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Potassium Dynamics and Relationships with Oil Palm Bunch Yields in Ultisols of NIFOR Main Station

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ABSTRACT

Background and Objective: Potassium is the most utilized element by oil palm for bunch production. It is labile and exists in four major forms that are in equilibrium with one another. It is important to know the form of K that correlates more with the bunch yield of oil palm. The objective of the study was to determine the most dynamic form of K that correlates with bunch yields of oil palm in an Ultisol. **Materials and Methods:** Potassium forms and dynamics and their relationships with fresh fruit bunch yields were studied in soils sampled from profile pits, accurately labelled, processed and analyzed for physical and chemical properties and forms of potassium using standard laboratory methods. Activities of potassium, calcium and magnesium were determined from their respective activity coefficients which in turn were determined from the extended Debye and Huckel equation. **Results:** The HNO_3 extractable K was the most dynamic form of K and constituted 31.95% of total K reserves bunch weight was significantly and positively correlated with HNO_3 extractable K (difficultly exchangeable K) with r = 0.943, $p<0.01$), residual K (r = 0.924, $p<0.01$); potassium activity coefficient (r = 0.834, $p<0.01$); calcium activity coefficient (r = 0.827, $p<0.05$) and calcium activity (r = 0.867, $p<0.05$). Bunch weight also correlated positively and significantly with the number of harvested bunches with (r = 0.902, $p<0.05$). **Conclusion:** It highlighted the need to manage the organic matter, nitrogen, potassium and calcium contents of Ultisols under oil palm by deliberate application of empty fruit bunches (EFB) to increase the total K reserve of the soil.

KEYWORDS

Bunch weight, number of harvested bunches, potassium dynamics, potassium activity, Ca activity, Mg activity

INTRODUCTION

Potassium is the most required element for bunch production in oil palm[1]. Its extraction is usually by ammonium acetate buffered at pH 7. This indicates the exchangeable K status in soils, which along with K saturation index have been commonly used to determine the potassium status of soils[2,3]. More studies on K nutrition have revealed that plants are able to use other forms of K to maintain their nutritional requirements[4]. This is mostly common in soils under tree crop cultivation like oil palm and shea tree[1]

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where potassium requirement is usually on a continuous with a constant drain on reserve potassium of the soils. It, therefore, follows that exchangeable potassium alone cannot adequately measure the potassium requirement of crops[5]. This is particularly true with tree crops such as oil palm as the drain on potassium is usually intensive. In Ultisols of the oil palm belt, the forms and dynamics of soil potassium are affected by changes in vegetative cover and biomass production[6]. This implies that the dynamic equilibrium that exists between the forms of potassium can be disrupted by changes in vegetative cover, biomass production and moisture content of soils under oil palm because soil potassium usually occurs in four forms which are in dynamic equilibrium with one another[4]. The direction of the dynamic equilibrium can shift depending on the preponderance of potassium in the soil. When potassium fertilization is made, the total K and other forms are replenished in the soil and K is immediately available for crops' uptake[4]. With respect to oil palm, this immediately available potassium is readily exhausted and palms begin to show signs of potassium deficiency as if potassium fertilization was never made. At this stage, the palms revert to mineral K reserves (acid extractable K) to maintain their nutritional K requirement. This process can only sustain the palm's nutritional K requirement for a short time after which it begins to shift again making the use of ammonium acetate extractable K unreliable for determining K requirement in oil palm. A more reliable way is to determine the forms of K along with the direction of its equilibrium. This study was conducted therefore to determine the forms and dynamics of potassium in Ultisols under oil palm at NIFOR main station. The specific objectives were to relate the forms of potassium with bunch yields of oil palm obtained from the field the soil samples were taken from.

MATERIALS AND METHODS

Description of the study area: The study commenced in 2015 and ended in 2018. It commenced by sampling soils of the Nigerian Institute for Oil Palm Research (NIFOR) developed on coastal plain sands (CPS) parent materials with four soil series: Ahiara, Orlu, Alagba and Kulfo[7]. The institute is located on Latitude 06°33'N and Longitude 05°371 with an Altitude of 149.4 m.a.s.l. Field 14, dominated by Orlu series was studied with the aid of three soil profiles measuring 100×70×120 cm.

Soil sampling: Soils from the three profiles were sampled from the bottom to the top of the horizons in polyethylene bags and accurately labelled and transported to the laboratory for further processing and analysis[8].

Laboratory analysis

Particle size distribution of the soils: The soils were air-dried and passed through a 2 mm sieve and thereafter analyzed for particle size distribution using the method outlined in Okalebo *et al.*[9].

Chemical properties of the soils: The chemical properties determined were soil pH, electrical conductivity, soil organic carbon, total nitrogen (N), available phosphorus and soil exchangeable cations using standard laboratory methods.

Determination of forms of potassium in the soils

The following forms of potassium were determined in the soils: Water soluble potassium was extracted in 1:2 soil-water suspensions after shaking for 2 hrs and allowing them to stand for an additional 16 hrs[10].

Exchangeable potassium was extracted by 1N NH_4OAc buffered at pH 7. The value includes both water-soluble and extractable forms. Water soluble K was subtracted from this value to obtain exchangeable K.

Fixed K or nitric acid-soluble K (difficultly exchangeable K) was obtained by extracting the soil with 1N HNO_3 in 1: 10 soil-acid suspensions after ten minutes of boiling[11]. The difference between the value obtained and that of exchangeable K is termed difficultly exchangeable K[11].

Potassium reserve: It was determined by the difference from the level of K extracted with 1N HCl using a soil-acid ratio of 1:10 and boiling the suspension for 60 minutes and exchangeable plus soluble K[12].

Total potassium was determined by HF/HClO$_4$ acid[13]. This was corrected for 10 M HCl extractable K and exchangeable K to give the residual K fraction. All K in the extract was read with the aid of a flame photometer[14].

Determination of activities of potassium, calcium and magnesium: Activity coefficients of potassium, calcium and magnesium were also determined[15]. The values of potassium, calcium and magnesium were those from water extraction and read by flame photo meter (Sherwood Scientific Model 410, manufactured in Cambridge, England, United Kingdom).

Ionic strength was determined as the product of 0.0129 and electrical conductivity[16]. Furthermore, weather data were obtained from the statistics division of the Nigerian Institute for Oil Palm Research (NIFOR) while yield data were obtained from the harvesting division.

Statistical analysis: All data obtained were subjected to one-way analysis of variance using Genstat Statistical Software version 12. A significant level of means was determined at 5% probability ($p<0.05$). Relationships between potassium dynamics and bunch yields were determined using simple correlation analysis and significant levels were determined at 1 and 5% levels of probability.

RESULTS

Physical properties of the soils: Sand and clay decreased significantly ($p<0.05$) with increased soil depths (Table 1). Silt also decreased with depth. There were higher values of sand and silt in the top soils in contrast with clay which had higher values in the subsoils. The textural class showed that the soils were sandy at the top soils and loamy sand at the subsoils while the silt/silt+clay ratios decreased with increased soil depth and were less than unity across the soil depth (Table 1).

Chemical properties of the soils: Soil pH, organic carbon, organic matter, total nitrogen and potassium decreased with increased soil depths while calcium and ECEC increased with increased soil depth. Available phosphorus, exchangeable sodium, magnesium and acidity were irregular with depth (Table 2).

Distribution of forms of potassium in the soils: Water soluble and exchangeable K as well as reserved K decreased with increased soil depths while the composition of water soluble K in exchangeable K also decreased with increased soil depth (Table 3). Difficulty exchangeable K, residual K and total K increased with increased soil depth. The composition of water-soluble K, exchangeable K, difficultly exchangeable K, reserved K and residual K in total K were 18.53, 22.44, 31.95, 27.07 and 50.49%, respectively with residual K having the highest percentage composition. The composition of water-soluble K in exchangeable K was high and ranged from 78.26 to 87.50% (Table 3).

Table 1: Physical properties of soils at NIFOR main station

Depth (cm)	Sand	Silt	Clay	Textural class	Silt/clay ratio
0-15	948.5^{a}	35.3^{a}	22.8^{a}	Sand	0.61
15-30	895.2^{ab}	35.3^{a}	69.5^{ab}	Sand	0.34
30-45	858.0^{b}	32.0^{a}	106.8^{bc}	Loamy sand	0.23
45-60	851.9^{b}	28.7^{a}	116.1^{bc}	Loamy sand	0.20
60-90	835.2^{b}	25.3^{a}	137.8^{c}	Loamy sand	0.16
90-120	834.0^{b}	20.3^{a}	146.0^{d}	Loamy sand	0.16
SE	42.85	NS	39.5		

Means with different alphabets were not significantly different using Duncan's Multiple Range Test at a 5% level of probability, NS: Non-significance and SE: Standard error

Table 2: Chemical properties of the soils at NIFOR main station

Depth (cm)	pH (H_2O)	Org. carbon	Org. Matter (g/kg)	Total N	P (mg/kg)	K	Na	Ca (cmol/kg)	Mg	EA	ECEC
0-15	5.53^{a}	10.03^{a}	17.29^{a}	0.33^{a}	12.28^{a}	0.02^{a}	0.49^{a}	3.29^{a}	0.23^{ab}	0.67^{a}	4.70^{a}
15-30	5.33^{ab}	6.61^{ab}	11.40^{ab}	0.33^{a}	14.43^{a}	0.02^{a}	0.47^{a}	3.19^{a}	0.21^{ab}	1.53^{b}	5.42^{a}
30-45	5.20^{ab}	4.81^{ab}	8.29^{ab}	0.52^{a}	17.36^{a}	0.02^{a}	0.45^{a}	3.17^{ab}	0.21^{ab}	0.87^{a}	4.72^{a}
45-60	5.00^{ab}	2.88^{b}	4.78^{c}	0.35^{a}	12.78^{a}	0.12^{a}	0.41^{a}	3.12^{b}	0.20^{a}	0.83^{a}	4.68^{a}
60-90	4.77^{b}	1.93^{b}	3.34^{c}	0.34^{a}	15.79^{a}	0.11^{a}	0.45^{a}	2.16^{c}	0.20^{b}	0.97^{a}	3.89^{a}
90-120	4.77^{b}	1.93^{b}	3.34^{c}	0.34^{a}	15.79^{a}	0.10^{a}	0.45^{a}	2.16^{c}	0.19^{b}	0.97^{a}	3.87^{a}
SE	0.17	2.56	5.80	NS	NS	0.01	NS	0.40	0.04	0.80	NS

Means with the same alphabets were not significantly different using Duncan's Multiple Range Test at 5% level of probability, NS: Non-significance, SE: Standard error. P: Phosphorus, mg/kg: Milligram per kilogram, K: Potassium, Na: Sodium, Ca: Calcium, Mg: Magnesium, EA: Exchangeable acidity, ECEC: Effective cation exchange capacity, Org.: Organic and H_2O: Water

Table 3: Distribution of forms of potassium in the soils at NIFOR main station

Depth (cm)	H_2O soluble K	NH_4OAC K	Diff-K (1N nitric acid K)	Reserved K (1N HCl-K)	Residual K (Total K-HCl+ Exch. K)	Total K ($HF/HCLO_4$)	Composition of H_2O-K in Exch.-K (%)	Status of K (Total K index)
0-15	0.18^{a}	0.23^{a}	0.20^{a}	0.26^{a}	0.34^{b}	0.72^{a}	87.50	Very low
15-30	0.16^{a}	0.19^{ab}	0.25^{a}	0.24^{a}	0.40^{a}	0.74^{a}	84.21	Very low
30-45	0.15^{a}	0.18^{ab}	0.26^{a}	0.22^{a}	0.41^{a}	0.82^{a}	83.33	Very low
45-60	0.14^{a}	0.16^{b}	0.27^{a}	0.22^{a}	0.43^{a}	0.88^{a}	81.25	Very low
60-90	0.13^{a}	0.16^{a}	0.33^{a}	0.17^{a}	0.49^{a}	0.94^{b}	81.25	Very low
90-120	0.13^{a}	0.16^{a}	0.33^{a}	0.17^{a}	0.49^{a}	0.94^{b}	78.26	Very low
Comp. in total K (%)	18.53	22.44	31.95	27.07	50.49			
SE	NS	0.01	NS	NS	0.04	0.02		

Means with the same alphabets were not significantly different using Duncan's Multiple Range Test at a 5% level of probability, NS: Non-significance and SE: Standard error

Table 4: Activity coefficients and activities of K, Mg and Ca in the soils

Depth (cm)	K activity coefficient (γ)	K activity (mol/L)	Mg activity coefficient (γ)	Mg activity (mol/L)	Ca activity coefficient (γ)	Ca activity (mol/L)
0-15	3.44^{a}	0.57^{a}	0.24^{a}	3.04^{b}	0.66^{b}	2.91^{a}
15 -30	3.50^{a}	0.64^{a}	0.23^{a}	3.03^{b}	0.66^{b}	2.93^{a}
30-45	3.52^{a}	0.67^{a}	0.22^{a}	3.0^{b}	1.89^{ab}	3.00^{a}
45-60	3.60^{a}	0.69^{a}	0.19^{a}	2.91^{ab}	2.29^{ab}	3.04^{a}
60-90	3.66^{a}	0.70^{a}	0.18^{a}	2.81^{a}	2.74^{ab}	3.14^{a}
90-120	3.66^{a}	0.70^{a}	0.18^{a}	2.81^{a}	3.63^{a}	3.14^{a}
SE	NS	NS	NS	0.12	1.29	NS

Means with the same alphabets were not significantly different using Duncan's Multiple Range Test at 5% level of probability, NS: Non-significance, SE: Standard error, K: Potassium; γ: Lower case gamma, mol/L: Moles per liter, Ca: Calcium, SE: Standard error and NS: Non-significance

Activity coefficients and activities of K, Mg and Ca in the soils: Potassium activity coefficient, potassium activity and calcium activity coefficient and calcium activity increased with increasing soil depths in the soils while magnesium activity coefficient and magnesium activity decreased with increasing soil depth (Table 4).

Correlation coefficient (r) between forms and thermodynamic properties of K and fresh fruit bunch yields of oil palm: Water soluble K positively and significantly correlated with magnesium activity coefficient and magnesium activity. Difficultly exchangeable K positively and significantly correlated with residual K, K activity coefficient, K activity, Ca activity coefficient, Ca activity and bunch weight while reserved K correlated with Mg activity coefficient and Mg activity. Similarly, residual K positively and significantly correlated with total K, K activity coefficient, K activity, Ca activity coefficient, Ca activity and bunch weight (Table 5). Furthermore, total K was positively and significantly correlated with K activity coefficient, K activity, Mg activity, Ca activity coefficient and Ca activity. The K activity coefficient was positively and significantly correlated with K activity, Ca activity coefficient, Ca activity and bunch weight. The K activity was positively and significantly correlated with Ca activity coefficient and Ca activity.

Table 5: Correlation coefficient between forms and thermodynamic properties of K and fresh fruit bunch yields of oil palm

	H_2O-K	Exch.-K	Diff. K	Res.-K	Red.-K	Total-K	K ACF	K activity	Mg ACF	Mg activity	Ca ACF	Ca activity	Bunch number	Bunch weight
H_2O-K	1													
Exch.-K	-0.390	1												
Diff. K	-0.961**	0.491	1											
Res.-K	-0.974**	-0.521	-0.987**	1										
Red.-K	-0.974**	0.474	0.998**	-0.979**	1									
Total-K	-0.963**	0.444	0.937**	-0.950**	0.946**	1								
K ACF	-0.973**	0.456	0.966**	-0.953**	0.977**	0.980**	1							
K activity	-0.979**	0.295	0.902*	-0.858*	0.921**	0.899*	0.909*	1						
Mg ACF	0.956**	-0.425	-0.922**	0.916*	-0.938**	-0.984**	-0.990**	-0.891*	1					
Mg activity	0.908*	-0.515	-0.938**	0.953**	-0.940**	0.968**	-0.975**	-0.803	0.970**	1				
Ca ACF	-0.914*	0.635	0.900*	-0.928**	0.903*	0.965**	0.929**	0.846*	-0.932**	-0.931**	1			
Ca activity	-0.946**	0.498	0.962**	-0.928**	0.962**	0.989**	0.976**	0.863*	-0.965**	-0.983**	0.961**	1		
Bunch number	-0.562	0.522	0.730	-0.722	0.695	0.487	0.533	0.522	-0.414	-0.521	0.515	0.580	1	
Bunch weight	-0.844*	0.615	0.943**	-0.942**	0.924**	0.807	0.834*	0.785	-0.757	-0.819*	0.827*	0.867*	0.902*	1

**Correlation is significant at 0.01 level, *Correlation is significant at a 0.05 level, H_2O-K: Water soluble K, Exch.-K: Exchangeable K, Diff.-K: Difficultly exchangeable K, Res.-K: Reserved K, Red.-K: Residual K, K ACF: K activity coefficient, Mg ACF: Mg activity coefficient and Ca ACF: Ca activity coefficient

Table 6: Yield parameters of oil palm

Year	Bunch number	Bunch weight (tons)
2005	405	1.631
2006	1024	7.142
2007	905	5.660
2008	2977	17.088
2009	3482	23.554
2010	3360	27.243
2011	4462	42.573
2012	4344	46.290
2013	3194	36.955
2014	4797	59.265
2015	5050	65.372

Source: Harvesting Division, NIFOR

The Mg activity coefficient was correlated with Mg activity. The Ca activity coefficient was positively and significantly correlated with Ca activity and bunch weight while number of harvested bunches positively and significantly correlated with bunch weight.

Yield parameters of Oil palm harvested from the plantation under investigation: The yield parameters of oil palm used for this study are indicated in Table 6. They were obtained from the plantation the soil samples were taken from. Records of number of harvested bunches and their weights averaged over a fifteen years were used for the study. Total number of harvested bunches were highest in 2015 with 5050 bunches weighing 65.372 tons (Table 6). The least number of harvested bunches recorded as 405 was obtained in 2005 with a weight of 1.631 tons (Table 6).

DISCUSSION

Particle size distribution of the soils showed that the top soils were sandy while the sub-soils were loamy sand. This indicated that the soils are poor retainers of nutrients and water. The silt/clay ratios decreased with increasing soil depth and were less than unity in the soils. This indicated that most of the silt was weathered into clay. Soil textural classes in the range of sand and loamy sand are poor in retaining water and nutrients and could account for the low soil water-soluble and exchangeable K contents of the soils[17]. The fact that most of the silt content had weathered into clay is buttressed by the lower amount of silt that progressively decreased with increased soil depths in contrast with clay which progressively increased with increased soil depths in this study. This observation was in agreement with Tarigan *et al.*[18]. Their work showed that higher amounts of clay that increased with increased depth indicated higher moisture and nutrient contents. The contents of the major nutrients were low being less than critical levels as reported by Subramaniam *et al.*[19] and Behera *et al.*[20]. Except for available P which was above the critical level as reported by Bai *et al.*[21]. Total N determined by micro Kjeldahl was below the soil critical value of 1.5% or

15 g/kg[22]. This was buttressed by the visible nitrogen deficiency observed on the palm leaflets during soil sampling. Available phosphorus (Bray-1) was quite adequate in the soils and fell within the recommended value of between 10.9 and 21.4 mg/k[21]. Potassium (K) and magnesium (Mg) determined by ammonium acetate buffered at pH 7 were well below established critical levels of 0.20 and 0.40 cmol/kg respectively[5,22,23]. Nitric acid extractable K, commonly referred to as difficultly exchangeable K positively and significantly correlated with bunch weight of the palms. This showed that oil palm utilizes more of this form of K than the labile forms which though equally important are readily exhausted and become limiting a few months after fertilization depending on the prevailing environmental factors. This assumption is buttressed by the positively significant correlations of difficultly exchangeable K with residual K which is the K in the structural lattice of the soils. Furthermore, it also correlated positively and significantly with total K, K activity coefficient and K activity itself as well as Ca activity coefficient and Ca activity. There was also a correlation between the number of harvested bunches and the bunch weight of the palms. In an earlier study of the same soils, Efosa *et al.*[1] found a relationship by means of simple regression analysis between the labile K content of the soils and the potential buffering capacity with respect to K (PBC^K) with a number of harvested bunches but not with the bunch weight. It, therefore, follows that inadequate K in Ultisols under oil palm may result in a reduced number of harvested bunches but not necessarily in weight since the NIFOR hybrid tenera palms derived from extension work seeds (EWS) are able to utilize the less readily soluble form of K for its K nutritional requirement.

The implication of the correlation between nitric acid extractable K and bunch weight is that regular application of potassium fertilizers to soils under oil palm is required to boost the K-reserves including the total K of Ultisols to cater for both the immediate and future K nutritional requirement of the palms. The results from this study could be applied to improve Ultisols under oil palm. It also recommends the inclusion of calcium-bearing materials in formulating fertilizers for the oil palm because bunch weight correlated significantly with calcium activity coefficient and calcium activity. The limitation of the study is that it did not determine the type and dosage of K-bearing materials to be used in improving the K reserves of Ultisols under oil palm.

CONCLUSION AND RECOMMENDATIONS

The study showed that the bunch weight of oil palm under Ultisols at field 14 of NIFOR main station correlated positively and significantly with HNO_3 extractable K (difficultly exchangeable K), potassium activity coefficient, calcium activity coefficient and calcium activity. The HNO_3 extractable K correlated positively and significantly with residual K, total K, K activity coefficient, Ca activity coefficient and calcium activity while bunch weight correlated positively and significantly with a number of harvested bunches. The study therefore recommends:

- Application of empty fruit bunches (EFB) to the soils to increase the organic matter content
- Application of lime-containing inorganic fertilizers to reduce acidity and improve overall soil fertility
- Adequate maintenance of the current cover cropping system using *Pueraria phaseoloides*

Finally and most importantly, the need to increase the K fertilization through K addition by way of Muriate of Potash to reduce the drain on the reserve and residual K contents of the soils.

SIGNIFICANCE STATEMENT

Determination of exchangeable potassium index has been the commonest means of assessing crop K requirement in soils. Recent studies have however shown that such assessment may be inadequate in assessing oil palm K requirement in Ultisols. The study was conducted therefore to determine the most dynamic form of K that correlates with the weight and the number of harvested bunches of oil palm in Ultisols. The study showed that HNO_3 extractable K was the most dynamic form of K in Ultisols under oil palm and constituted 31.95% of total K. Water soluble and exchangeable K were less significant. The study has shown that potassium requirement of oil palm can be sustained through replenishment of the total K reserves of the soils.

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