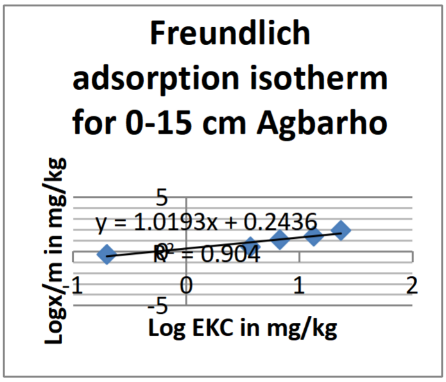


Figure 1: Freundlich adsorption Isotherm for 0 – 15 cm of Agbarho soils

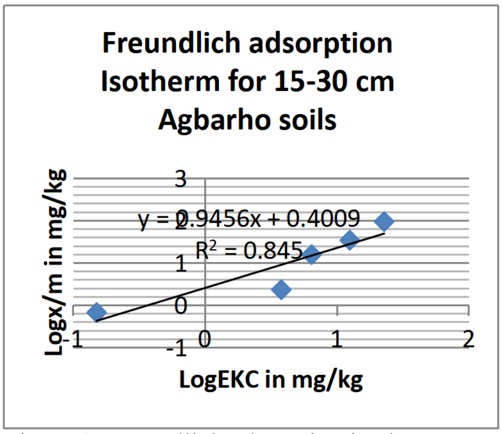


Figure 2: Freundlich adsorption isotherm for 15-30 cm Agbarho soil

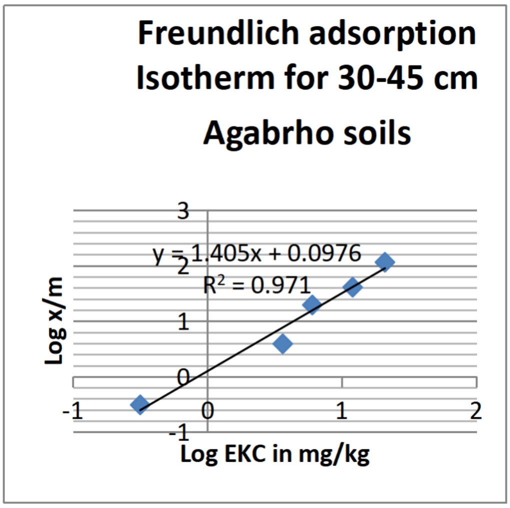


Figure 3: Freundlich Adsorption Isotherm
for 30-45 cm Agbarho soils

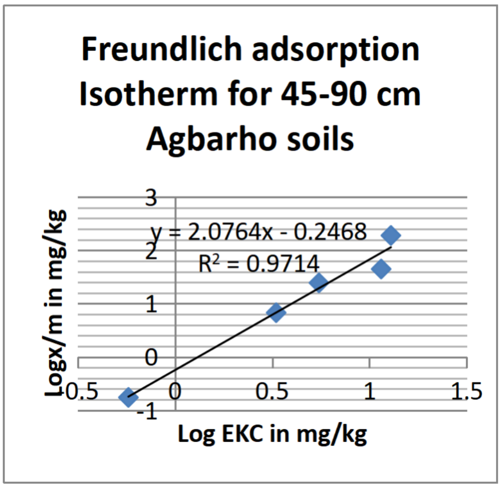


Figure 4: Freundlich adsorption Isotherm
for 45-90 cm Agbarho soils

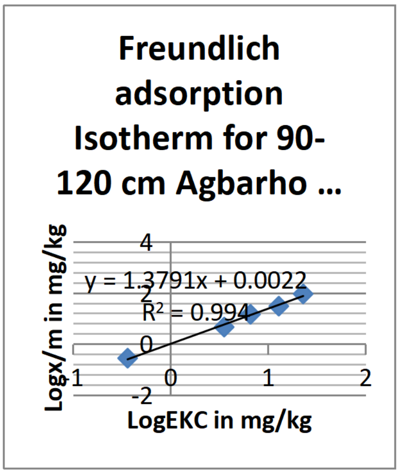


Figure 5: Freundlich adsorption Isotherm
for 90 - 120 cm of soils under Alluvium

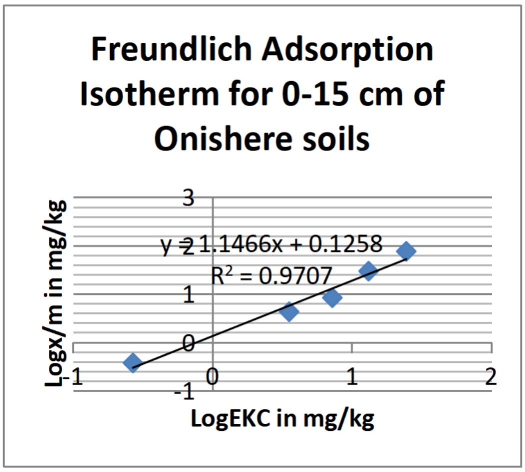


Figure 6: Freundlich adsorption Isotherm
for 0 - 15 cm of soils under basement complex rocks

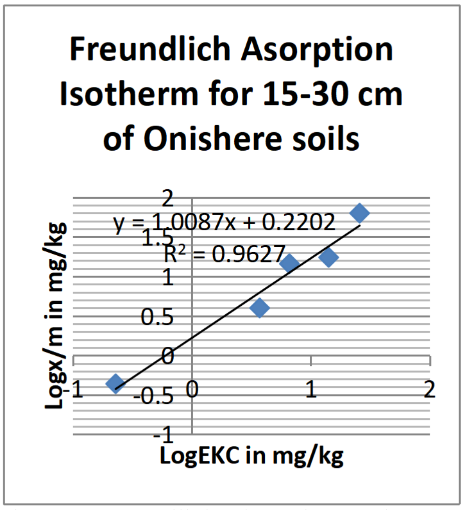


Figure 7: Freundlich adsorption Isotherm
for 15 - 30 cm of soils under basement
complex rocks

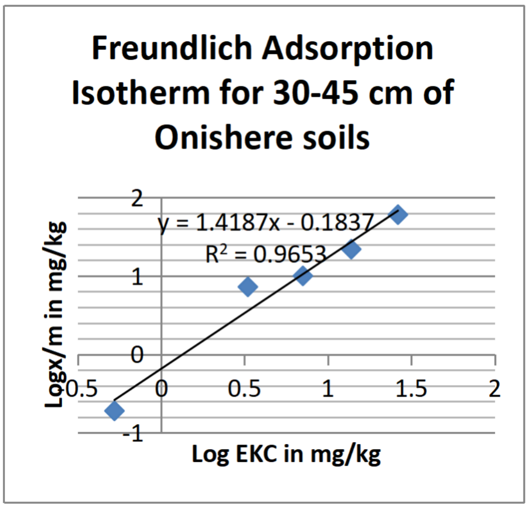


Figure 8: Freundlich adsorption Isotherm
for 30 - 45 cm of soils under basement complex rocks

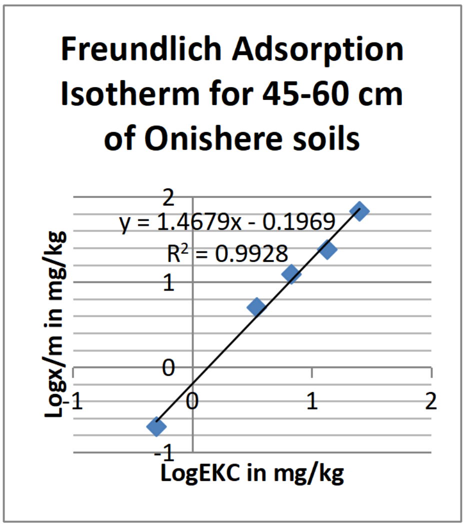


Figure 9: Freundlich adsorption Isotherm for 45 - 60 cm of soils under basement complex rocks

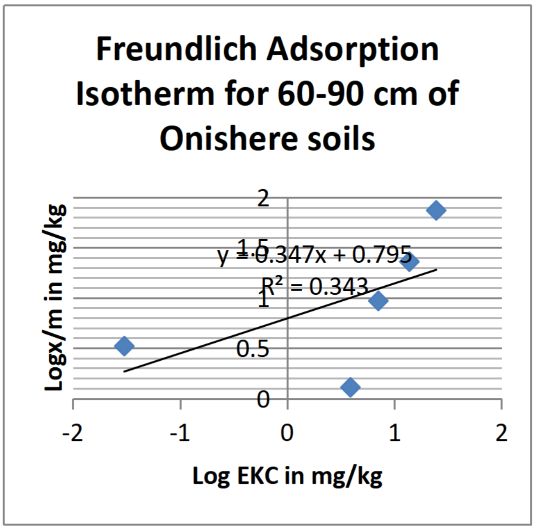


Figure 10: Freundlich adsorption Isotherm for 60 - 90 cm of soils under basement complex rocks

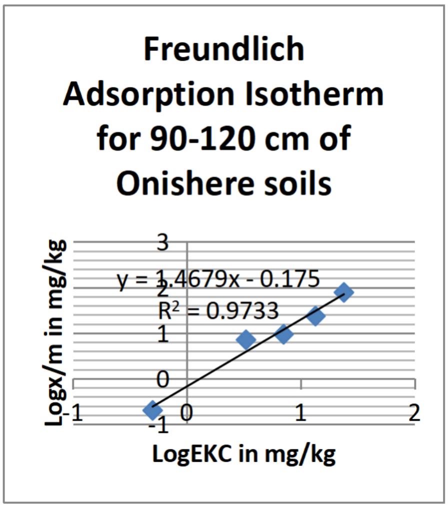


Figure 11 Freundlich adsorption Isotherm for 90 - 120 cm of soils under basement complex rocks

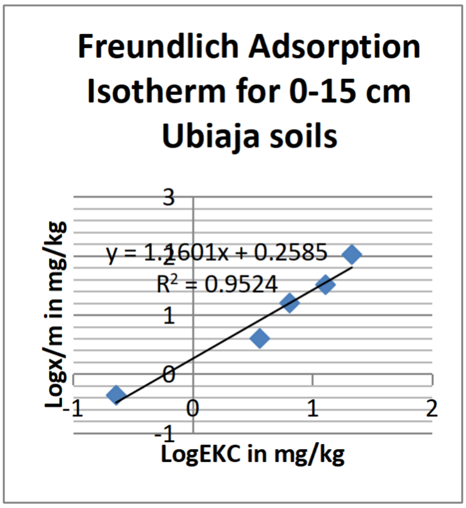


Figure 12: Freundlich adsorption Isotherm for 0 - 15 cm of soils under shale mixed with sandstone and clay

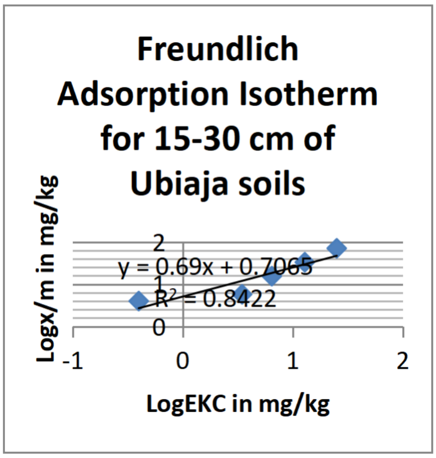


Figure 13: Freundlich adsorption Isotherm for 15 - 30 cm of soils under shale mixed with sandstone and clay

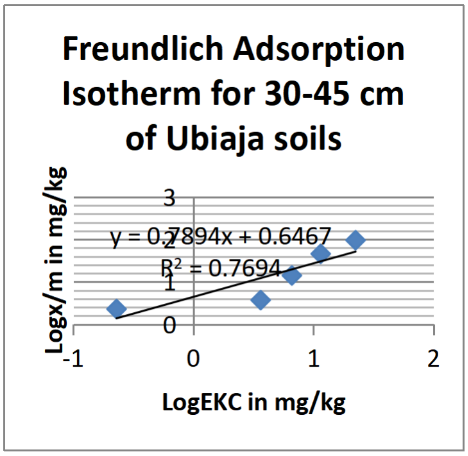
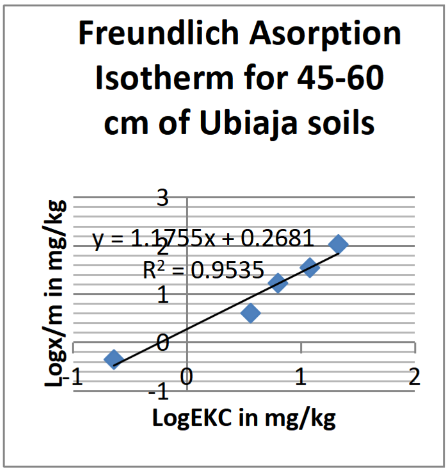


Figure14: Freundlich Adsorption Isotherm for 30-45cm of soils under shale mixed with



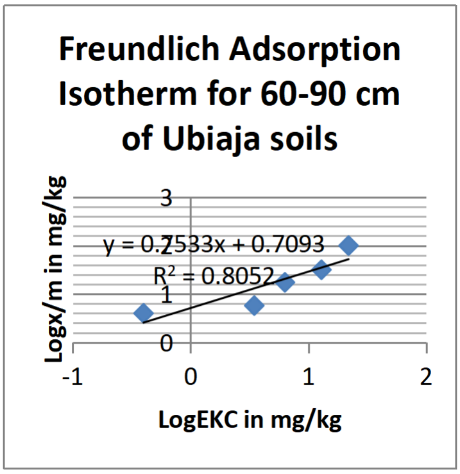


Figure 15: Freundlich Adsorption Isotherm for 45 - 60 cm of soils under shale

Figure16 :Freundlich Adsorption Isotherm For 60 – 90 cm soils under shale mixed with

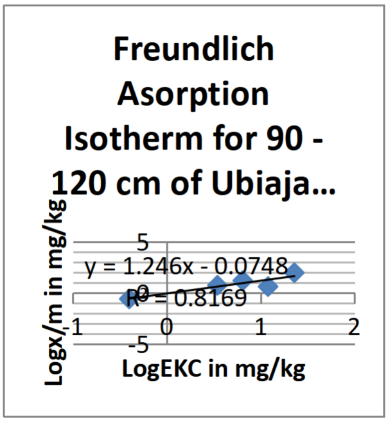


Figure 17: Freundlich Adsorption Isotherm for 90-120 cm of soils under shale mixed with sandstone and clay

ranged from 0.35 to 1.47 cmol/kg/mol/L and 0.125 to 0.795 cmol/kg respectively (Figures VI – XI). In soils under shale mixed with sandstone and clay PBC^{-K} and labile K ranged from 0.69 to 1.25 cmol/kg/mol/L and 0.074 to 0.709 cmol/kg respectively (Figures 12 –. 17).

3.4 Correlation matrix between chemical and thermodynamic properties of soils under the different parent materials:

ECEC was significantly correlated with potassium activity coefficient, potassium activity and potential buffering capacity with respect to potassium of the soils under alluvium parent material with r = 0.925*; 0.941* and 0.953* respectively. Potassium saturation index had a significant correlation with activity ratio with r = 0.956* while sodium had a significant correlation (r = 0.888*) with electrical conductivity (Table 4). Similarly, exchangeable calcium and magnesium had significant correlations (r = 0.960** and 0.982**) with their respective activities while organic matter had a significant correlation (r = 0.892*) with activity ratio of potassium (Table IV). In soils under basement complex rocks, soil pH and sodium were significantly correlated (r = 0.902* and 0.912*) with electrical conductivity respectively while exchangeable calcium was significantly correlated with potassium activity coefficient, potassium activity and calcium activity with r = 0.969**; r = 0.982** 132.and r = 0.986** respectively (Table 5). Exchangeable acidity was significantly correlated 133.with labile K with r = 0.898*. Similarly, ECEC was significantly correlated with potassium and calcium activities while potassium saturation was significantly correlated with electrical conductivity of soils under basement complex rocks (Table 5). In soils under shale mixed with sandstone and clay, organic matter and total nitrogen were significantly correlated with calcium activity coefficient with r = 0.949** and r = 0.925**) respectively. Similarly, exchangeable potassium was significantly correlated with magnesium and calcium activity coefficients with r = 0.868* and r = 0.874*) respectively (Table 6). Exchangeable calcium was significantly correlated with potassium activity coefficient, calcium activity and electrical conductivity of the soils while exchangeable magnesium was significantly correlated with magnesium activity. Exchangeable acidity was significantly correlated with potassium activity coefficient and electrical conductivity while potassium saturation was significantly correlated with calcium activity coefficient (Table 6)

3.5 Potassium status of the soils using K saturation index computed over ECEC:

Table 7 shows the potassium status of the soils using the K-saturation index. Potassium saturation < 0.05 % was regarded as very low, 0.05 – 0.07 % was low while 0.08 – 1.4 % was regarded as medium or moderate, Potassium saturation index of between 1.5 – 2.4 and 2.5 - 3.5 were regarded as high and very high respectively (Table 7).

Table 1**:** Chemical properties of the soils from profile pits under oil palm in some locations of southern Nigeria

Location/ Parent Material	Depth (cm)	pH (H_2O)	Org. Matter (g/kg)	Total N →	P (mg/kg)	K ←	Na	Ca (cmol/kg)	Mg	EA	ECEC →	K. Sat
Agbarho	0-15	5.60^{a}	41.71^{a}	0.95^{a}	23.30^{a}	0.32^{ab}	0.43^{a}	2.24a	1.92a	0.23a	3.80a	0.08
(Alluvium)	15-30	5.37^{a}	17.38^{b}	0.78a	23.40^{a}	0.27^{b}	0.41^{a}	2.59ab	0.88a	0.33a	3.80a	0.07
	30-45	5.33^{a}	8.66^{c}	0.73a	24.40^{a}	0.21^{c}	0.42^{a}	3.39ab	1.76a	0.87a	4.79ab	0.04
	45-90	5.22^{a}	5.24^{cd}	0.65^{a}	55.70^{b}	0.18^{c}	0.43^{a}	4.29bc	1.23a	0.80a	5.29b	0.03
	90-120	5.13^{a}	1.85^{d}	0.47a	57.30^{a}	0.13^{a}	0.42^{a}	5.29c	1.01a	0.60a	4.62ab	0.03
Onishere	0-15	6.77^{a}	39.24^{a}	1.63a	28.40^{a}	0.67^{a}	0.62^{a}	8.27a	5.60a	0.10a	15.10a	0.04
(Basement	15-30	6.33^{b}	28.96^{a}	1.54a	28.70^{a}	0.54^{a}	0.46^{b}	10.19ab	6.30a	0.10a	17.71ab	0.03
Complex	30-45	6.23^{b}	15.36^{b}	1.33a	29.30a	0.38^{a}	0.39^{b}	11.33b	6.89a	0.10a	19.09ab	0.02
Rocks)	45-60	6.23^{b}	11.56^{b}	0.97a	29.30^{a}	0.48^{a}	0.39^{b}	13.76c	7.46a	0.10a	22.25^{bc}	0.02
	60-90	6.23^{b}	9.69^{b}	0.82	31.10a	0.51^{a}	0.44^{b}	15.44cd	8.36a	0.17b	24.17c	0.02
	90-120	6.07c	4.56^{b}	0.59a	32.03^{a}	0.39^{a}	0.41^{b}	16.31d	5.81a	0.13^{ab}	26.47c	0.02
Ubiaja	0-15	5.03^{ab}	29.96^{a}	1.87^{a}	15.90^{a}	0.17^{c}	0.51^{a}	4.08a	0.85ab	0.45a	4.74a	0.04
(Shale	15-30	4.93^{bc}	14.09^{a}	0.97^{b}	21.20^{a}	0.16^{bc}	0.42^{ab}	4.19a	1.96a	0.77a	6.99ab	0.02
Mixed	30-45	4.47^{c}	9.29^{a}	0.93^{b}	22.40^{a}	0.09^{a}	0.40^{b}	4.21b	0.27b	0.80a	5.78ab	0.02
With	45-60	4.37^{c}	5.36^{b}	0.57b	22.80a	0.10^{ab}	0.62^{ab}	4.49b	1.39ab	0.47a	6.70ab	0.02
Sandstone	60-90	4.23^{cd}	3.52^{b}	0.33^{b}	23.60^{a}	0.11^{abc}	0.46^{ab}	4.55b	1.89a	1.13a	8.09b	0.01
& Clay)	90-120	4.10^{cd}	2.14^{b}	0.21^{b}	28.60^{a}	0.12^{abc}	0.40^{ab}	5.89c	0.29b	1,10a	7.80b	0.02

Table 2: Thermodynamic properties of soils from profile pits under oil palm in some locations of southern Nigeria

Location/Depth (cm)	K Activity Coefficient (γ)	K Activity (mol/L)	Activity Ratio	Mg Activity Coefficient (γ)	Mg Activity (γ)	Ca Activity Coefficient (γ)	Ca Activity (mol/L)	Ionic strength (μ) (mol/L)	EC (ds/m)	Free Energy of Replacement (-ΔF)
Agbarho										
0-15	3.43a	0.69a	0.28a	2.92a	5.73a	3.57a	7.03a	2.93×10^{-7a}	0.000023a	-1500.00a
15-30	3.46a	0.71a	0.25a	2.98a	5.51a	3.25a	7.70a	2.97×10^{-7a}	0.000031a	-1086.70a
30-45	3.49a	0.78a	0.17a	3.23a	3.64a	3.16a	12.22ab	3.97×10^{-7a}	0.000035^{a}	-1073.00a
45-90	3.58a	0.94a	0.17a	3.24a	3.21a	2.98a	14.24ab	4.53×10^{-7a}	0.000035^{a}	-1054.00a
90-120	3.59a	0.96a	0.16a	3.27a	2.69a	2.88a	15.35b	5.53×10^{-7a}	0.000043^{b}	-841.10a
Onishere										
0-15	3.59a	1.41a	0.34b	3.12a	17.64a	3.38a	25.05a	1.43×10^{-7a}	0.000013a	-1104.80b
15-30	3.63a	1.70a	0.29ab	3.08a	19.68a	3.12a	31.86ab	1.70×10^{-7a}	0.000014a	-991.20ab
30-45	3.65a	1.90a	0.26ab	3.07a	21.30a	3.08a	35.01ac	1.87×10^{-7a}	0.000017a	-977.50ab
45-60	3.67a	2.02a	0.20a	3.05a	22.49a	3.07a	41.66c	2.17×10^{-7a}	0.000018a	-813.90ab
60-90	3.68a	2.49a	0.19a	3.03a	25.57a	3.03a	47.36cd	2.30×10^{-7a}	0.000019a	-750.20a
90-120	3.72a	2.52a	0.16a	3.02a	27.64a	3.03a	55.33d	2.50×10^{-7a}	0.000068b	-672.90a
Ubiaja										
0-15	3.50a	0.40a	0.13a	3.11a	2.61ab	3.39a	9.44a	1.53×10^{-7a}	0.000012a	-1432.00a
15-30	3.52a	0.40a	0.13a	3.06a	4.13ab	3.11ab	10.02a	2.00×10^{-7a}	0.000015a	-1359.00a
30-45	3.57a	0.46a	0.13a	2.98a	6.05ab	2.98ab	12.23a	3.47×10^{-7a}	0.000027b	-1273.00a
45-60	3.58a	0.46a	0.12a	2.97a	6.79a	2.97ab	12.08a	3.87×10^{-7a}	0.000023b	-1273.00a
60-90	3.67a	0.46a	0.11a	2.92a	9.13b	2.92b	13.01a	4.67×10^{-7a}	0.000036bc	-1237.00a
90-120	3.71a	0.46a	0.10a	2.90a	9.86a	2.90b	17.53b	5.17×10^{-7a}	0.000040c	-1237.00a

Table 3: Influence of parent materials on the thermodynamic properties of the soils

Location/ Parent material	K Activity Coefficient (γ)	K Activity (mol/L)	K Activity Ratio (M/L)	Mg Activity Coefficient (γ)	Mg Activity (mol/L)	Ca Activity Coefficient (γ)	Ca Activity (mol/L)	Ionic Strength (mol/L)	EC (ds/m)	Free Energy of Repla cement (-ΔF)	PBC-K cmol/kg/mol/L	Labile-K cmol/Kg	K. sat (%)
Agbarho (Alluvium)	3.50a	0.78a	0.21a	3.03	4.16a	3.17	11.30a	$3.99\text{x}10^{-7ac}$	$3.34\text{x}10^{-5}$	1111.00^{a}	1.37	0.20	0.050a
Onishere (Basement Complex)	3.66b	2.01c	0.24ab	3.06	2.62b	3.12	39.40b	$1.99\text{x}10^{-7c}$	$2.48\text{x}10^{-5}$	885.00b	1.15	0.28	0.025b
Ubiaja (Shale, Sandstone & Clay')	3.59ab	0.44b	0.12c	2.99	3.93a	3.05	12.40a	$3.45\text{x}10^{-7c}$	2.5510^{-5}	1302.00^{c}	0.96	0.44	0.022b
SE	0.07	0.23	0.05	NS	2.52	NS	6.14	$1.37\text{x}10^{-7}$	NS	149.10	NS	NS	0.006

Table 4: Correlation matrix between soil properties and thermodynamic parameters of soils under Alluvium parent materials

	K. Activity Coefficient	K. Activity	Activity ratio	Mg. Activity Coefficient	Mg. Activity	Ca. Activity Coefficient	Ca. Activity	Electrical Conductivity	Free energy of replacement	PBC^{K}	Labile K
pH	-0.825	-0.720	0.703	-0.416	0.554	0.344	-0.917*	-0.466	-0.424	-0.635	0.547
Org. M	-0.796	-0.695	0.892*	-0.702	0.454	-0.013	-0.869	-0.175	-0.718	-0.614	0.452
Av. P	0.681	0.783	-0.380	-0.446	-0.072	0.335	0.249	0.638	0.047	0.807	0.328
Exch. K	-0.805	-0.704	0.853	-0.683	0.369	0.105	-0.974**	-0.398	-0.452	-0.640	0.686
Na	0.280	0.412	-0.071	-0.443	0.499	0.292	0.179	0.888*	-0.775	0.521	-0.212
Ca	0.784	0.686	-0.751	0.573	-0.384	-0.235	0.960**	0.500	-0.313	0.624	-0.709
Mg	-0.391	-0.246	0.176	-0.173	0.982**	0.685	-0.302	0.234	-0.824	-0.090	-0.177
EA	0.759	0.764	-0.976**	0.599	0.139	0.593	0.797	0.426	0.316	0.783	-0.516
ECEC	0.925*	0.941*	-0.935*	0.363	0.004	0.407	0.873	0.700	0.204	0.953*	-0.471
K.Sat	-0.887*	-0.832	0.956*	-0.622	0.192	-0.153	-0.983**	-0.528	-0.375	-0.801	0.652

** Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

Table 5: Correlation matrix between soil properties and thermodynamic parameters of soils under Basement Complex Rocks

	K. Activity Coefficient	K. Activity	Activity ratio	Mg. Activity Coefficient	Mg. Activity	Ca. Activity Coefficient	Ca. Activity	Electrical Conductivity	Free energy of replacement	PBC^{K}	Labile K
pH	-0.911*	-0.827*	0.528	-0.214	-0.404	-0.561	-0.836*	0.902*	0.548	-0.121	-0.243
Org. M	-0.960**	-0.927**	0.746	0.114	-0.491	-0.492	-0.925**	0.703	0.742	-0.068	-0.361
Av. P	-0.513	-0.252	0.024	0.342	0.031	-0.279	-0.404	0.427	-0.053	-0.763	0.465
Exch. K	-0.779	-0.652	0.592	-0.156	-0.227	-0.533	-0.668	0.735	0.573	-0.379	0.010
Na	-0.761	-0.657	0.460	-0.190	-0.504	-0.301	-0.649	0.912*	0.460	-0.221	-0.155
Ca	0.969**	0.982**	-0.695	-0.165	0.440	0.556	0.986**	-0.632	-0.711	-0.106	0.482
Mg	0.321	0.484	-0.519	0.039	0.997**	-0.418	0.324	-0.562	-0.555	-0.554	0.797
EA	0.551	0.782	-0.691	0.044	0.560	0.234	0.656	-0.305	-0.765	-0.737	0.898*
ECEC	-0.981**	0.975**	-0.670	-0.167	0.362	0.623	0.996**	-0.616	-0.684	-0.048	0.418
K. Sat	-0.858*	-0.819*	0.699	-0.033	-0.606	-0.316	-0.787	0.837*	0.698	-0.069	-0.356

** Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

Table 6: Correlation matrix between soil properties and thermodynamic parameters of soils under Shale mixed with sandstone and clay parent materials

	K. Activity Coefficient	K. Activity	Activity ratio	Mg. Activity Coefficient	Mg. Activity	Ca. Activity Coefficient	Ca. Activity	Electrical Conductivity	Free energy of replacement	PBC^K	Labile K
pH	-0.939**	-0.892*	0.584	0.732	-0.045	0.797	-0.878*	-0.928**	0.543	-0.304	0.265
Org. M	-0.813*	-0.844*	0.540	0.649	-0.154	0.949**	-0.748	-0.837*	0.406	0.020	-0.054
Total N	-0.856*	-0.781	0.657	0.674	-0.096	0.925**	-0.797	-0.906*	0.530	0.162	-0.156
Av. P	0.348	0.346	-0.524	-0.244	0.805	-0.585	0.091	0.304	-0.406	-0.327	0.398
Exch. K	-0.543	-0.947	0.097	0.868*	0.108	0.874*	-0.505	-0.655	0.051	-0.002	-0.088
Na	-0.265	0.030	0.389	0.072	0.183	0.206	-0.327	-0.339	0.307	0.443	-0.320
Ca	0.940**	0.758	-0.540	-0.614	-0.279	-0.626	0.996**	0.935**	-0.515	0.413	-0.434
Mg	-0.186	-0.304	-0.326	0.281	0.931**	0.001	-0.454	-0.263	-0.252	-0.503	0.538
EA	0.819*	0.467	-0.884*	-0.509	0.237	-0.635	0.701	0.837*	-0.810	-0.284	0.226
ECEC	0.802	0.504	-0.850*	-0.363	0.487	-0.713	0.651	0.750	-0.718	-0.134	0.124
K. Sat	-0.643	-0.657	0.643	0.578	-0.492	0.922**	-0.461	-0.684	0.491	0.435	-0.468

** Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

Table 7: Potassium status of the soils using K-saturation index (%) computed over ECEC

Very low	Low	Medium	High	Very high
< 0.05	0.05 -0.07	0.08 – 1.4	1.5 – 2.4	2.5- 3.5

4.0 DISCUSSION

Thermodynamic parameters describe the rate at which potassium at solid phase replenishes soil solution potassium. Thermodynamic approach has been successfully used to describe potassium replenishment in several soils (Al -Zubaidi, 2003) except for soils under oil palm (Osayande 2018). These parameters include ionic strength, activity coefficient and activity of K, activity ratio and free energy of replacement. In this study, the low values of ionic strength indicated that much of the potassium required for maximum fresh fruit bunch (FFB) yield by the oil palm existed in active form in the soil solution where it could be taken up by the palms or leached beyond the palms roots. The value of K-activity coefficient and K –activity in this study seems to complement those of ionic strength. The high values of both parameters indicated that much of the potassium ions in the soils existed in active forms especially as ionic strength values were low. This also indicated that ionic strength on one hand and K-activity coefficient and activity on the other have an inverse relationship with the same underlying meaning, i.e., K existing in active form in the soil solution (Al-Zubaidi, *et al.*, 2008). The activity ratio is a measure of the energy of exchange of K by exchangeable Ca in a soil. The value of the activity ratio depends on the potential of K in the soil but also on the potential of Ca in the same soil (Beckett 1964). Accordingly, for soils of comparable Ca status, the activity ratio should provide an adequate comparative measure of the potential of labile K and of the availability to plants of K in the soil so long as its uptake is not hindered by metabolites or antagonistic ions. The high values of activity ratio of this study indicated that much of the K in active form in the soil solution was labile and potentially available for the palms uptake or leachable depending on the prevailing environmental conditions. This agrees with earlier findings of Al-Zubaidi *et al.*, (2008); that high values of activity ratio indicated that more potassium was available for plants' uptake. In this study, the obtained activity ratio values in the equilibrium solutions were plotted against the values of change in exchangeable K, a series of linear curves as earlier observed by Rowell (1994) with high coefficient of determination ($R^2 = 0.75 – 0.99$) except for soils under basement complex rocks at 60 - 90 cm were obtained for the soils and this according to Al-Zubaidi *et al.*, (2008) confirmed Gapon coefficient. In this study, the obtained linear curves from the Freundlich Adsorption Isotherm differed in slopes and intercepts which defined the varied texture and mineralogy of the soils. Consequently, the soils under the three different parent materials differed in potassium activity coefficient, potassium activity, potassium activity ratio, magnesium activity, calcium activity, ionic strength and free energy of replacement. The nature of the soils parent materials however did not influence the potential buffering capacity and labile K content of the soils as these parameters were only influenced by cropping pattern (Osayande, 2018). In soils under alluvium, potassium activity, its coefficient and potential buffering capacity were controlled by ECEC while potassium saturation was controlled by its activity ratio. In soils under basement complex rocks, potassium and calcium activities were controlled by ECEC while the labile K content of the soils was controlled by exchangeable acidity. Potassium saturation was controlled by the electrical conductivity of the soils. In soils under shale mixed with sandstone and clay, potassium saturation was significantly correlated with calcium activity coefficient while exchangeable acidity had a significant correlation with potassium activity coefficient.

The suitability of the Freundlich Adsorption Isotherm in describing Q/I relationships has earlier been confirmed by several workers (Rowel, 1994; Al-Zubaidi, 2003; Al-Zubaidi *et .al*., 2008; Kenyanya, *et al*., 2013; Wajid *et al*., 2013; Osayande *et al*., 2017, 2020). In this study, the values of the Potential Buffering Capacity (PBC^K) and labile K from the slope and intercept of the curves respectively indicated that the soils had low capacities to replenish soil solution K when the K in solution was depleted due to palms' uptake or leaching. Furthermore, very little K was held in unspecific sites in the soil exchange complex while the free energy of replacement (-ΔF) indicated that the soils had poor capacities to supply potassium which could probably be attributed to the dominance of low activity clay minerals (LAC) in the soils. Potassium saturation was determined in consideration with the ECEC of the soils (Osayande, 2018). This is particularly due to the acidic nature of soils of the oil palm belt where hydrogen and aluminium are the dominant acidic cations and influence the adsorption and ultimate uptake of potassium in soils under oil palm. Potassium saturation values indicated that potassium status of the soils was very low. This was buttressed by values of the labile K and free energy of replacement (-ΔF).

5.0 CONCLUSION

The potassium status of soils under three different parent materials of the oil palm showed a very low potassium status of the soils. The soils differed in their potassium activity coefficient, potassium activity, potassium activity ratio, calcium activity, ionic strength, free energy of replacement and potassium saturation index due to influence of the soils parent materials. In soils under alluvium, potassium activity, its coefficient and potential buffering capacity were controlled by ECEC while potassium saturation was controlled by its activity ratio. In soils under basement complex rocks, potassium and calcium activities were controlled by ECEC while the labile K content of the soils was controlled by exchangeable acidity. In soils under shale mixed with sandstone and clay, potassium saturation was controlled by calcium activity coefficient with a significant correlation between exchangeable acidity and potassium activity coefficient. It follows that adequate maintenance of the ECEC status of soils under alluvium and Basement Complex Rocks through deliberate maintenance of cover cropping and frequent K fertilization could suffice in maintaining the soils K and Ca potential in contrast with soils under Shale Mixed with Sandstone and Clay that requires the application of K fertilizers blended with a little bit of lime.

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