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Determination of K fertilization on the yield and nutrient uptake of maize (*Zea mays . L*) from three diverse parent materials in Eastern Nigeria

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Abstract

The effects of K fertilization on the yield of maize grown on soils developed from Shale (SH) Coastal Plain Sand (CPS) and River Alluvium (RA) parent materials were determined. A laboratory study was carried out to access the physiochemical properties and leaching potential of the soils using column leach test at different days intervals (1, 7, 30, 90, and 180 days). In a screen house experiment, the design was arranged in a split-plot in a completely randomized design CRD with three replications. The main plots comprised of five rates of K_20, (0.00, 0.14, 0.28, 0.42, 0.56g), equivalent to 0, 30, 60, 90, 120 $kgha^{-1}K_2O$, and were applied to 10kg potted soils grown with hybrid maize (Oba super 2) two week after planting. The subplot is comprised of three (3) soil types. The soils were kept moist at 5 days interval till harvest at 45 days. The growth, yield, and NP and K contents were determined. The results revealed that the soils were light in texture, salt-free, acidic and the nutrient status of the soil where low to medium. Soils developed from River Alluvium had higher K concentration in leachate, and lowest K retained in the soil while Shale soils had a lower concentration in leachate and higher K retained in the soil. The trend was River alluvium > coastal plain sand > shale soils. The study also reveals that high leach soils (RA) produce lower (DM) yield while less leached K soil shale produced the highest dry matter yield. The interaction of soils developed from Shale, River Alluvium, Coastal Plain Sand with $60kgha^{-1}$ k_20 produced a significantly ($P<0.05$) highest dry matter yield and NPK content. The trend was 7.79 ton ha^{-1}(RV), 0.90 ton ha^{-1}(CPS), and 0.96 ton ha^{-1}(SH), and $60kgha^{-1}$of K produced the highest yield of $0.93tonsha^{-1}$. Therefore this rate is recommended for the optimum yield of maize in these soils.

Keywords: Maize; nutrient-uptake; biomass yield; soil nutrient content.

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1.0 Introduction

Potassium K is one of the major nutrient elements which affect the development and yield of crops. Its functions particularly concerning solution ionic strength in plant cells, involved in water relations, charge balance, and osmotic pressure in cells across the membrane which explains its high mobility in the plant (Hakan *et al*., 2010; Alias *et al.,* 2012). Adequate K enhances fruit, size, colour, taste, and thickness, and it is essential for photosynthesis and energy transfer (Iken and Amusa 2004; Nawaz *et al.,* 2006). Potassium has been identified as one of the most limiting nutrient elements in crop production in tropical soils. The major problem associated with the K fertilization in soils is its high fixation, being related to the presence of oxide of Al and Fe, making K unavailable to crop (Ano, 2003: Umoh *et al.,* 2017). Most soils have a relatively large amount of total K, and a considerable part of water-soluble potassium added to the soil gets converted into insoluble forms due to the reversion process, and a little of this nutrient is recovered. (Umoh*et al.,* 2017). The fertilizer K so retained in the soil, however, is not entirely lost, except through runoff or leaching. Umoh *et al.* (2018) carried out a study to assess the leaching behavior of K in some soils of southeastern Nigeria and observed high leaching potentials of K in sandy soil, with a high rate of application within the contact time of K in that soil. Currently, in the topic, there is a widespread decrease in yields of crops in the existing agricultural land, due to depletion of soil nutrients as a result of high leaching of basic cations leading to soil degradation (Yebo, 2015). The extent to which essential nutrition elements are lost or retained in soils varies due to large differences in soil parent materials (Umoh *et al.,* 2017; Umoh *et al*., 2019).

Bayer *et al.,* 2014 reported that a large amount of K could be leached in Sandy soil with low clay by rainfall or irrigation. Alfaro *et al.,*(2010) also reported that under 480mm rainfall over 7 months, the K loss due to leaching ranged from 1 – 39 Kgh^{-1} also affirmed that K loss due to leaching could quickly occur in excessively fertilized soils. Igbal *et al.*(2015) observed an increase in the yield of maize due to proper management of soil and fertilizer K application.

Maize (*Zea mays* L.) is considered a high potassium demanding crop requiring about 90 days to mature (Bangroo *et al.,* 2012). As a staple food crop in Nigeria. Flour mill industries highly demand it. The crop, therefore, has a strong potential for providing food for the increasing population as well as improving financial returns.

Less attention has been paid to the K loss in these soils. Therefore this study was carried out to determined the efficient use of fertilizer by maize, given proper management to obtain optimum K requirement of three soils of the zone.

2.0. Materials and methods

2.1 Location of the experimental site

Table 1: Distribution of Soil Parent Materials by Sample Location

S/n	Parent Material	Ecological Zone	Soil Class USDA	Locations	States	Coordinates
1	Coastal Plain Sand	Rain forest	Typic Paleudult	Umudike	Abia	$5^0 28^1$N 7^0 32^1E
2	River Alluvium	Mangrove Swamp Forest	Rhodic Tropudult	Itu	Akwa Ibom	$5^0 10^1$N 7^0 59^1E
3	Shale	Rainforest	Typic Hapludults	Odukpani	Cross River	$5^0 7^1$N 8^0 20^1E

The soils were chosen to reflect the various ecological zone and parent materials. The parent materials, ecological zone, classification, location are shown in Table 1.

2.2 Sampling Procedure

Soil samples were collected from 0-15 cm depth, air dried, sieved to pass through a 2mm diameter sieve, and used for some physical and chemical analysis, as shown in Table 2. Particle size analysis was done by the hydrometer method as described by Klute (1986), pH was determined in 1:2.5 soil to water ratio using a glass electrode pH meter. Soil organic carbon was determined by wet oxidation method as described by Udo *et al.*(2009) and values converted to organic matter by multiplication using a factor of 1.72, Total nitrogen in the soil was determined by macro Kjeldahl method, available P in the soils was extracted by the Bray 1 method. Exchangeable acidity was measured by a 1M KCl extraction procedure as described by Udo *et al.* (2009). The exchangeable cations in the soils were extracted using IM NH_4OAC, K, and Na in the extracts were measured using flame photometry while Mg and Ca were determined by atomic absorption spectrophotometry. Effective cation exchange capacity (ECEC) was taken as the sum of the exchangeable cations.

2.3 Incubation Studies

Twenty grams (20g) of soil was weighed into a duplicated cup with a capacity of 23cm in diameter and 13cm in length and the upper cups perforated. A 20ml portion of the treatment solution containing 0, 50, 100, 150, and 200mg/l of K prepared from KCl was added to each of the soil in the cups, mixed thoroughly for effective mixing of the K solution with the soils, and allowed to dry. The cups were carefully covered and allowed to stand for 1, 7, 30, 90, 180 days, respectively (Ayodele and Agboola 1981). The soils were kept moist with 30ml distilled water at the weekly interval and covered for the duration of incubation. At the set days, K in soil samples and the leachate were extracted using ammonium acetate, and exchangeable K in the extract was determined with the flame photometry. The amount of K determined in soil and leachate were potted against the days of incubation to evaluate its lasting effects in soil and availability to plant.

2.4 Pot Experiment

The experiment was carried out in the screen house of Michael Okpara University of Agriculture Umudike located at 5^0 28^1N 7^0 32^1E. The treatments were arranged in a split-plot experiment in a completely randomized design (CRD) with three replications. The main plots comprised five rates of Potassium (K) (0.00, 0.14, 0.28. 0.42, 0.56g), equivalent to 0, 30, 60, 90, 120kgha^{-1} $k_2$0 and were applied two weeks after planting. Ten kilograms of each of the soil samples were weighed into a 12 – litre plastic pot and moistened to field capacity. Hybrid maize (Oba supper 2) at the seed rates of 3 per pot were sown and later thinned down to one seedling per pot two weeks after planting, and the potassium (K) rates were then applied. Irrigation was done at five days interval. Plant height was measured with a meter ruler, as the height from the base of the crop to the tip of the inflorescence. Leaf number was taken as all the fully opened leaves per plant, and stem diameter was measured with a Vernier Caliper. The fresh weight per plant was determined using an electronic balance. Some plant tissues were ashed, ground and NPK content of the plants were determined.

2.5 Statistical Analysis

Data of growth and yield parameters were statistically analyzed using ANOVA techniques, and means were compared using the least significant differences (LSD) 5% level of probability. The relationship between soil properties, soil types, and yield, were examined using correlation analysis (Wahua, 2006).

3.0. Results and Discussion

3.1 Soil Properties

The physiochemical properties of the experimental soils are shown in Table 1. The particle size analysis showed that the soils were light-textured, ranging from loamy sand in coastal bare sand, sandy loam in alluvium, and sandy clay loam in shale soils. Soils derived from coastal plain sand had the highest sand content (84.1%) while shale had the least sand content (46.2%). Soil formed on alluvium had the highest silt contents (11.20%), and coastal plain sand had the least (6.00%). Soils form on shale had the highest clay contents (42.6%) while coastal plain sand had the least (10.0%). The variation in the texture reflects the differences in the parent materials. These characteristic differences in texture will affect water and nutrient leaching and retention as well as the suitability of soils as a rooting medium in these soils (Enwezor *et al.,* 1990; Umoh *et al.,* 2018). The soils were acidic, and values range from 4.42 in coastal plain soil to 5.82 in river alluvium. The soils had low electrical conductivity indicating that they are salt-free. The organic matter contents of the soils were above the critical level of (2g kg^{-1}) set for crop production in most soils of southeastern Nigeria (Aduayi *et al.,* 2002). The available P in all the soils was lower than the critical level of 12-15mgkg^{-1} proposed for most crops. The order of abundance of the exchangeable base for the soils were Ca > Mg > K > Na. The exchangeable potassium (K^+)in the soils except coastal plain sand were within the critical K level for most crops in the zone (Enwezor *et al.,* 1989). The Effective Cation Exchange Capacity ECEC was lower than the critical range of 12cmolkg^{-1}. The low ECEC values are an indication of the presence of low activity clays as initiated by Sparks (2000). The base saturation which described the fertility status of every soil were seam to be moderate for crop production, and there were no significantly differences among the parent materials except alluvium soils, as shown in Table 2.

Table 2: Soil physicochemical properties of the experimental site before and after the experiment

	Coastal Plain Sand		River Alluvium		Shale	
	Before	After	Before	After	Before	After
Sand %	84.00	84.00	69.00	68.40	46.20	46.20
Silt %	6.00	5.00	11.00	12.00	11.20	11.10
Clay %	10.00	11.00	20.00	19.60	42.60	42.70
Texture	LS	LS	SL	SL	SC	SC
pH_{H20}	4.42	4.38	5.82	5.79	5.63	5.60
EC (dSm^{-1})	0.12	0.11	0.18	0.18	0.16	0.15
Organic Matter	3.80	3.79	3.16	3.13	3.26	3.24
Total N (g kg^{-1})	0.23	0.23	0.2	0.20	0.18	0.18
Available P (mg kg^{-1})	5.64	5.62	7.23	7.20	5.22	5.18
Exch. Ca (cmol kg^{-1})	3.25	3.12	3.50	3.48	5.48	4.48
Exch. Mg (cmol kg^{-1})	2.32	2.32	2.19	2.22	3.04	3.04
Exch. Na (cmol kg^{-1})	0.05	0.05	0.54	0.54	0.07	0.07
Exch. K (cmol kg^{-1})	0.36	0.40	0.22	0.21	0.38	0.37
Ex. Acidity (cmol kg^{-1})	3.40	3.54	2.53	2.53	12.05	12.07
ECEC (cmol kg^{-1})	9.32	9.34	6.38	6.34	20.20	20.00
Base Saturation (%)	75.10	75.60	62.50	62.10	74.40	74.60

CPS – coastal plain sand, RAL – river alluvium, SHL – shale, EC – electrical conductivity, SL – Sandy, SCL – Sandy Clay Loam, SL – Loamy Sand, EC – Electrical Conductivity, OM – Organic Matter, Av. P – Available Phosphorous, EA – Exchangeable acidity, ECEC – Effective Cation exchange capacity

3.2 Effects of Incubation Period on K released in Soils

The amount of K obtained at different rates of K addition over the different time intervals from the leachate and soils derived from coastal plain sand (CPS) River Alluvium (RA), and Shale (SH) parent materials are shown in Figure 1 and 2. The concentration of K in leachate (solution) as a function of time was higher than the K extracted from the soils, indicating that more K^+ were released into the soil medium considered as available K which can be lost or taken up by the plant. The trend was as follows River Alluvium > Coastal Plain Sand > Shale. The highest concentration of K in (RA) indicating the lowest affinity of the soil to retain K, whereas shale exhibited the least concentration of K in the leachate at different time intervals having a strong affinity to retain K compared to River Alluvium and Coastal Plain Sand. These findings could be due to high sand content and low activity clay in the two soils, but the high retention and less concentration of (K) in the leachate could be attributed to the high clay content of shale soil (Table 2). The results also revealed that the soils have a low to medium capacity to absorb nutrients (Ewenzor *et al.,* 1989). The amounts of K extracted in the soil at each time interval increased with

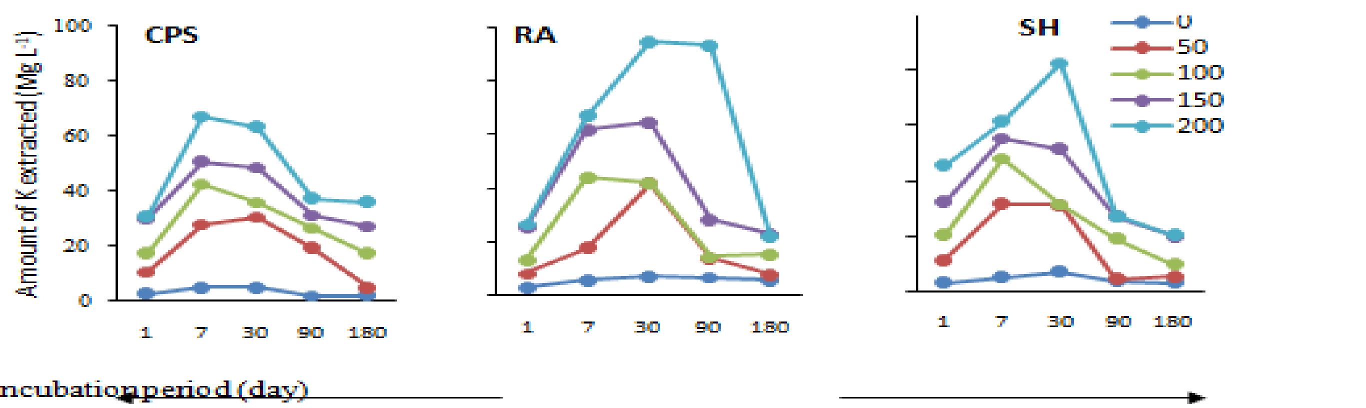

Figure 1: Amount of K obtained at different rates of K addition over the different period from the leachate in Coastal Plain Sand (CPS), River Alluvium (RA) and Shale (SH) parent materials

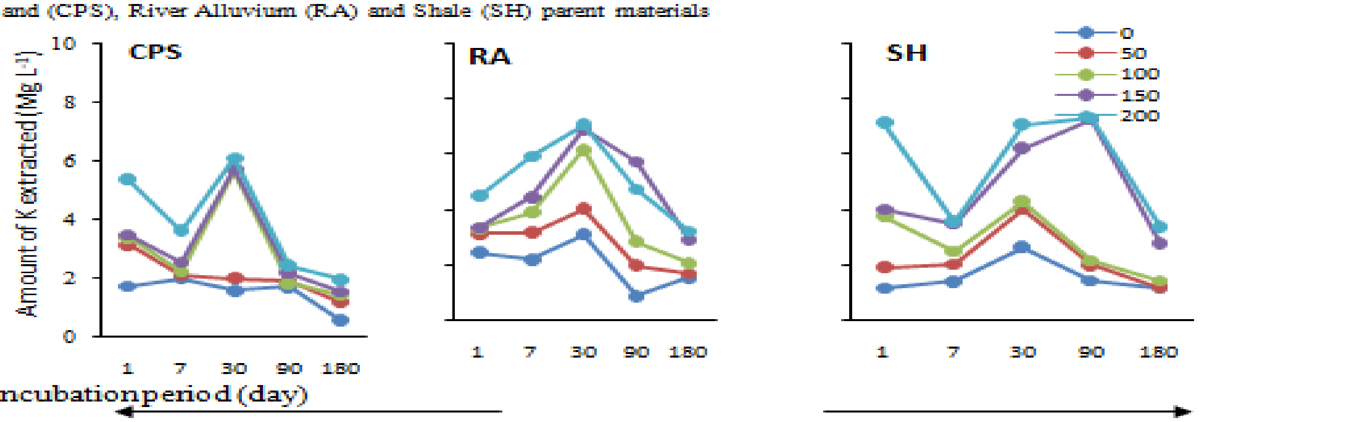

Figure 2: Amount of K obtained at different rates of K addition over the different period from the soil in Coastal Plain Sand (CPS), River Alluvium (RA) and Shale (SH) parent materials

increasing levels of K applied with $0mgl^{-1}$ being the lowest and $200mgl^{-1}$ being the highest for all the soils. The study also revealed that the amount of K released decrease with days of incubation as in the order: CPS (7 days) RA (30 days) and SH (30 days). Allan *et al.* (1998) observed a 30% reduction in the yield of alfalfa after a contact time of 12 weeks (84 days). Therefore, in the study area, a contact of 30 days is the best time for crops to optimize the benefits of added K. It is evident that after 30 days of incubation, more of the added K were leached or absorbed into exchange sites.

3.3 Effects of Parent Materials and K rates on the growth and yield of maize

The growth and yield of maize as affected by parent materials are presented in Table 3. Maize planted on soils developed from Coastal Plain Sand was significantly taller and produced the highest number of leaves (P<0.05) than Shale and River Alluvium Soils. This growth parameter contributed to the highest fresh weight of maize, while River Alluvium produces the lowest fresh weight but maize grown on shale soil was not significantly (P < 0.05) different from these Coastal Plain Sand (CPS). Soil derived from shale produced the highest stem diameter, which contributed significantly to the highest dry matter yield. The trend was as follows: Shale ($965kgha^{-1}$) > Coastal Plain Sand ($896kgha^{-1}$) > River Alluvium ($686\ gha^{-1}$).

The growth parameter favoured the significantly higher yield produced from the soil developed from shale as taller plant, highest stem diameter, leave number and length produced highest yield and which also could be due to high K reserved in the soil (Figure 2) while the lower yield produces in River Alluvium could be due to the high leaching of K observed in that soil (Figure 1). The variation in yield is based on the inherent fertility of the soils (Table 2).

The growth and yield of maize as influenced by K rates are presented in Table 4. The pot that received $60kgha^{-1}$ of K was significantly higher (P < 0.05) in plant height, number of leaves, stem diameter and leave length across the other rates applied, the growth parameters contributed significantly to the highest dry matter yield at the rate of $60kgha^{-1}$ while the pot that received $120kgha^{-1}$ produced the lowest yield. The soils with $60kgha^{-1}$ of K was not significantly different in dry matter yield from that pot in which 30, 90 and $120kgha^{-1}$were applied but significantly higher than that of the control pot ($0kgha^{-1}$) this implies that K is needed to improve the yield of maize (Essufie *et al.,* 2017). The trend was as follows: $60kgha^{-1}$ (0.93 tons ha^{-1}), $90kgha^{-1}$ (0.81 tons ha^{-1}), $120kgha^{-1}$ (0.77 tons ha^{-1}), $30kgha^{-1}$ (0.88 tons ha^{-1}) > $0kgha^{-1}$ (0.86 tons ha^{-1}).The decline in yield at $90kgha^{-1}$ could be due to nutrient imbalance as a result of high leaching effects, observed in these soils (Figure 1). The interaction of parent material and K rates on the growth and yield of maize plant was not significantly different from K rates and parent materials (P < 0.05), except at the interaction with leaves length as shown in Table 5 and Figure 3. Potassium rates of $60kgha^{-1}$are observed to be the critical level of effective utilization of K by maize for optimum yield. These yield values observed fall within the range of 0.2 tons ha^{-1} to 2.0 tons ha^{-1} reported by Ibia (2012) to be the average maize yield in Nigeria.

Table 3: Growth and yield of maize as affected by parent material

Parent Material	Plant height (cm)	No. of leaves	Stem Diameter (cm)	Leaves length (cm)	Fresh weight (g)	Dry matter yield ($Kgha^{-1}$)	Dry matter yield (ton ha^{-1})
CPS	35.75 a	6.52 a	4.13 a	45.19 a	52.47 a	896 a	0.90
RAL	28.24 c	6.15 b	3.27 b	40.89 b	38.61 b	786 b	0.79
SHL	31.62 b	6.05 b	4.15 a	44.79 a	50.53 a	960 a	0.96

Table 4: Growth and yield of maize as affected by K level

Fertilizer rate ($kgha^{-1}$)	Plant height (cm)	No. of leaves	Stem Diameter (cm)	Leaves length (cm)	Fresh weight (g)	Dry matter yield ($kgha^{-1}$)	Dry matter yield ($tonha^{-1}$)
0	30.20 b	5.89 b	3.72 b	43.66 a	38.84 b	858 a	0.86a
30	31.83 ab	6.19 ab	3.81 ab	41.98 a	48.67 a	876 a	0.88b
60	34.27 a	6.47 a	3.93 b	44.49 a	50.86 a	926 a	0.93a
90	31.68 ab	6.22 ab	3.82 ab	44.40 a	48.50 a	808 a	0.81b
120	31.38 b	6.42 b	3.96 a	43.60 a	49.16 a	770 a	0.77c

Table 5: F Probability and LSD (0.05) values for the growth and yield of maize as affected by the interaction of parent material and K rates.

	Plant height (cm)	No. of leaves	Stem Diameter	Leaves length (cm)	Fresh weight	Dry matter weight
F Prob	0.205	0.933	0.143	<.001	0.628	0.302
LSD (0.05)	ns	ns	ns	4.455	ns	ns

3.4 Effects of parent material and K rates on the concentration of macronutrients

The concentration of macronutrients in the maize plant as affected by parent materials is presented in Table 6. The soil developed from River Alluvium (RA) was significantly higher (P < 0.05) in N content of maize than soils developed from Shale (SH) and Coastal Plain Sand (CPS). The trend was as follows: RA (2.51%) > SH (2.34%) > CPS (2.13%) the P content was not significantly different from the three soils (Table 6). The interactive effect of parent materials and K rate on NPK contents shows the highest concentration on shale soil, and the contents increased with the increasing rate of K application. (Figure 4,5 and 6) These could be attributed to high K reserved in that soil (Figure 2)

Table 6: Concentration of macronutrients in maize as affected by parent material

Parent Material	N	P	K
		%	
CPS	2.14 b	0.05 a	1.25 b
RAL	2.51 a	0.05 ab	1.48 b
SHL	2.34 ab	0.04 b	1.82 a

and high native K (Table 1). The pot applied with 60kgha^{-1} gave a significantly higher percentage of NPK content of the maize plant while 120kg ha^{-1} produced the highest P and K contents. The trends were N (2.50%), P (0.057%), K (1.96%) this indicates the beneficial roles of K which increased the NPK content than control pot (0kgha^{-1}). According to Alias *et al.* (2012), potassium in combination with N is synergistic in uptake, translocation, and utilization of nutrients for assimilation in growth and development. Pervez *et al.* (2008) reported that adequate K is needed to maintain N and P metabolism. The application of K enhanced the translocation of the nitrogenous compound from the roots and stem towards the grain (Herbet *et al.,* 2001).

Table 7: Concentration of macronutrients in maize as affected by K level

Fertilizer rate (kgha^{-1}K)	N	P	K
		%	
0	2.25 ab	0.038 c	0.96 c
30	2.46 ab	0.044 bc	1.30 bc
60	2.50 a	0.053 ab	1.76 b
90	2.11 b	0.046 bc	1.62 ab
120	2.35 ab	0.057 a	1.96 a

Table 8: F Probability and LSD (0.05) values for concentrations of macronutrients in maize as affected by the interaction of parent material and K rates.

	N	P	K
F Prob.	<0.001	<0.001	<0.001
LSD (0.05)	0.396	0.007	0.373

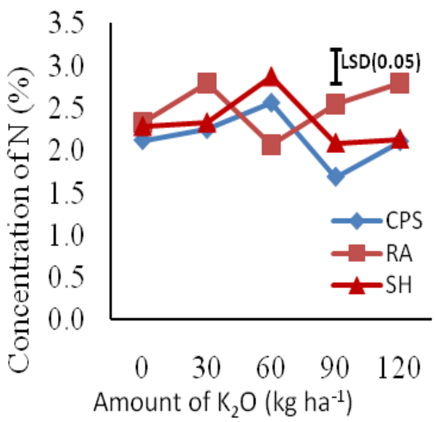

Figure 4: Interactive effect of parent material and K level on the concentration of nitrogen in the soil

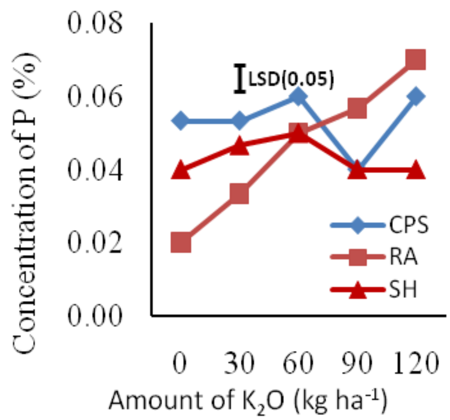

Figure 5: Interactive effect of parent material and K level on the concentration of phosphorus in the soil

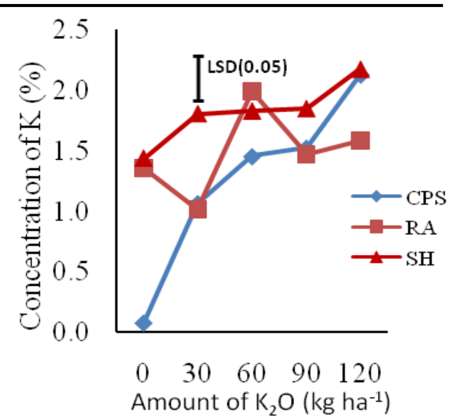

Figure 6: Interactive effect of parent material and K level on the concentration of potassium in the soil

4.0. Conclusion

The results from the studies showed that the soils were light-textured, moderately acidic, salt-free, and low to moderate nutrient ranges. The amount of K leached increased with increasing rates of K applied, and the K recovered started declining at 30 days of incubation in all the soils. Shale soil had the highest K reserved. The soil-applied with K were significantly (P <0.05) higher in terms of growth and yield parameters then than control across the soils. Shale soils had the best maize performance at 60kgkha^{-1}K application. Split dosages of K fertilizer are recommended for coastal plain sand and river alluvium for effective utilization of K for optimum growth of maize.

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