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Research Article
Relationship Between Some Thermodynamic Properties and Yield Parameters of Oil Palm in an Ultisol

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Abstract

Background and Objective: *Elaeis guineensis* Jacq commonly known as oil palm is considered as one of the most important source for oil production globally. The relationship between some thermodynamic properties (Potential Buffering Capacity to potassium (PBC^K), Labile K, activity ratios) and yield parameters (number and weight of fresh fruit bunches) of oil palm in an Ultisol was evaluated at the Nigerian institute for oil palm research (NIFOR) main station to determine which thermodynamic parameter are require to manage for yield improvement in oil palm. **Materials and Methods:** Potential buffering capacity with respect to potassium (PBC^K) and Labile K were obtained from linearised isotherms obtained after equilibrating 2.5 g of the soils in 0.01M $CaCl_2$ at a temperature of 25+1°C for 24 h. Activity ratios of potassium (AR^K) were computed from $^aK/(^aCa+^aMg)^{1/2}$ while yield parameters averaged over a 15 year period from field 14 at NIFOR main station from which the soil samples were obtained were related to these parameters by simple linear regression models. **Results:** Results showed that 73.1% of the total variations in number of bunches of oil palm were accounted for by the Labile K content of the soils while 53.0% of the variations in number of bunches could only be accounted for by the PBC^K. **Conclusion:** The study concludes that the lack of relationship between activity ratios and oil palm yield parameters shows that potassium fertilization made to improve yield of oil palm does not necessarily need to be made in consideration with Ca and Mg minerals.

Key words: Activity ratio, labile K, oil palm, PBC^K and yield parameters

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The Oil palm (*Elaeis guineensis* Jacq), widely known for its red palm oil[1], is cultivated on a wide range of soils, notably amongst which are the so called acid sands, which have been classified as Ultisols or Alfisols depending on their base saturation percent[2]. These acid sands dominate soils of the Nigerian Institute for Oil Palm Research (NIFOR) main station[2] and are developed on coastal plain sand parent materials[3]. Ultisols is a prominent soil order within the tropics[4-6] and form bulk of the soils under oil palm at the main station of the Nigerian Institute for Oil Palm Research. These soils vary in their nutrient content, particularly potassium, which undoubtedly is the most required element for fresh fruit bunch production by the oil palm[7]. Assessment of potassium uptake by plants according to Zharikova[8] must be done using both the intensive parameters (p-values) and extensive parameters, i.e., the contents of potassium and calcium in soils. These two factors characterize two aspects of ion status in soils and their complementary relationships can be interpreted by use of the potential buffering with respect to potassium (PBC^K). The PBC^K is related to sorption-desorption processes acting in the soil. The range of its values is divided into very low (<20), low (20-50), medium (50-100), elevated (100-200) and high (>200).

Labile-K is the K that is adsorbed on unspecific sites (p-positions) in the soil exchange complex. These positions are of relatively low and even energy of bonds that are believed to be associated with exchangeable cations[9]. In addition, K is present in positions with higher but uneven energy of bonds and projected parts of crystal surfaces, i.e., on specific exchange positions also constitute part of the labile-K pool.

The intensity which is related to the K in solution is defined as the activity ratio given by:

$$AR^k = {}^aK/({}^aCa+{}^aMg)^{1/2}$$

assuming Ca and Mg to be the dominant cations in the soil[10]. In the equation, ^aK, ^aCa and ^aMg refer to the activities of K, Ca and Mg ions respectively in the soil solution[9-11]. These parameters (PBC^K, Labile-K and AR^K) have been related to cropping activities by various workers[10], found a reduction in labile-K and activity ratios, AR^K with increased PBC^K after cropping on the soils while[11] found a good relationship between activity ratio which considered aluminium for the acid Nigerian soils known as unified activity ratio, AR_u and yield response to K in oil palm field experiments.

In this present study, attempt has been made to determine the relationship between yield parameters of oil palm (Number and weight of fresh fruit bunches) and PBC^K, labile-K and Ar^K.

MATERIALS AND METHODS

Soil sampling procedures: Eighteen soil samples were obtained in 2015 from 3 profile pits sunk at field 14 dominated by Orlu series at the Nigerian Institute for Oil Palm Research (NIFOR) main station to cover slight differences in the location. This research project was conducted from September, 2015 to November, 2018. Profiles I, II, III were sited on 164 m ASL on N $06°32^{1}59.7^{11}$, E $005°37^{1}15.8^{11}$, 159 m a.s.l (N $06°32^{1}59.9^{11}$, E $005°37^{1}18.5^{11}$), 160 m a.s.l (N $06°33^{1}00.7^{11}$, E $005°37^{1}17.3^{11}$). The soil samples were taken to the laboratory, air-dried and sieved through a 2 mm mesh after which further analysis were carried out.

Determination of PBC^K and labile K: 2.5 g of the soil samples were put in 25 mL solutions of 0.01M $CaCl_2$ that contained potassium concentrations of 0, 4, 8, 16 and 32 mg L^{-1} and shaken for 24 h at 25+1°C to achieve equilibration. The contents were filtered using Whatman No 42 filter papers. The concentration levels of potassium in the filtrate were measured using a flame photometer[12].

Adsorption isotherms were constructed using the method described by Kenyanya *et al.*[13]. The amount of K adsorbed was obtained by subtracting the amount found in filtrate from the initial amount that was in solution as shown in Eq. 1:

$$\Delta K = (CK_i - CK_f)\frac{V}{M} \qquad (1)$$

where, 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 Kenyanya *et al.*[13], given as follows:

$$\text{Log } x/m = \text{Log } a + b \log C \qquad (2)$$

where, x/m is the mass of adsorbed K per unit mass of soil (mg kg^{-1}, C is the equilibrium K concentrations of solutions (mg L^{-1}), a and b are constants obtained from the intercept and slope, respectively. The ionic strength of the soils was calculated by a formula proposed by Griffin and Jurinak[14]:

$$\text{Ionic strength} = 0.0129 \times EC \quad (3)$$

where, EC is electrical conductivity of soil pastes in dS m^{-1}.

Activities of potassium, calcium and magnesium ions were tabulated as the product of their activity coefficients (f_i) and their concentrations (C_i) as shown in Eq. 4:

$$a_i = f_i \times C_i \quad (4)$$

The f_i of the ions were determined using the extended Debye and Huckel[15] equation cited by Al-Zubaidi *et al.*[9] as shown in Eq. 5:

$$\text{Log } f_i = -AZ_i^2 \frac{\sqrt{\mu}}{1+\beta d_i \sqrt{\mu}} \quad (5)$$

Where:

- Z_i = Valency of ion
- A = 0.508 for water at 298 Kelvin
- β = 0.328×10^8 at 298 Kelvin
- d_i = Effective size of hydrated ions
- μ = Ionic strength of cation

Determination of activity ratio of potassium (^{Ark}): The activity ratio of potassium ions were calculated as suggested by Beckett[16] and Zubaidi *et al.*[9]:

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

Statistical analysis: Data obtained were fitted into a simple linear regression with yield parameters taken as the dependent variable (Y) while values of PBC^K and Labile-K obtained from the isotherms as well as computed values of the activity ratios taken as the independent variable (X).

RESULTS AND DISCUSSION

PBC^K, Labile-K, activity ratio and yield of oil palm: The values of the PBC^K and labile-K are indicated in Fig.1-6. The values of the PBC^K ranged from 0.70-1.82 cmol kg^{-1} mol L^{-1} (Fig.1-6). These are extremely low values using[10] classifications as follows: very low (<20), low (20-50), medium (50-100),

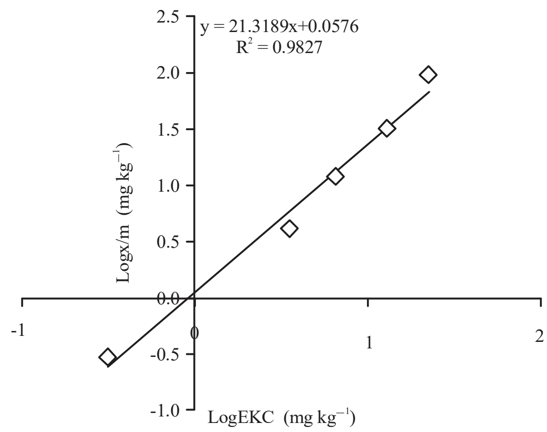

Fig. 1: Freundlich adsorption isotherm for 0-15 cm NIFOR soils

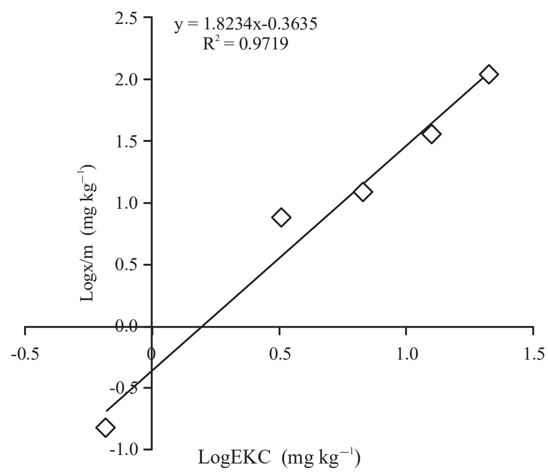

Fig. 2: Freundlich adsorption isotherm for 15-30 cm of soils of NIFOR

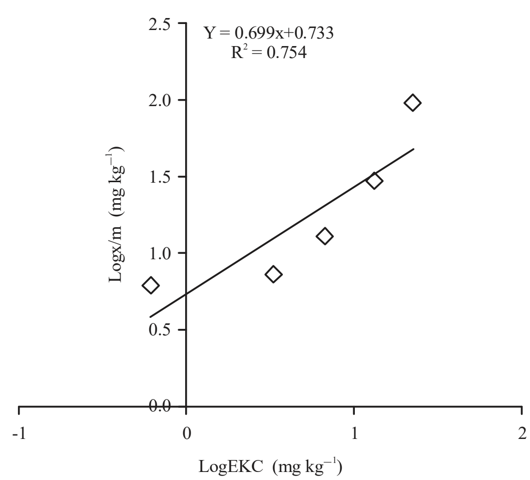

Fig. 3: Freundlich adsorption isotherm for 30-45 cm of soils of NIFOR

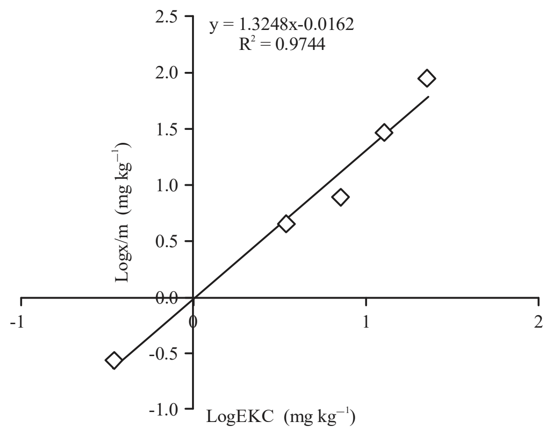

Fig. 4: Freundlich adsorption isotherm for 45-60 cm of NIFOR soils

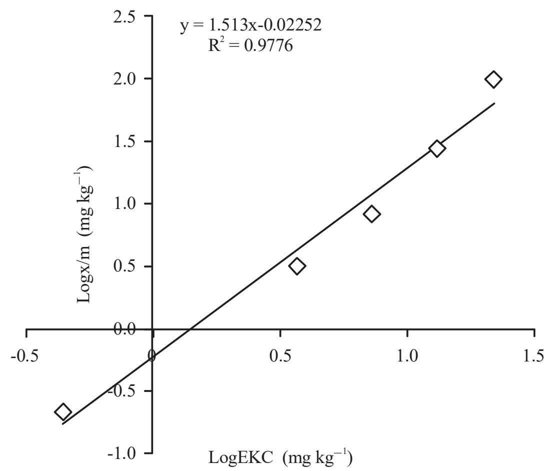

Fig. 5: Freundlich adsorption isotherm for 60-90 cm NIFOR soils

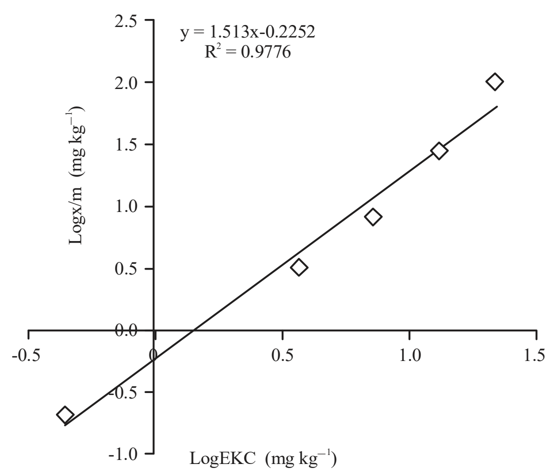

Fig. 6: Freundlich adsorption isotherm for 90-120 cm soil of NIFOR

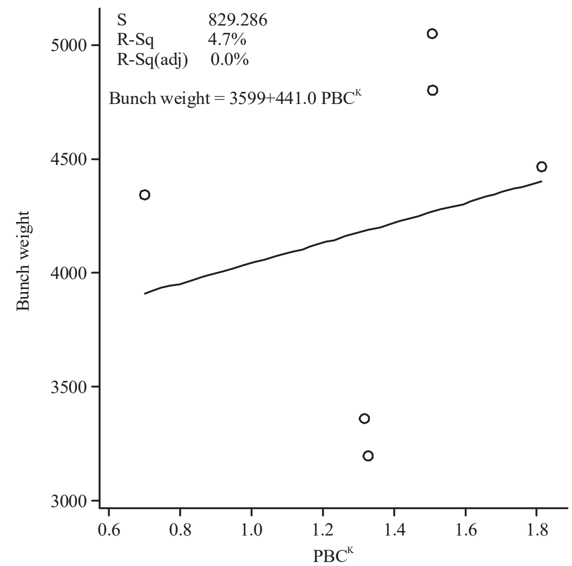

Fig. 7: Relationship between bunch weight and PBC^K of oil palm

elevated (100-200) and high (>200). These very low values indicated that the soils are poor in their ability to resist changes with respect to potassium. In concrete terms, it signifies that the dynamics of potassium in the soils might be in one direction only. Simply put, if K is often leached in the soils due to high rainfall, high total porosity and the presence of low activity clays, this might continue for a long time because the soils lack what it takes to prevent this phenomenon. Furthermore, the extremely low PBC^K values indicated the lack of inputs in the soils with respect to potassium fertilizers. The values of the labile-K were just as low and ranged from 0.016 -0.733 cmol kg^{-1} (Fig. 1-6). This is the K held in unspecific sites and ready to be taken up by the palms or leached. The low values of the labile-K were due to the low values of the PBC^K. The computed activity ratio values ranged from 0.18 -0.24 $(M\ L^{-1})^{1/2}$ (Table 1) and compare well with values obtained by earlier workers[9-11]. The yield parameters of oil palm averaged over a fifteen year period were indicated in Table 1.

Relationship between yield parameters of oil palm, PBC^K, labile-K and activity ratios of the soils: The fitted regression equations relating the yield parameters with PBC^K, Labile-K and activity ratios respectively are indicated in Fig. 7-11. The relationship between yield parameters of oil palm (number of bunches and bunch weight of fresh fruit) and PBC^K are shown in Fig. 7 and 8. There was no relationship between PBC^K and bunch weight of oil palm (Fig. 7) as shown by the values of coefficient of determination R^2 since only 4.7% of the

Table 1: Yield parameters and computed activity ratios of Oil Palm at NIFOR main station

Years	Bunch number	Bunch weight	Depth (cm)	Activity ration (m $L^{-1})^{½}$
2005	405	1.631	0-15	0.24
2006	1024	7.142	15-30	0.23
2007	905	5.660	30-45	0.22
2008	2977	17.088	45-60	0.19
2009	3482	23.554	60-90	0.18
2010	3360	27.243	90-120	0.18
2011	4462	42.573		
2012	4344	46.290		
2013	3194	36.955		
2014	4797	59.265		
2015	5050	65.372		

Source of yield records: Harvesting division, Nigerian institute for oil palm research (NIFOR)

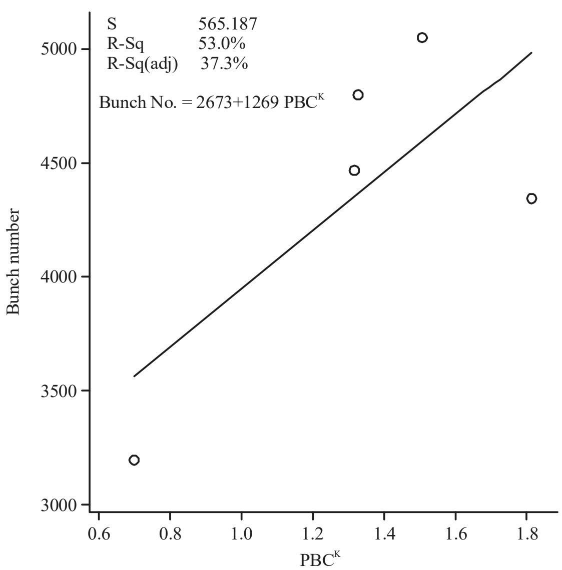

Fig. 8: Relationship between bunch number and PBC^K of oil palm

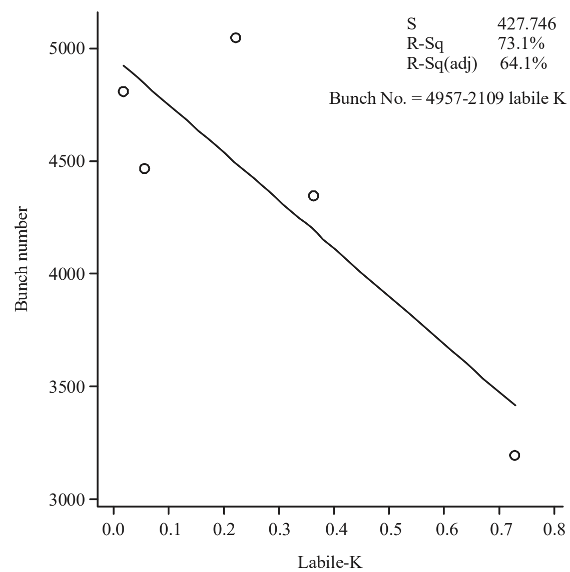

Fig. 10: Relationship between bunch number and labile K of oil palm

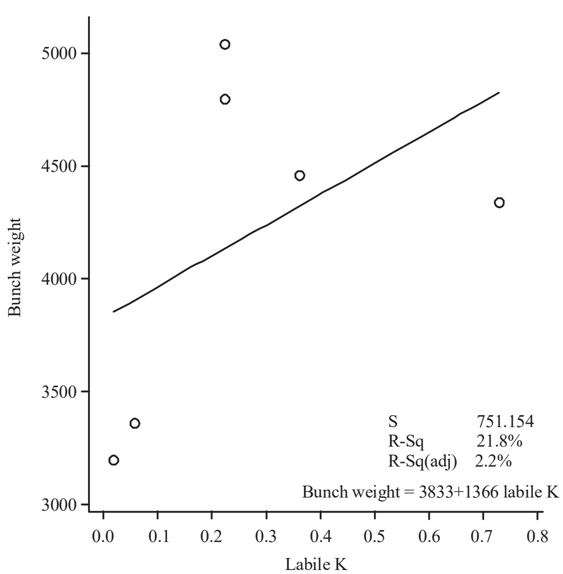

Fig. 9: Relationship between bunch weight and labile K of oil palm

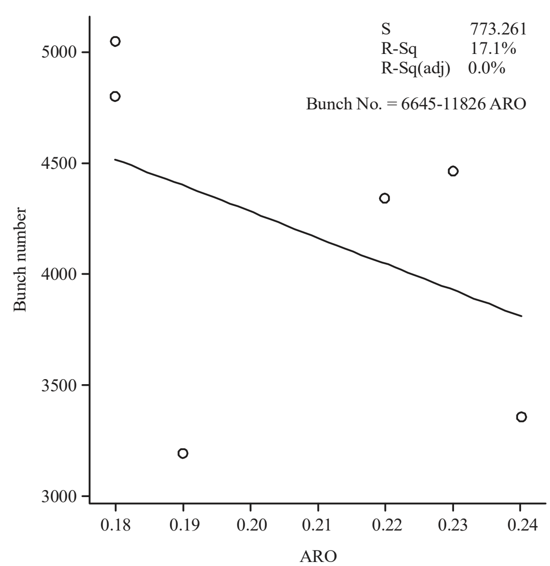

Fig. 11: Relationship between bunch number and activity ratio of oil palm

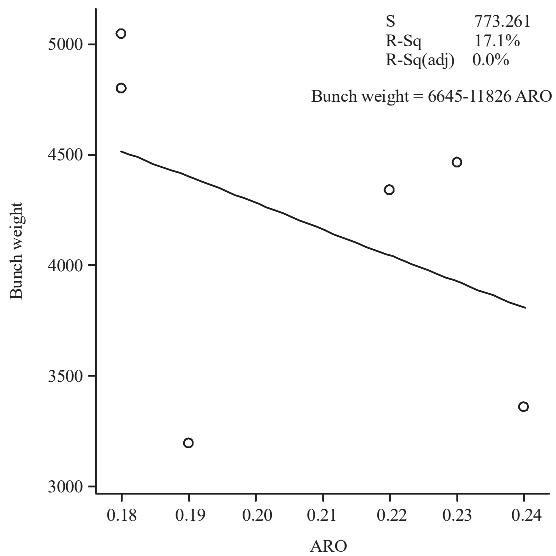

Fig. 12: Relationship between bunch weight and activity ratio of oil palm

bunch weight were accounted for by the labile-K content of the soils. There was however a very strong relationship between number of bunches and labile-K content of the soils (Fig. 10) as 73.1% of the variations in number of bunches of oil palm were accounted for by the labile-K content of the soils. The labile-K content of soils is the K that can be taken up by plants or leached when not taken up. There were no relationships between bunch weights, number of bunches and activity ratios of the soils (Fig. 11, 12) as only 17.1% of the variations in bunch weights and number of bunches were accounted for by the activity ratios of the soils. It has been shown that oil palm yields may fluctuate with a 3-5 years cycle[17]. To overcome this, Tinker averaged oil palm yield records for at least 4 years[11]. In this study, oil palm yield records were averaged for 15 years.

CONCLUSION

The relationship between labile-K and number of bunches showed that 73.1% of the variations in number of bunches were accounted for by the labile-K content of Ultisols under oil palm while 53.1% of the variations in number of bunches were accounted for by the PBC^K. The lack of relationship between bunch weight, number of fresh fruits of oil palm and activity ratios of the soils showed that potassium fertilization for oil palm yield improvement need not be made in consideration with Ca and Mg minerals as earlier suggested.

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SIGNIFICANT STATEMENT

This study has discovered that there exists a relationship between labile-K (soil solution K) and number of bunches of oil palm grown on Ultisols. It has shown that potassium fertilizers made to improve oil palm can be applied without a corresponding application of Ca and Mg minerals. This study will help the researcher to uncover the critical areas of potassium fertilization for yield improvement in the oil palm. Thus a new theory detailing the mechanism of action of potassium fertilization on PBC^K and number of fresh fruit bunches may be arrived at.

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