Nigerian Journal of Soil Science
Journal homepage:www.soilsjournalnigeria.com

DISTRIBUTION OF FORMS OF POTASSIUM IN SOILS CULTIVATED TO SHEA (*Vitellaria paradoxa* C.F. GAERTN) TREES AT BIDA, NIGER STATE, NIGERIA.

[1]Osayande, P.E., [1]Oviasogie, P.O., [2]Orhue, E.R., [1]Udoh, J. J. and [1]Awanlemhen, B. E.
[1]Chemistry Division, Nigerian Institute for Oil Palm Research, P.M.B. 1030, Benin City-Nigeria.
[2]Department of Soil Science, Faculty of Agriculture, University of Benin, P.M.B.1145, Benin City-Nigeria.

ABSTRACT
The distribution of potassium forms was studied at Bida, Niger state as part of the Shea butter tree domestication effort of the Nigerian Institute for Oil Palm Research. Soil samples were obtained with the aid of a soil auger at 0-15 and 15-30 cm. The soil samples were air dried, sieved with a 2 mm sieve and analyzed for some physical, chemical and potassium forms using standard methods. Results indicated that a state of dynamic equilibrium exists among the forms of potassium as significant correlations were obtained between total K and difficultly exchangeable K, total K and exchangeable K and total K and residual K with ($r = 1.000$, $P< 0.01$); ($r = 0.983$, $P< 0.01$); ($r = 0.944$, $P< 0.01$)) respectively. In terms of relationship between the forms of K and the particle size distribution of the soils, total K had a very strong relationship with silt with an r^2 value of 61.7 % while difficultly exchangeable K had a strong and moderate relationship with silt and clay with r^2 values of 65.9 % and 50.1% respectively. Water soluble K had strong relationships with silt and clay with r^2 values of 67.5 % and 60.1% respectively. A weak relationship however exists between the forms of K and sand in the soils. While there may not be an urgent K-fertilization need in the soils as revealed by the K-saturation index, the mobile K however showed a moderate K status of the soils. This implies that it might be useful if K fertilization is made at the onset of flowering, a period which corresponds to peak demand in K by crops.
Key words: Bida, NIFOR, Shea tree, potassium

INTRODUCTION

The Shea butter plant (*Vitellaria paradoxa* C.F. Gaertn) is a tree species growing extensively in the Agroforestry parklands of Semi-arid Africa zone from Senegal to Uganda, where it is protected and managed (Hall *et al.,* 1996; Maranz *et al.,* 2004). The tree according to Abubakari *et al.* (2012) is very important in the rural health care and the rural economies in the Sudano-Sahelian regions of Africa. The distribution of the Shea tree in the savannah regions of Africa is greatly affected by climatic and soil factors. Critical soil factors affecting the distribution of the Shea tree appear to be soil physical and chemical properties (Abubakari *et al.,* 2012). The physical and chemical properties of soils have a direct correlation with the nutrient status of soils. Responses to applied nitrogen and phosphorus fertilizers have been reported for Shea seedlings (Dianda *et al.,* 2012). Next to nitrogen, potassium is the mineral nutrient required in large amount by plants. It plays a direct role in fruit quality and maintenance of cellular organizations by regulating permeability of cell membranes and keeping the protoplasm in a proper degree of hydration (El-Nemr *et al.,* 2012). Plants growing in potassium deficient soils are susceptible to fungal and bacterial disease attack (Biswas and Mukherjee, 1994).

Exchangeable potassium (K) is widely used for evaluating the soil potassium status and prediction of crop potassium requirements (Samadi, 2006; Krauss, 2003), while in some countries, the potassium saturation index (%) is used for the assessment of soil potassium status (Mutscher, 1995). However, recent studies have shown that exchangeable potassium alone cannot be used as the basis for evaluating potassium availability under intensive cropping (Bansal *et al.,* 2002). According to Bansal *et al.* (2012) soils that were considered sufficient in exchangeable potassium were not able to maintain that condition for long under intensive cropping with high yielding varieties. This confirmed an earlier observation that as cropping becomes more intensive, the drain on potassium increases and the occurrence of potassium deficiency will likely become more widely spread in the soils of the Savanna zone of Nigeria (Wild, 1971). There is a continuous but slow transfer of potassium in the primary minerals to the exchangeable and slowly available forms of potassium (Kirkman *et al.,* 1994). The release of these non-exchangeable forms of potassium occur when the level of exchangeable potassium and solution potassium (labile K) was decreased by crop removal and or leaching (Sparks, Martens and Zelanzny, 1980). The quantity of these non-exchangeable forms of potassium (Total K, reserved K, mobile and residual K) present in a soil has been the basis for the assessment of the potassium status in soils in recent times.

This study was therefore undertaken to determine the quantity of non-exchangeable forms of potassium in soils supporting Shea tree cultivation at Bida, Niger state with a view to predicting Shea tree potassium requirement. This is part of the effort at domesticating the Shea butter tree in Nigeria.

MATERIALS AND METHODS:

Study area

This study was conducted at the Nigerian Institute for Oil Palm Research Substation, Bida, Niger State. The area falls within the Southern Guinea Savannah zone of Nigeria and is located on Latitude 080 05.278'N and Longitude 006^0 47.789'E with annual rainfall ranges between 500 mm to 1200 mm per annum. Minimum and maximum temperature ranges between 24 ^{0}C and 33 ^{0}C respectively. The site is generally flat with the presence of a few ant hills. The major land use types in the area are arable crop production intercropped in Shea tree parklands. The Shea field used for this study is part of the domestication effort for Shea butter tree of the Nigerian Institute for Oil Palm Research at Bida. And no previous fertilizer application has been made in the field.

Soil sampling

Representative soil samples were obtained at two depths, surface (0-15 cm) and subsurface (15-30 cm) with the aid of a soil auger from a field cultivated to the Shea tree. Soil samples obtained were bulked into a composite, mixed thoroughly and replicated three times. Soil samples obtained were air-dried and sieved to pass through a 2- mm mesh.

Soil analysis

The particle size distribution was determined by the hydrometer method as described by Boyoucous (Gee and Or 2002). The soil organic carbon was determined by the Walkley-Black method (Nelson and Sommer, 1996) and multiplied by 1.724 to obtain organic matter. Soil pH was determined in 1:1 Soil to water solution using a pH meter (Hendershot *et al.*, 1993). Soil exchangeable bases were extracted by the ammonium acetate method buffered at pH 7 (Thomas, 1982). Calcium and magnesium were read with the aid of a UV 2100 Spectrophotometer while potassium and sodium were read with a flame photometer. Effective cation exchange capacity (ECEC) was determined by summation of exchangeable cations and exchangeable acidity ((Kamprath,1970; Mylavarapu and Kennelley, 2002).

Potassium fractionation:

1 *Water soluble potassium*:

Water soluble K was extracted in 1:2 soil-water suspensions after shaking for two hours and allowing them to stand for additional sixteen hours (Maclean, 1961).

2 *Exchangeable potassium:*

Exchangeable potassium was extracted by normal ammonium acetate (1N NH_4OAc) buffered at pH 7 (Thomas 1982)

3 *Potassium supplying power*:

The potassium supplying power was obtained by extracting the soils with 1N Nitric acid (1 N HNO_3) in 1: 10 soil – acid suspension with boiling for 10 minutes (Graley *et al.*, 1960).

4 **Potassium reserve**:

Potassium reserve was extracted with 1N HCl using a soil – acid ratio of 1: 10 and boiling the suspension for 60 minutes (Graley *et al.*, 1960)

5. **Total potassium**:

Total potassium was obtained by digesting the soils in a mixture of concentrated HNO_3 and Perchloric acid ($HClO_4$) using a soil – acid ratio of 1:10.

*Data analysi*s: Data obtained were subjected to One- way analysis of variance (ANOVA) and the Least Significance Difference (LSD) at 5 % level of probability was used to separate the means while regression analysis was used to estimate the relationship between the forms of K and some physical and chemical properties.

RESULTS AND DISCUSSION

Physico-chemical properties of the soils

The physical and chemical properties of the soils are shown in Table 1. Sand was 953.3 g/kg and 946.7 g/kg in both top and sub soils respectively and decreased with increased soil depth. Silt also decreased with increasing soil depth while clay increased with increasing soil depth (Table 1). The soils are therefore sandy in texture.The soil pH was slightly acidic in both soil depths. Soil pH and organic matter had the same trend of decreasing significantly with increasing soil depth. Organic matter content of the soils was low with values of 6.21 g/kg and 5.17 g/kg at the top and sub soils respectively. Low soil organic matter contentis typical of the Guinea Savanna regions of Nigeria (Amakhian and Osemwota, 2012). Agboola and Corey, (1972) reported a value of 30 g/kg as the critical level of organic matter in soils. According to Agboola and Corey (1972) the low value of organic matter coupled with the sandy texture of the soil would encourage a rapid leaching of cations into the subsoil from the surface soils.This probably explains the increase in calcium, magnesium, sodium and potassium with increasing soil depth (Table 1).The low values of ECEC observed in the soils agrees with those of Amakhian and Osemwota (2012) who reported low values of ECEC in soils of the Southern Guinea Savanna Zone of Nigeria.

Forms of potassium in the soils

Total potassium: The various forms of potassium are shown in Table 2. Total potassium was 0.56 cmol/kg and 0.59 cmol/kg at the top and sub soils respectively and increased significantly with increasing soil depth (Table 2). The low values recorded for total potassium agrees with the findings of Wild (1971) who reported that total potassium of soils derived from Nupe Sandstones and false bedded sandstones contained only 0.06 % to 0.11% (0.57-0.58 cmol/kg) of the forms of potassium in the soils. The soils under observation are derived from Nupe Sandstones and false bedded Sandstones. Total potassium significantly correlated with potassium supplying power, exchangeable potassium and residual potassium with ($r = 1.00$, $P<0.01$); ($r = 0.983$, $P< 0.01$) and ($r = 0.944$, $P< 0.01$) respectively (Table 3) thus indicating a state of equilibrium among these forms of K. Ano (1991) observed a significant correlation between total K and potassium supplying power, exchangeable potassium and residual potassium and concluded that they were in equilibrium with one another. Total K had a strong and very strong relationship with silt and organic matter with r^2 values of 61.7% and 94.7 % respectively (Table 4). Aghimien and Osemwota (2010) obtained a sig-

Table 1: Physical and chemical properties soils cultivated with Shea butter trees at Bida.

Depth (cm)	Sand	Silt	Clay	Org. Matter.	pH	Ca	Mg	Na	K	CEC
	←		(g/kg)	→		←		cmol/kg		→
0-15	**953.33**	**243.33**	**234.33**	**6.21**	**5.50**	**1.05**	**0.49**	**0.32**	**0.12**	**1.98**
15-30	**946.67**	**230.00**	**260.00**	**5.17**	**5.30**	**1.06**	**0.87**	**0.49**	**0.10**	**2.52**
LSD (5%)	NS	NS	NS	0.2	0.2	NS	0.10	0.02	0.02	0.02

LSD= Least Significant Difference.

Table 2: Forms of potassium in the soils of a Shea field at Bida, Niger state.

Depth (cm)	Total K	H_2O Soluble K	Reserved K (HCl extract)	Difficultly Exch. K (HNO_3 extract)	Exchangeable K (NNH_4OAc extract)	Residual K (Total K-(Exch. K + HCl extracted K)	K-saturation Index
	←		cmol/kg			→	
0-15	0.56	0.13	0.35	0.33	0.12	0.03	0.06
15-30	0.59	0.13	0.34	0.36	0.10	0.13	0.04
LSD (5%)	0.02	NS	NS	0.02	0.02	0.02	

LSD= Least Significant Difference.

nificant correlation between total K and silt of soils formed from Shale mixed with sandstone and clay and fresh water swamps.

Water soluble K was low with values of 0.13 cmol/kg at both soil depths. These low values corresponded with the findings of Aghimien and Osemwota (2010) who reported water soluble K values of 0.12, 0.09, 0.08, 0.10 and 0.10 for soils formed from five different parent materials which were Crystalline metamorphic and igneous rocks, Shale mixed with sandstone and clay, Coastal plain sand, Coastal alluvium and Fresh water swamps respectively.Water soluble K significantly correlated with reserved K which according to Ano, (1991) indicated a state of equilibrium between water soluble K and reserved K in the soil under observation. Water soluble K had a strong relationship with silt and clay components of the soil with r^2 values of 67.5 % and 60.1 % respectively (Table 4).

The values of the potassium reserve were lower than the values of the total potassium but were slightly higher than difficultly exchangeable potassium. The low values of reserved K observed in these soils agrees with the findings of Adegite (1993) who reported low potassium reserved values in soils of Nupe Sandstones parent materials. Reserved K constitutes a major part of the total non-exchangeable potassium which is released under intensive cropping (Udo and Ogunwale, 1978). The degree of sufficiency of K for crop uptake depends on the level and ease of release of K from the K reserves of the soils (Udo and Ogunwale, 1978). The values of K reserve which were 0.35 cmol/kg and 0.34 cmol/kg in both top and subsoil respectively also agrees with the findings of Aghimien and Osemwota (2010) who recorded K reserve values of 0.34 cmo/kg, 0.2 cmol/kg, 0.39 cmol/kg and 0.27 cmol/kg for surface soils of Southern Nigeria formed from Shale mixed with sandstone and clay, Coastal plain sands, Coastal alluvium and Fresh water swamps respectively. Reserved K had no correlation or relationship with particle sizes and organic matter of these soils.

The Difficultly exchangeable K or Mobile K is generally regarded as the K-supplying power of the soil and refers to the K extracted with 1N HNO_3 with 10 minutes boiling. The values were 0.34 cmol/kg and 0.37 cmol/kg in both top and sub soils respectively. These values increased significantly with increasing soil depth (Table 2).Difficultly exchangeable K had a positive and significant correlation with exchangeable K with (r = 0.983, P< 0.01) and residual K with (r = 0.944, P< 0.01) (Table 3). This according to Ano (1991) means that difficultly exchangeable K is in equilibrium with exchangeable K and residual K. The mobile K is a measure of the capacity factor, which in turn is an index of the potential K reserve of soils. It follows that it constitutes an important aspect of the K status

Table 3: Correlation coefficient (r) between the various forms of potassium in soils cultivated with Shea butter tree at Bida, Niger state.

	Total K	H_2O Sol-K	Reserved K	Diff Ex. K	Exch. K	Residual K
Total K						
H_2O Sol-K	0.478					
Reserved K	-0.051	0.853*				
Diff Ex. K	1.000**	0.478	-0.051			
Exch. K	0.983**	0.632	0.135	0.983**		
Residual K	0.944**	0.161	-0.378	0.944**	0.856*	1

**Correlation significant at 0.01 level, *Correlation significant at 0.05 level.

Table 4: Regression analysis showing coefficient of determination (R^2) between forms of K, Particle sizes and organic matter in soils cultivated with Shea butter trees at Bida.

Total K	=	-0.375 + 0.1sand	15.4
Total K	=	0.362 + 0.9silt	61.7
Total K	=	0.654-0.003202clay	46.4
Total K	=	0.399 + 0.03093organic matter	94.7
Reserved K	=	1.295 - 0.01sand	36.4
Reserved K	=	0.274 + 0.003silt	21.8
Reserved K	=	0.3761 - 0.001257clay	22.7
Reserved K	=	0.3734 – 0.004997organic matter	7.9
Difficultly exchangeable K	=	-0.595 + 0.01sand	11.4
Difficultly exchangeable K	=	0.142 + 0.009silt	65.9
Difficultly exchangeable K	=	0.4341 – 0.003202clay	50.1
Difficultly exchangeable K	=	0.179 + 0.03093organic matter	94.7
Water soluble K	=	0.6150 – 0.005sand	12.5
Water soluble K	=	0.0335 + 0.0045silt	67.5
Water soluble K	=	0.1831 – 0.001743clay	60.1
Water soluble K	=	0.1173 + 0.003986organic matter	6.9
Residual K	=	-4.185 + 0.045sand	26.3
Residual K	=	-0.3715 + 0.0195silt	32.9
Residual K	=	0.2533 – 0.006606clay	22.4
Residual K	=	-0.4436 + 0.09381organic matter	87.2

of soils (Unamba-Opara, 1985). Quoting earlier works, Haylock (1956) and Page *et al.,* (1968), the potassium status of the soils of Northern Imo were graded into three fertility categories based on the values of mobile K of those soils (Unamba-Opara, 1985). These categories were K-deficient soils (mobile K < 0.31 cmol/kg), soils with moderate K (mobile K between 0.31 cmol/kg and 0.49 cmol/kg) and soils with adequate K (mobile K > 0.49 cmol/kg) and concluded that only the soils that were deficient or moderate in K were the soils that will respond to applied K fertilizer. Similarly, six soil series were studied in the Guinea and Rainforest agro-ecologies of Nigeria and graded into fertility classes (Udo and Ogunwale, 1978) using the value of mobile K (0.3 cmol/kg to 0.64 cmol/kg) earlier suggested by Ekpete, (1972). They concluded that three (Ondo, Nkologu and Etinan) out of the six soil series contained inadequate levels of mobile K whereas the remaining three soil series (Egbeda, Gaba and Biu) appeared to have adequate capacity to supply K for the needs of crops (Udo and Ogunwale, 1978). They however pointed out that the critical level of mobile K that would provide adequate supply of K depends on the soil and crop grown. In this study, potassium status of this soil was classified as moderate (Table 5) using the scale for mobile k as proposed by Unamba-Oparah (1985).

The values of exchangeable potassium were 0.12 cmol/kg at the top soil and 0.10 cmol/kg in the subsoil and decreased significantly with increasing soil depth (Table 2). According to Ekpete (1972) response to applied K was only noticed in millet when the exchangeable K values were below 0.11 cmol/kg in Guinea Savanna and Rainforest Agro-ecological zones of Nigeria. This follows that these soils have adequate supply of K using the exchangeable K as an index of availability (Table 5). A more recent than Ekpete (1972) scale of classification of potassium status of soils using exchangeable K is the one proposed by Unamba-Oparah (1985).

Table 5: Potassium status of soils cultivated with Shea butter trees at Bida using mobile k, exchangeable k and k-saturation Index.

K-Variable	Deficient K	Moderate K	Adequate K	K status of Shea butter soils
Mobile K	< 0.31 cmol/kg	0.31cmol/kg-0.49 cmol/kg	> 0.49 cmol/kg	Moderate
Exchangeable K	< 0.13 cmol/kg	0.13 cmol/kg	> 0.31 cmol/kg	Deficient
K-saturation Index	< 0.01	0.01-0.015	> 0.015	Adequate

The Unamba-Oparah scale showed that soils with exchangeable K less than 0.13 cmol/kg were regarded as K deficient while soils with exchangeable K between 0.13 cmol/kg and 0.31 cmol/kg were regarded as being moderate in K. Soils with greater than 0.31 cmol/kg were however regarded as having adequate K. Based on Unamba-Oparah (1985) classification, these soils are deficient in K (Table 5). Preliminary investigations carried out to assess the status of degradation of these soils placed the scores on potassium under contrary land use types as 3 and 4 using FAO (1979) indicators and criteria for chemical degradation of soils. 3 (highly degraded) soils and 4 (very highly degraded) soils were recorded in soils under grass fallow and melon respectively (Osayande *et al.*, 2014). Exchangeable K had a significant correlation with residual K with ($r = 0.856$, $P < 0.05$) and had a very strong relationship with organic matter with r^2 of 87.2 % (Table 4).

The residual K is regarded as the structural K in the K-bearing minerals (Udo and Ogunwale, 1978). The residual K represents the difference between total K and the sum of exchangeable K and the K extracted by 1 N HCl (reserved K). In this study, residual K was 0.04 cmol/kg at the top soil and 0.14 cmol/kg at the sub soil and increased significantly with increased soil depth (Table 3). The values were much lower than total k in the soils. Residual K significantly correlated with total K with ($r = 0.944$, $P< 0.01$). Residual K had a very strong relationship with organic matter with an r^2 value of 98.9 %.

CONCLUSIONS

The forms of potassium in soils of a cultivated Shea butter field was studied as part of the on-going Shea tree domestication effort of the Nigerian Institute for Oil Palm Research sub-station at Bida, Niger State. The result indicated that potassium was adequate in the soils using the K-saturation index while the mobile K showed a moderate K status of the soils. The soils were however deficient in potassium using values of the exchangeable K. The mobile K implies that it might be useful if K fertilization is made at the period of peak demand in K which normally corresponds with the onset of flowering.

ACKNOWLEDGEMENT

The corresponding author is grateful to the Executive Director of the Nigerian Institute for Oil Palm Research (NIFOR) and the Director, Date Palm & Shea Tree Development Department for funding.

REFERENCES

Abubakari, A H., Nyako, G., Yidana, J.A., Mahunu, G.K., Abagale, F.K., Quainoo, A., Chimsah, F. and Avornyo, V (2012). Comparative studies of soil characteristics in Shea parklands of Ghana. *Journal of Soil Science and Environmental Management*. Vol 3 (4), pp 84-90

Adegite, K.A. (1993). Characteristics and Pedogenesis of the soils of the flood plains of River Niger, in Kwara and Kogi States, Nigeria. *Ph.D. Thesis, University of Ilorin, Ilorin, Nigeria.*

Agboola, A.A. and Corey, R.B. (1972). Soil test calibration for N.P.K. for maize in the soils derived from metamorphic and igneous rocks of Western States of Nigeria. J*ournal of West Africa Science Association,*17, 93-100.

Aghimien, E.A. and Osemwota, I.O. (2010). Distribution of potassium forms in some surface soils of Southern Nigeria. *Nigerian Journal of Soil Science* 20 (1) 2010. PP 122-127.

Amakhian, S.O. and Osemwota, I.O. (2012). Physical and chemical properties of soils in Kogi State, Guinea Savanna Zone of Nigeria. *Nigerian Journal of Soil Science*. Volume 22 (1)

Ano, A.O. (1991). Potassium status of the Nigerian Coastal Plain Sands. *Journal Of Potassium Research* 7: 247-254.

Bansal, S.K., Rao, C.S., Pasricha N.S. and P. Imas (2002). Potassium dynamics in major benchmark soil series of India under long-term cropping. *Symposium* No. 54, Paper No. 276, pp: 1-21, 17th WCSS, Thailand.

Biswas, T.D. and Mukherjee, S.K. (1994). *A Textbook of Soil Science.* Tata McGraw Hill Publishing Company LTD

Dianda, M., Bayala, J., Diop, T. and Ouédraogo, S.J. (2009). Improving growth of Shea butter tree (*Vitellaria paradoxa* C.F.Gaertn.) seedlings using mineral N, P and arbuscular mycorrhizal (AM) fungi. *Biotechnol. Agron. Soc. Environ.* 13(1): 93-102.

El-Nemr, M.A., M.M.H. Abd El-Baky, S.R. Salman and W.A. El-Tohamy (2012). Effect of different potassium levels on the growth, yield and quality of tomato grown in sand-ponic culture. *Australian Journal of Basic and Applied Sciences,* 6 (3). Pp 779-784

Ekpete, D.M. (1972). Predicting responses of potassium for soils of Eastern Nigeria. *Geoderma* 8: 178-189.

FAO (1979). A provisional methodology for soil degradation assessment. FAO Rome, 84 pp

Gee, G.W. and Or, D. (2002). Particle size distribution. In: Dane J.H and Topp. G.C. (eds). *Methods of soil Analysis. Part 4, Physical methods. Soil Sci. Am Book Series* No.5, ASA and SSSA, Madison, W.I. PP 255-293.

Graley, A.M., Nicolls K.D. and C.S. Piper (1960). The availability of potassium in some soils. I. The variability of soil potassium in the field and its fractionation. *Aust. J. Agric. Res.* 11: 750-773

Hall, J.B., Aebischer, D.P., Tomlinson, H.F., Osei-Amaning, E. and Hindle, J.R. (1996). *Vitellaria paradoxa: A Monograph. School of Agricultural and Forest Sciences Publication* University of Wales, Bangor, UK. p. 8.

Haylock, D.A. (1956). A method for estimating the availability of non-exchangeable potassium. *Trans. 6th Int. Congr. Sci. Sol.* Paris B: 403-408

Hendershort, W.H., Lalande, H. and Duquette, M. (1993). Soil reaction and exchangeable acidity. In: Carter M.R. (ed). *Soil Sampling and Methods of Soil Analysis.* Canadian Soc. Soil Sci. Lewis Publishers, London, PP 141-145.

Kamprath, E.J., (1970). Soil acidity and liming. In: P.A. Sanchez (Ed.), *A review of soil re-*

search in tropical Latin America. N.C. Exp. *Station Technical Bulleti*n No219.

Kirkman, J. H., A. Basker, A. Surapaneni and A.N. MacGregor (1994). Potassium in the soils of New Zeland- A review, New Zealand *J. Agric Res*., 37: 207-227

Krauss, A., (2003). Assessing soil potassium in view of contemporary crop production. *Regional IPI-LIALUA Workshop on Balanced fertilization in contemporary plant production.* Kaunas-Marijampol, Lithuania, September 30 – October 1, 2003

Maclean, A.J. (1961). Potassium supplying power of some Canadian soils. *Canadian Journal of Soil Science* 41: 196-206.

MaClean, E.O (1982). Aluminium. In: C.A. Black (ed). *Methods of Soil Analysis.* Part 2, *Agro Monograph* 9, Second edition, ASA and SSA, Madison, Wisconsin. PP 539-579

Maranz, S., Kpikpi, W., Wiesman, Z, De Saint Sauveur, A. and Chapagain, B. (2004). Nutritional values and indigenous preferences for Shea fruits (*Vitellaria paradoxa* C.F. Gaertn. F.) in African agroforestry parklands. *Econ. Bot.,* 58: 588–600.

Mylavarapu, R.S. and D.E. Kennelley (2002). *UF/IFAS extension soil testing laboratory (ESTL)*: *Analytical Procedures and training manual*. Institute of Food and Agricultural Sciences, University of Florida, Gainesville, USA, pp 28.

Mutscher, H. (1995). *Measurement and assessment of soil potassium. IPI Research Topics No. 4 (revised version).* International Potash Institute, Basel, Switzerland, pp: 102

Nelson, D.W. and L.E. Sommer (1996).Total carbon, Organic Carbon and Organic Matter. In: Sparks, D.L. (Ed), *Methods of Soil Analysis. Part 3. SSSA Book Series* No. 5 SSSA Madison, WI,PP: 960-1010

Osayande, P.E. Oviasogie, P.O., Ekebafe, M.O. and Maidoh, F.U. (2014). Assessment of degradation in soils of transplanted Shea tree (*Vitellaria paradoxa* Gartn C.F.) under two land use types at Bida, Niger State. *Nigerian Journal of Soil Science* 24 (1): 108-116

Page, L.H., Ramadan H., and I. Unamba-Oparah (1968). *Beitraege zur Kennetnis des Naehrstaffhashaites wichtiger Boeden der humiden Tropen: 7. Miltoilung: Zur Bewertung des K – Versorgungsgrades der Untersuchten Boeden. Beitr. Trop. Substrop. Landwirtsch, Tropenveterinaermed, H.,* (2): 133-146.

Piper, C. S., (1950). *Soil and Plant Analysis*. Interscience Publishers, New York.

Samadi, A. (2006). Potassium exchange isotherms as a plant availability index in selected calcareous soils of Western Azarbaijan Province, Iran, *Turk J. Afric. For*., 30: 21-222.

Sparks, D.L., D.C. Martens and L.W. Zelanzny (1980). Plant uptake and leaching of applied and indigenous potassium in Dothan soils. *Agron. J*., 72: 551-555.

Thomas, G.W. (1982). Exchangeable cations. In: Page A.L. *et al* (eds). *Methods of Soil Analysis part 2. Agron. Monogr* 9. Wisconsin 3rd edition. ASA and SSSA Madison, pp 159-165.

Udo, E.J. and Ogunwale, J. A. (1978). Forms and distributions of potassium in selected Nigerian soils. *Nigerian Journal of Science*. 13: 215-225

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

Wild, A.A. (1971). The potassium status of soils in the savanna zone of Nigeria. *Expl. Agric*., 7: 257-270.