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# Use Of Adsorption Isotherm Models To Determine Potassium Fertilizer Acreage Doses For Optimum Maize Growth And Yields In Nyamira County, Kenya

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**ABSTRACT:** The present work determined nutrients levels in farm soils of the intensive agricultural region of Nyamira County, Kenya and used Freundlich isotherm model to formulate potassium acreage doses necessary for optimum maize growth and yields. Data obtained from equilibria concentrations of potassium in various soil solutions were fitted into Langmuir, Freundlich, Temkin and Van Hauy equations. The Freundlich isotherm model gave the best fit and was used to calculate acreage doses. Maize was grown under same doses of nitrogenous and phosphorus fertilizer and tendifferent doses of potassium in plots of 6m by 5m at two farm sites. The study found that maize growth parameters of plant height and stem girth and its yield parameters of ear weight, ear length, ear girth and grain yields increased steadily as potassium doses were increased and reached their optimum values at potassium doses of 155.84 and 144.76kgha$^{-1}$ giving yields of 3315.27kgha$^{-1}$ and 3340.50kgha$^{-1}$for farm sites 1 and 2 respectively.External potassium concentration of 7.9mgL$^{-1}$ associated with 95% relative yield was required for optimal maize yield. The study also established that potassium doses significantly affected concentrations of phosphorus and nitrogen in the tissues.

***Key words:*** potassium buffering capacity, adsorption isotherms, fertilizer doses, soil nutrients, optimum maize yields

## INTRODUCTION

Maize (Zea mays L) is one of the most important cereal crops of the world. It ranks third bestcereal crop in the world, only towheat and rice according to Bukhshet al, 2010. Maize forms major diet part for millions of people in world. In Kenya, it is a staple food for majority of Kenyans. Besides human consumption, maize has become the main component of livestock and poultry feed(Witt and Pasuquin, 2007).Large quantities maize are currently used in the manufacture of manyimportant products such as soaps, ammunitions, varnishes, paints cooking oil, glucose, bakery products, pharmaceutical products, making plastics, photographic films, and seed cake for livestock feed. Farther, maize starch can be used in the production of biofuels after fermentation.

Maize is a versatile crop grown across a wide range of agro-ecological zones and climatic conditions throughout the year ranging from temperate, sub-tropical and tropical regions of the world(Bukhshet al, 2012). The crop has extremely wide range of environmental adaptability and large number of varieties differing in period to maturity. Despite of expansion of acreage areas under maize productionby Kenyan farmers, yield is still low.This is mainly due to continuous cropping without replenishment of the soils with appropriate nutrients,increase in intensity of cropping, substantial removal of straw from the field, leaching and use of insufficient fertilizers resulting in severe nutrient shortage and depletionin the soils; hence need for adequate supply ofnutrients predominantly nitrogen, phosphorus and potassium for good growth and high yield of maize. So, replenishment of soil nutrients with fertilizers is critical in improving the productivity of maize. Nitrogen and phosphorus are very essential for good vegetative growth and grain development in maize production. Potassium plays an important role in physiological process in plants. In fact, more than 50 enzymes responsible for energy transfer, formation of sugars, starch and proteins are affected by presence of potassium in crops(Bukhsh, 2012).

Different approaches are used to evaluatesoil nutrient requirements of crops for optimum growth in whichadsorption isothermtechnique has proved to be the most accurate and best method(Samadi, 2006). The technique takes into account the intensity and capacity factors which are important in predicting the amount of soil nutrient required for maximum growth. The technique is very important in estimation of specific nutrient requirement of a given soilaccurately.There is limited information on which to base potassium fertilizer recommendation for maize production in this region. As a result, there is need for clear guidelines to promote efficient fertilizer use in maize production with both economic and environmental factors fully considered. By keeping view the facts, the present study was aimed atdetermining potassium adsorption capacity of the soils, computing potassium doses for field experiments,quantifying internal and external potassium requirements of maize and determining optimum potassium requirement for maximum maize yield inintensive agricultural soils of Nyamira County, Kenya.

## MATERIALS AND METHODS

### *Experimental site description*

The field experiments were carried out in Gachuba location of NyamiraCounty Kenya. Two experimental sites that have been under continuous and intensive farming without potassium fertilizer application were chosen. The soils in the area are well drained and receive an annual rainfall ranging from 1700 – 1800mm. Due to high population density most of the land is under cultivation with only small portion left for pasture. The main crops grown include: maize, beans, bananas sugarcane, finger millets, coffee, cassava, kales and cabbage.

### *Land preparation and experimental design*

Theland was ploughed and harrowed to pulverize the soil. The experimental fields were marked into plots of 6m by 5m. The experiment was laid out in a randomized complete block design. Tendifferent potassium fertilizer doses were subjected to different plots (table I) and this was replicated three times per farm site.Plots where no potassium doses were applied were used as control.Maizeseeds of hybrid variety (H629) that are recommended for the area were used. They were purchased from Kenya Seed Company,the leading packing seed company in the country.Planting holes were spaced at 25cm from plant to plant by 75cm between rows and two seeds were planted per hole. The seedlings were later thinned to one plant per hole. All the plots received basic recommended nitrogenous and phosphorus fertilizer dosage at the rate of 75kgha$^{-1}$ to ensure the nutrients did not cause a constraint over the growth period. The fertilizerswere mixed thoroughly with soil to avoid direct contact with the seeds.Diammonium phosphate (DAP) was used during planting as source of phosphorus, urea as source of nitrogen during planting, calcium ammonium phosphate (CAN) for top dressing of the maize crops at knee height and tasseling stage of growth and muriate of potash (MOP) to supply potassium nutrient. Throughout the experiment weeds were controlled to reduce competition for space, water, light and nutrients. Growth and yield parameters measured in the study included: ear weight, plant height, stem girth, ear length, ear girth, and grain yield

Table 1. Freundlich K fertilizer doses applied to the maize crop in field experiments

| Treatment code | Concentration of K solution (mgL$^{-1}$) | Dosage of K (mgkg$^{-1}$) | | Dosage of K (Kgha$^{-1}$) | |
|---|---|---|---|---|---|
| | | Site 1 | Site 2 | Site 1 | Site 2 |
| TR1 | Control | 0.00 | 0.00 | 0.00 | 0.00 |
| TR2 | 2 | 14.97 | 13.51 | 29.94 | 27.02 |
| TR3 | 5 | 44.54 | 40.97 | 89.08 | 81.94 |
| TR4 | 8 | 77.92 | 72.38 | 155.84 | 144.76 |
| TR5 | 11 | 113.82 | 106.55 | 227.64 | 213.10 |
| TR6 | 14 | 151.56 | 142.54 | 303.12 | 285.08 |
| TR7 | 17 | 191.08 | 180.32 | 382.16 | 360.64 |
| TR8 | 20 | 231.84 | 219.54 | 463.68 | 439.08 |
| TR9 | 23 | 273.80 | 260.03 | 547.60 | 520.06 |
| TR10 | 26 | 316.80 | 301.65 | 633.60 | 603.30 |

### *Soil sampling*

Soil samples were collected from each farmwithin a depth of between 0-30cm before sowing. Due to uniform soil characteristics in the area, grid sampling was employed whereby 15 to 20 cores (a core is an individual boring or coring spot in a field) were collected from each farm at random with the help of a soil auger. The cores were mixed thoroughly in a clean plastic pail to make composite soil samples. The collected bulk composite samples were air dried ground, passed through a 2mm sieve to remove: large particles, debris and stones then packed in clean polythene bags and kept cool and ready for analysis.

### Soiland plant samples analysis

The prepared samples were analyzed for soil pH in a ratio of 1:2.5 soils to water paste using pH meter.Electrical conductivity was determined in soil water paste. Organic carbon was determined using the standard Walkey Black 1947 rapid titration method. Total nitrogen was determined by the Kjeldal method (1983). The concentration levels of potassium done using a flame photometer. Phosphorus was extracted by Olsen method and determined calorimetrically at a wavelength of 880 nm. Plant samples were dry-ashed and analysedas described by Okalebet al, 2002. The method is simple, non-hazardous and less expensive compared with nitric acid and perchloric acid wet digestion of plant samples.

### Adsorption studies

Adsorption studies were done as per the method described by Rowell 1994. In the study,2.50g of the soil samples were put in 25mL solutions of 0.01M $CaCl_2$ that contained potassium concentrations of 0, 25, 50, 75, 100, 125, 150, 175, 200, 225 and 250mgL$^{-1}$ and shaken for 24hrs at 25±1°C to achieve equilibration. The contents were filtered using Whatman filter papers No. 41. The potassium content in the filtrate was determined using a flame photometer.The amount of K adsorbed by the soil wascalculated from the differences between the amounts found in filtrate from theinitial amount that was in solutions using the following equation.

$$\Delta K = (C_i - C_f)^* V / M \qquad (1)$$

Where $\Delta$K amount adsorbedby the solid phase of soil; $C_i$and $C_f$are the initial and equilibrium Kconcentrations in solution respectively;V and M are the solution volume and mass of the soil used. The K adsorption data were fitted into linearized forms of the Langmuir,Temkin, Freundlich and Van Hauyadsorption equation given.

### Langmuir adsorption equation

The equation model fits monolayer reactions. The experimental data is fitted into the linearized form of the equation 2(Pal et al., 1999).

$$\frac{C}{(x/m)} = \frac{1}{kb} + \frac{C}{b} \qquad (2)$$

The constants in the equation they have their usual meaning, in which Cis the equilibrium solution K concentration (mgL$^{-1}$), x / m is the mass ofK adsorbed per unit mass of soil (mgkg$^{-1}$), k is a constant related to bonding energy of K to the soil, and bis the maximum K adsorption capacity of the soil.

### Temkin adsorption equation

The linearized form of the equation is shown in equation 3 below.

$$\frac{x}{m} = a + b\mathrm{In}C \qquad (3)$$

Where x/m is the mass of K adsorbed per unit mass of soil (mgkg$^{-1}$), C is equilibrium solution K concentration (mgL$^{-1}$), a andb are constants obtained from the intercept and the slope respectively**.**

### Freundlich adsorption equation

Freundlich isotherm model gives a closer description of the real adsorption phenomena in the soil. The un-linearized form of the equation is shown in equation 4

$$\frac{x}{m} = aC^b \qquad (4)$$

By rearranging and log transforming equation 4, the linearized form of the equation will be as shown in equation 5. For fitting experimental data, equation 5 below is used.

$$\log\left(\frac{x}{m}\right) = \log a + b\log C \qquad (5)$$

Where x/m is the mass of Kadsorbed per unit mass of soil (mgkg$^{-1}$), C is the equilibrium concentration of K solutions (mgL$^{-1}$), a and b are constants obtained from the intercept and slope respectively

### Van Hauy adsorption equation

The linearized form of the equation is shown in equation 6 below.

$$\frac{x}{m} = m + n\sqrt{C} \qquad (6)$$

Where x/m is the mass of Kadsorbed per unit mass of soil (mgkg$^{-1}$), C is the equilibrium solution K concentration (mgL$^{-1}$), m and nVayHauy isotherm constant obtained from the intercept and slope respectively.

### *K fertilizer dosage for field experiments*

From the study, Freundlich equation best described the soils and hence was farther used in the calculation of the K fertilizer dosage to be applied in the soils so as to give final soil solution K concentrations of 0, 2, 5, 8, 11, 14, 17, 20, 23, and 26 mgL$^{-1}$ as shown in equation 7 and 8.

$$\text{Fertilizer dose } \frac{X}{m}\,(\text{mgkg}) = aC^{b} \quad (7)$$

$$\text{Fertilizer dose (kgha}^{-1}\text{)} = \text{Fertilizer dosage } \frac{X}{m}\,(\text{mgkg}^{-1}) \times 2 \quad (8)$$

In the case a andb are Freundlich constants which represent the intercept and slope of the adsorption isotherms respectively.

### *Determination of internal and external K requirement*

The crops were harvested at maturity. The yields representing each potassium solution level were expressed as percentage of maximum yield of the experiment as shown in equation 9.

$$\text{Relative yield (R.Y)} = \frac{\text{Actual grain yield}}{\text{Maximum grain yield}} \times 100\ \% \quad (9)$$

Relative yield (%) was plotted against soil solution K levels and K concentration (%) in maize tissues to determine external and internal K requirements respectively.

### *Statistical analysis*

The data obtained were statistically analyzed using the analysis of variance (ANOVA) and standard statistical packages of social science SPSS software(Levesque, 2007). The charts were drawn using Microsoft Excel. Mean comparisons were done using the Duncan multiple range test (DMRT) at 5% probability.

## RESULTS AND DISCUSSION

### *Soil analysis*

The chemical properties of the soil at the two sites are given in table 2. The soils had a pHthat rangedfrom 4.81-5.20 which indicates that the soils are strongly acidic. The electrical conductivity values ranged from 0.20 - 0.28mmhos/cm indicating that the soils were non-saline. The total organic carbon was moderate as revealed by percentage organic carbon of between 1.87 - 2.03%. The total nitrogen ranged between 0.154 - 0.196% while available phosphorus and potassium ranged between 0.0970-0.0973% and 57-70mg/kg respectively. This confirms that the soils have insufficient nutrient levels.

Table 2. Some chemical properties of the studied soils

| Parameter | Site 1 | Site 2 |
|---|---|---|
| pH | 5.20±0.00 | 4.81±0.00 |
| Total nitrogen (%) | 0.196±0.01 | 0.154±0.00 |
| Cation exchange capacity (Cmolkg$^{-1}$) | 28.05±0.00 | 19.40±0.00 |
| Total phosphorus (%) | 0.3124±0.00 | 0.3131±0.00 |
| Available phosphorus (%) | 0.0970±0.00 | 0.0973±0.00 |
| Organic carbon (%) | 2.03±0.00 | 1.87±0.00 |
| Electrical conductivity (mmhos/cm) | 0.28±0.00 | 0.20±0.00 |
| Available potassium (mgkg$^{-1}$) | 70.2±0.2 | 57.0±0.1 |

### *Comparison of adsorption model*

Data obtained from potassium adsorption to the soils best fitted Freundlich model as ascertained by the R$^2$ values of 0.985 and 0.927 for sites 1 and 2 respectively as shown in table 3.Freundlich model assumes unlimited adsorption sites having heterogeneous surface which correlates better with the mixed mineralogy of the soils(Hannan, 2008). The Langmuir adsorption isotherm which assumes homogeneity of adsorption sites with a complete monolayer adsorption of solutes(Pal et al, 1999) could not fit well.The Freundlich parameters (a) and (b) may be taken as a measure of adsorption and the rate of adsorption/ constant related to bonding energy of the soils. As shown on table 4 the buffering capacities (b)obtained from the slope of the curves of the studied soils were 15.49Lmg$^{-1}$ and 16.26Lmg$^{-1}$while their potassium adsorption were 6.56 and 5.83mgkg$^{-1}$for site 1 and 2 respectively. The constant (a) is obtained from the intercept of plot and represents the labile pool of potassium which is adsorbed in fixed sites which may cause a decrease in solution potassium.The parameters are very important in formulation precise fertilizer recommendation as per the adsorption capacities of the soils(Samadi, 2003).

Table 3. Langmuir, Temkin and Van Hauyand modified Freundlich model equations

| Soil site | Model | Freundlich Model form $K=aC^b$ | Linear form | $R^2$ |
|---|---|---|---|---|
| 1 | Freundlich | $K=6.56C^{1.190}$ | $y = 1.19x + 0.817$ | 0.985 |
|  | Langmuir |  | $y = -0.000x + 0.093$ | 0.743 |
|  | Temkin |  | $y = 0.001x + 2.892$ | 0.847 |
|  | Van Hauy |  | $y = 0.004x + 4.023$ | 0.926 |
| 2 | Freundlich | $K=5.83C^{1.211}$ | $y = 1.211x + 0.766$ | 0.927 |
|  | Langmuir |  | $y = -3E - 05x + 0.072$ | 0.006 |
|  | Temkin |  | $y = 0.001x + 2.734$ | 0.827 |
|  | Van Hauy |  | $y = 0.004x + 3.675$ | 0.910 |

Table 4 . K adsorption parameters of the freundlich model

| Soil site | Amount adsorbed (a) mg $kg^{-1}$ | Buffering capacity in (b) L $mg^{-1}$ |
|---|---|---|
| 1 | 6.56 | 15.49 |
| 2 | 5.83 | 16.26 |

### *Growth parameters*

Growth parameters provide information on the capacity of the plant system in the synthesis, transportation, utilization and storage of photo assimilates(Taiz and Zeiger, 2006). Growth parameters measured in this study include plant height and stem girth of the maize plants at maturity.

### *Plant height*

Table 5 shows the effect of varying doses of potassium on growth parameters of maize.As shown in the table, the lowest mean plant heights of 191.81±0.49cm (site 1) and 192.37±1.65cm (site 2) were obtained in the control plots. These heights increased steadily as the dosage were increased to optimum mean heights of 234.46±0.71 and 234.87±0.21cm at optimum doses of 155.84 and 144.76kgha$^{-1}$ for sites 1 and 2 respectively. It was observed that further increase of K fertilizer dosage beyond the optimum values did not have a direct statistically significant effect on plant height. These means that the amounts of potassium added to the soils for the plants to attain maximum heights constitute optimum doses for the soils to provide adequate nutrients for optimum growth. The high growth is associated with consumption of increased potassium absorption leading to high osmotic potential which causes increase in cell expansion pressure and length through solutions regulation(Yahiya et al., 1996). Plant height is an important parameter in estimating growth rate of and determines light interception in plants. It is a primary determinant for high yield for individual plants(Winner and Fisherman, 1994) and depends on the genetic makeup of a plant but can be improved through balanced nutrition. Data regarding plant height (table 5) indicates that the application of different levels of potassium fertilizer had a significant effect on maize height.

Table 5. Effect of different potassium levels on growth parameters of maize

| Treatment code | Solution K in (mgL$^{-1}$) | Maize height (cm) |  | Stem girth (cm) |  |
|---|---|---|---|---|---|
|  |  | Site 1 | Site 2 | Site 1 | Site 2 |
| TR1 | Control | 191.81±0.49g | 192.37±1.65g | 6.34±0.10f | 6.49±0.20e |
| TR2 | 2 | 194.06±0.89g | 196.22±0.60g | 7.38±0.15e | 7.56±0.14d |
| TR3 | 5 | 199.22±0.21f | 199.69±0.95f | 7.68±0.40e | 7.81±0.17d |
| TR4 | 8 | 234.46±0.71a | 234.87±0.21a | 10.53±0.22a | 10.44±0.34a |
| TR5 | 11 | 219.02±0.30d | 220.71±2.44d | 9.12±0.09c | 9.99±0.75ba |
| TR6 | 14 | 233.27±0.55a | 232.89±3.45b | 9.41±0.45cb | 9.72±0.27b |
| TR7 | 17 | 230.53±1.60b | 231.77±0.75b | 9.33±0.16cb | 9.44±0.18b |
| TR8 | 20 | 212.39±1.42a | 215.63±1.58e | 8.51±0.64d | 8.43±0.40c |
| TR9 | 23 | 221.74±0.87c | 224.71±0.89c | 9.72±0.09b | 9.71±0.51b |
| TR10 | 26 | 232.82±3.27a | 233.68±1.22b | 9.70±0.37b | 10.00±0.33ba |

Mean sharing the same letters in a column are statistically at par at 5% level of probability (DMRT)

### *Stem girth*

As shown in table 5, the lowest mean stem girthof 6.34cm (site 1) and 6.49cm (site 2) were obtained in the control plots. These increased steadily as the doses were increased to optimum values of 10.52and 10.44cm at optimum doses of 155.84 and 144.76kgha$^{-1}$ for sites 1 and 2 respectively. It was observed that further increase of K fertilizer dosage beyond the optimum values did not have a direct statistically significant effect on stem girth. The girth of a plant is an important parameter that determines its strength and ability to resist lodging. As shown from the data (table 5) the mean stem girth comparison differed significantly ($P<0.05$). The increased stem girth of maize under balanced K fertilization, and specifically at higher levels of K application might be due cell expansion which induces sturdiness and healthiness of plants which includes better root development and increased stem strength(Ahmed et al., 1992). Potassium deficiency causes epidermis sclerenchyma tissues and xylem vascular cells to be thin(Syers, 2001).

Table 6. Effects of K levels on yield parameters of maize site 1

| Treatment code | Solution K in (mgL$^{-1}$) | Grain yield | Ear length | Ear girth | Ear weight |
|---|---|---|---|---|---|
|  |  | Kg/ha | cm | Cm | Gm |
| TR1 | Control | 690.13±6.54f | 15.57±0.41f | 15.85±0.68e | 155.49±0.9k |
| TR2 | 2 | 793.23±35.3e | 17.04±0.38e | 14.90±0.31f | 163.85±1.1i |
| TR3 | 5 | 841.94±9.17e | 17.91±0.62ed | 16.33±0.15e | 191.90±0.88h |
| TR4 | 8 | 3315.27±12.4a | 21.66±0.50a | 19.39±0.23a | 252.65±0.55a |
| TR5 | 11 | 2877.63±73.7b | 19.07±1.53cb | 18.42±0.97bc | 215.31±0.10f |
| TR6 | 14 | 2897.17±78.8b | 19.46±0.65b | 18.84±0.58ba | 243.48±2.12b |
| TR7 | 17 | 2765.80±22.2c | 18.25±0.27cd | 17.74±0.26cd | 243.48±2.22c |
| TR8 | 20 | 2491.90±41.6d | 17.63±0.57ed | 17.36±0.15d | 211.82±0.15g |
| TR9 | 23 | 2556.33±25.4d | 19.55±0.27b | 17.73±0.05cd | 233.68±0.67d |
| TR10 | 26 | 2503.03±52.0d | 17.73±0.52ed | 18.39±0.29bc | 230.340.61e |

Mean sharing the same letters in a column are statistically at par at 5 % level of probability (DMRT)

### *Yield parameters*

The yield parameters measured in the study included ear weight, ear length and girth and grain yields.

### *Grains yield*

Grain yields were significantly affected by different levels of potassium fertilizer application ($p<0.05$). Data represented in Tables 6 and 7 show the effect of different potassium doses on the grains yields. At site 1, the mean grain yields increased significantly from 690.13 to the highest mean value of 3315.17±12.4kgha$^{-1}$ as potassium doses were increased to an optimum potassium dose of 155.84kgha$^{-1}$. Similarly the mean grain yield at site 2 increased from 751.41 to a maximum mean value of 3340.50±64.9kgha$^{-1}$ attained at an optimum potassium dose of 144.76kgha$^{-1}$. These confirmed that these were the optimum potassium doses for the two sites to achieve the desirable maximum production per unit area. Wiebold 2006 indicated that optimum potassium is essential in regulation of stomata opening and closure and as a result prevents water wastage and improves growth conditions in corns. It was observed that increasing potassium doses above the optimum value did not cause any significant increase on grain yield. The treatments remained statistically the same. These might be due to excessive consumption of potassium nutrient by the plants leading to luxurious growth. These indicate that application of potassium above optimum rate is uneconomical and just wastage of money. Luxury consumption of potassium can be limited by applying only enough potassium to optimize yield and by several split application(Hannan, 2008). Figure 1 shows the effect of different K fertilization dosages on maize grain yields.

### *Ear weight*

The control plots gave the lowest mean ear weights of 155.49 and 156.72g for sites 1 and 2 respectively. These increased to the highest mean values of 252.65and 254.52kgha$^{-1}$ at optimum potassium doses of 155.84and 144.76kgha$^{-1}$ for sites 1 and 2 respectively. The ear weight obviously increased from control plots due to low availability of native K status in soils. The significant increase in ear weight due to K fertilization at the sites is a sign of low soil K nutrients at the sites. These yield response underscores the significance of potassium fertilization in enhancing maize yields in the studied soils. It was observed that potassium application increased the ear weights producing well developed and health ears

Table 7 .Effects of K levels on yield parameters of maize site 2

| Treatment code | Solution K in (mgL$^{-1}$) | Grain yield | Ear length | Ear girth | Ear weight |
|---|---|---|---|---|---|
| | | Kg/ha | cm | Cm | Gm |
| TR1 | Control | 751.41±10.9f | 17.07±0.49d | 16.38±0.19ef | 156.72±1.1k |
| TR2 | 2 | 810.90±17.1fe | 17.83±0.12cd | 15.76±0.08f | 169.91±0.6i |
| TR3 | 5 | 876.95±18.2e | 18.76±0.20bc | 16.73±0.12de | 193.57±3.1h |
| TR4 | 8 | 3340.50±64.9a | 22.25±0.25a | 20.19±0.51a | 254.52±1.1a |
| TR5 | 11 | 2934.27±16.6b | 19.07±1.43bc | 19.65±0.71ab | 218.64±0.9f |
| TR6 | 14 | 2970.63±18.6b | 20.09±1.57b | 19.90±1.15ab | 254.52±0.7b |
| TR7 | 17 | 2762.43±56.4c | 18.73±0.47bc | 18.13±0.15c | 245.431.6c |
| TR8 | 20 | 2555.83±103d | 17.82±0.22cd | 17.41±0.46cd | 213.40±0.6g |
| TR9 | 23 | 2709.33±64.7c | 19.28±0.87bc | 18.16±0.40c | 235.49±0.5d |
| TR10 | 26 | 2686.83±18.9c | 17.75±0.91cd | 19.20±0.06b | 230.67±1.1e |

Mean sharing the same letters in a column are statistically at par at 5% level of probability (DMRT)

### *Ear girth and ear length*

The control plots gave the lowest mean ear girth of 15.85 and 15.76cm for sites 1 and 2 respectively. These increased to the highest mean values of 19.39 and 20.19cm at optimum potassium doses of 155.84and 144.76kgha$^{-1}$ for sites 1 and 2 respectively. There were significant differences in ear length in the treatments (table 5 and 6). The highest ear length was recorded in treatment TR4. The average ear lengths ranged 15.57 - 19.07cm for experimental site 1 and 17.07 - 22.25cm for experimental site 2. From the results, ear girth and length with application of potassium fertilizers improved.

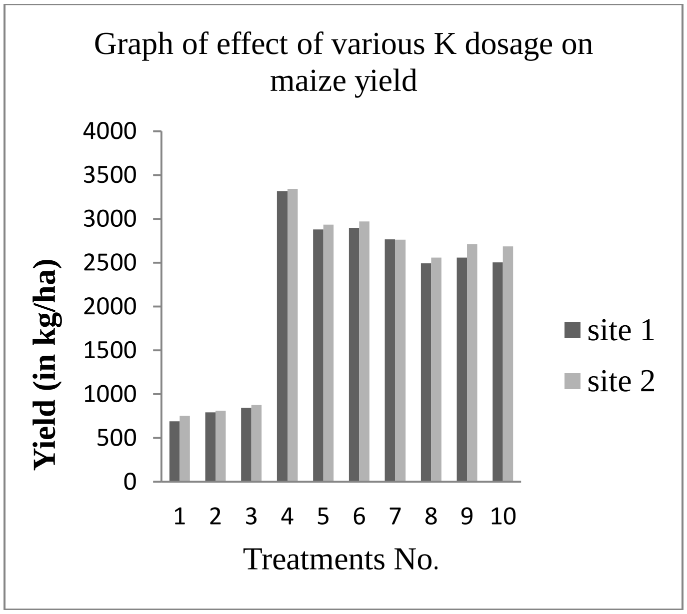

Figure 1. Maize grain yield at different K fertilization dosages

### *Effect of different potassium fertilizer rates on K concentration in maize grains, cobs and stover*

The concentration levels of potassium in the maize grains, cobs and stover significantly increased with increase in potassium doses. Tables 8 and 9 contain data that shows the effect of increased potassium doses on its concentration in the grains, cobs and stover at site 1 and 2.They show a general increase in the concentration levels of potassium in the tissues as potassium doses were increased. The potassium concentration in the stover ranged from 0.41 % to optimum concentration of 1.43% for experimental site 1 and 0.33 - 1.34% in experimental site 2.

Table 8. K concentration (%) in maize grain, stover and cobs site 1

| Treatment code | Solution K levels | Grain K | Cobs K | Stover K |
|---|---|---|---|---|
| | $MgL^{-1}$ | % | % | % |
| TR1 | Control | 0.66±0.01d | 1.9±0.57h | 0.45±0.01f |
| TR2 | 2 | 0.67±0.01d | 2.0±0.55h | 0.41±0.03f |
| TR3 | 5 | 0.67±0.01d | 2.40±0.57g | 0.59±0.01e |
| TR4 | 8 | 0.71±0.01c | 2.5±0.50fg | 0.66±0.01de |
| TR5 | 11 | 0.77±0.01b | 2.9±0.10e | 0.77±0.01d |
| TR6 | 14 | 0.77±0.00b | 2.6±0.00f | 0.93±0.03c |
| TR7 | 17 | 0.81±0.01a | 3.3±0.15d | 0.92±0.01c |
| TR8 | 20 | 0.81±0.02a | 3.9±0.15c | 1.44±0.13a |
| TR9 | 23 | 0.81±0.00a | 4.0±0.10b | 1.13±0.19b |
| TR10 | 26 | 0.82±0.00a | 4.4±0.10a | 1.25±0.34b |

Mean sharing the same letters in a column are statistically at par at 5% level of probability (DMRT)

Potassium concentration in the cobs ranged from 1.9 – 4.4% in site 1 and in site 2 the concentration ranged from 1.6 - 4.3%. Similarly, the concentration in grains rose from 0.66 to 0.82% for site 1 and 0.52 to 0.87% for site 2. The concentration of the potassium in tissues was observed to rise possibly due to increase of soil solution potassium with application of potassium fertilizer and as result the crops absorbed more potassium into the plant tissues. It was also noted that, potassium concentration in cobs was highest in comparison to potassium concentration the stover and in the grains. These might be due to reason that more potassium was trans-located to the cobs and grains during reproductive growth stage. In fact, potassium is essential in trans-location photo assimilates to storage organs(Romheld, 2010). Marchner, 1995 said potassium has an important role in material transfer; leaf made assimilates transfer to reproductive organs causing better seed filling, make hydrocarbons, proteins and quickly transfer the products towards the grains.

Table 9 . K concentration (%) in maize grain, stover and cobs site 2

| Treatment code | Solution K levels | Grain K | Cobs K | Stover K |
|---|---|---|---|---|
| | $MgL^{-1}$ | % | % | % |
| TR1 | Control | 0.54±0.02f | 1.6±0.04h | 0.33±0.00g |
| TR2 | 2 | 0.61±0.01e | 2.2±0.10g | 0.41±0.01f |
| TR3 | 5 | 0.70±0.01d | 2.1±0.30g | 0.41±0.13f |
| TR4 | 8 | 0.74±0.02c | 2.3±0.05gf | 0.61±0.00d |
| TR5 | 11 | 0.74±0.01c | 2.7±0.05fe | 0.54±0.00e |
| TR6 | 14 | 0.81±0.02a | 2.8±0.04ed | 0.88±0.00c |
| TR7 | 17 | 0.79±0.00b | 3.2±0.12dc | 0.90±0.00c |
| TR8 | 20 | 0.87±0.06a | 3.3±0.58c | 1.23±0.01b |
| TR9 | 23 | 0.80±0.06ba | 3.9±0.06b | 1.31±0.01a |
| TR10 | 26 | 0.81±0.00a | 4.3±0.41a | 1.34±0.00a |

Mean sharing the same letters in a column are statistically at par at 5% level of probability (DMRT)

### *External and internal K requirements*

The term external K requirement can be defined as the concentration of potassium in the soil associated with near maximum (95%) yield. The K solution levels developed for maize growth were plotted against the 95% relative yield by boundary line technique (figure 2). From the plot it was observed that K requirements in soil solution near maximum maize yield were $7.9mgL^{-1}$ for obtaining optimum maize yield in soils under study.

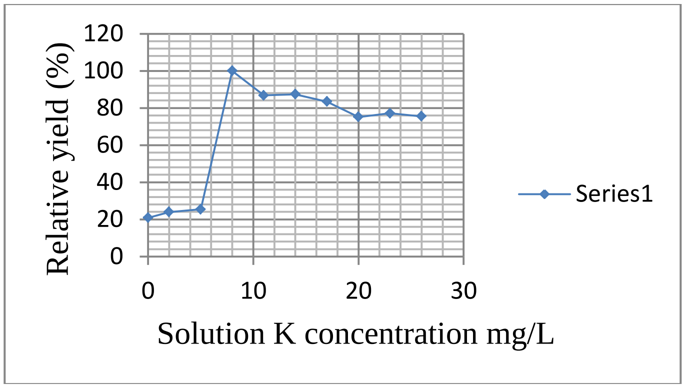

Figure 2. External K requirements of maize

### *Internal potassium requirement of maize*

The internal K requirement refers to concentration of potassium in the plant tissues associated with near maximum 95% relative yield. The internal requirement is a reflective of available nutrient status of the soil. The internal K requirement of maize was determined at crop maturity in the maize grains by making a plot of K concentration in the grain against optimum attainable 95% relative yield (figure 3). The values for internal K requirement obtained for maize were 0.708% for site 1 and 0.729% for experimental site 2.

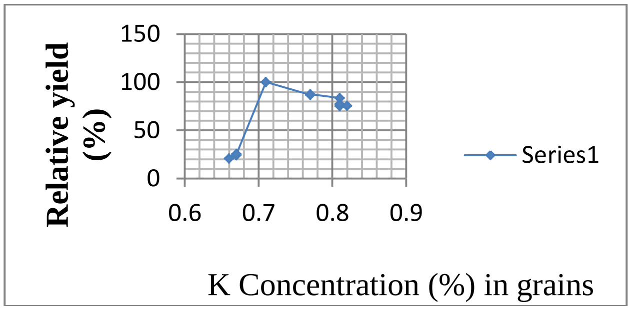

Figure 3.Internal potassium requirement of maize

Further, internal K requirements of maize cobs and stover at maturity were determined. The data revealed that internal K requirements in maize cob and stover were 2.5 and 0.66% for experimental site 1 and 2.25 and 0.59% in site 2 respectively. It was observed that internal K requirements in the maize cobs were higher than in grains and stover. This might be due to the high mobility of potassium within the plant to younger leaves and it role in the transfer of photo assimilates to storage organs.

Table 10. Effect of K concentration on nitrogen in maize tissues site 1

| Treatment code | Solution K levels | Grain N | Cobs N | Stover N |
|---|---|---|---|---|
| | MgL$^{-1}$ | % | % | % |
| TR1 | Control | 0.07±0.01c | 0.26±0.02a | 0.54±0.01c |
| TR2 | 2 | 0.07±0.00c | 0.13±0.00c | 0.41±0.02e |
| TR3 | 5 | 0.07±0.00c | 0.19±0.01b | 0.68±0.01b |
| TR4 | 8 | 0.06±0.01c | 0.12±0.02c | 0.46±0.01d |
| TR5 | 11 | 0.13±0.00ba | 0.27±0.00a | 0.94±0.00a |
| TR6 | 14 | 0.06±0.001c | 0.21±0.02b | 0.33±0.02f |
| TR7 | 17 | 0.14±0.00a | 0.21±0.02b | 0.54±0.00c |
| TR8 | 20 | 0.13±0.01b | 0.26±0.01a | 0.27±0.01g |
| TR9 | 23 | 0.06±0.01c | 0.25±0.02a | 0.34±0.00f |
| TR10 | 26 | 0.13±0.01ba | 0.25±0.02a | 0.20±0.01h |

Mean sharing the same letters in a column are statistically at par at 5% level of probability (DMRT)

### *Effect of K concentration on nitrogen and phosphorus in maize tissues*

### *Nitrogen concentration (%) in maize grain, stover and cobs*

The concentration levels of nitrogen in the maize grains, cobs and stover significantly increased with increase in potassium doses. Tables 10 and 11 contain data that shows the effect of increased potassium doses on nitrogen concentration in the tissues at site 1 and 2. They show a general increase in the concentration levels of nitrogen as potassium doses were increased.

Table 11. Effect of K concentration on nitrogen in maize tissues site 2

| Treatment code | Solution K levels | Grain N | Cobs N | Stover N |
|---|---|---|---|---|
| | MgL$^{-1}$ | % | % | % |
| TR1 | Control | 0.04±0.01f | 0.28±0.01a | 0.49±0.01d |
| TR2 | 2 | 0.05±0.01f | 0.16±0.01g | 0.44±0.01e |
| TR3 | 5 | 0.06±0.01e | 0.18±0.00f | 0.60±0.00b |
| TR4 | 8 | 0.08±0.00d | 0.15±0.00h | 0.39±0.00f |
| TR5 | 11 | 0.14±0.01a | 0.27±0.00b | 0.88±0.01a |
| TR6 | 14 | 0.01±0.00c | 0.18±0.00f | 0.34±0.01g |
| TR7 | 17 | 0.12±0.00b | 0.19±0.00e | 0.52±0.00c |
| TR8 | 20 | 0.14±0.02a | 0.20±0.00d | 0.25±0.00i |
| TR9 | 23 | 0.11±0.01b | 0.22±0.00c | 0.31±0.01h |
| TR10 | 26 | 0.08±0.01d | 0.22±0.00c | 0.18±0.01j |

Mean sharing the same letters in a column are statistically at par at 5% level of probability (DMRT)

The results show that the nitrogen concentration in the stover ranged from 0.20 - 0.94%, in maize cobs, 0.12 - 0.26% in cobs and 0.06 -0.14% in the grains for experimental site 1. In experimental site 2 (table 10), nitrogen concentration ranged from: 0.18 - 0.88% in the stover 0.18 - 0.28% in the cobs and 0.04 - 0.14% in grains. It was observed that nitrogen concentration in the tissues increased with increase with application K fertilizer to certain levels. Previous studies indicates that nitrogen and potassium influence plant growth in a synergetic way(Fridgen and Varca, 2004). Above optimum levels the concentration of nitrogen decreased possibly due to interference of high potassium concentration with other ions hence affecting the absorption of the nutrient by the roots. Both of the elements should be present in substantial and balanced quantities for proper plant growth. Also it was observed that N concentration in grains was lowest in comparison with nitrogen concentration in stover and the cobs. These might be due to

***Phosphorus concentration (%) in maize grain, stover and cobs***

The concentration levels of phosphorus in the maize grains, cobs and stover significantly increased with increase in potassium doses. Tables 12 and 13 contain data that shows the effect of increased potassium doses on phosphorus concentration in the tissues at site 1 and 2. They show a general increase in the concentration levels of phosphorus as potassium doses were increased, From the data, it was revealed that phosphorus in the grains ranged from 0.19 - 0.46%, in the cobs it ranged from 0.12 - 0.34% and in the stover it ranged from 0.18 - 0.29% in experimental site 1 and in field experimental site 2 (table 13) phosphorus percentage concentration in grains ranged from 0.22 - 0.44%, in the cobs it ranged from 0.17 - 0.40% and 0.14 -0.26% in the stover. It was observed that in the grains; phosphorus concentrations were higher in comparison to the concentration in the stover and the maize cobs. These might be due to the reasons that at reproductive stage the phosphorus being highly mobile in plants; was rapidly translocated to the seed(Duivenboodenet al, 1996). Phosphorus is essential for carbohydrates synthesis, seed and fruit maturation.Equally it is an important nutrient for root development, key element for plant cell membrane and all energy functions within the plant. Phosphorus fertilization has shown to increase plant uptake of magnesium. Deficiency of phosphorus is important as lack of nitrogen in limiting maize performance.

Table 12.Effect of K concentration on phosphorus in maize tissues site 1

| Treatment code | Solution K levels | Grain P | Cobs P | Stover P |
|---|---|---|---|---|
| | MgL$^{-1}$ | % | % | % |
| TR1 | Control | 0.27±0.02e | 0.20±0.00e | 0.18±0.01d |
| TR2 | 2 | 0.19±0.01f | 0.34±0.03a | 0.16±0.00e |
| TR3 | 5 | 0.30±0.02dc | 0.26±0.01d | 0.17±0.02e |
| TR4 | 8 | 0.31±0.00c | 0.27±0.02d | 0.23±0.01c |
| TR5 | 11 | 0.36±0.03b | 0.28±0.01dc | 0.26±0.00b |
| TR6 | 14 | 0.21±0.02f | 0.22±0.00e | 0.24±0.01c |
| TR7 | 17 | 0.28±0.00ed | 0.30±0.01cb | 0.29±0.00a |
| TR8 | 20 | 0.210.01f | 0.12±0.01f | 0.24±0.01c |
| TR9 | 23 | 0.460.02a | 0.31±0.02b | 0.24±0.01c |
| TR10 | 26 | 0.380.01b | 0.28±0.03dc | 0.26±0.01b |

Mean sharing the same letters in a column are statistically at par at 5% level of probability (DMRT)

Table 13.Effect of K concentration on phosphorus in maize tissues site 2

| Treatment code | Solution K levels | Grain P | Cobs P | Stover P |
|---|---|---|---|---|
| | MgL$^{-1}$ | % | % | % |
| TR1 | Control | 0.30±0.00d | 0.17±0.01f | 0.17±0.01c |
| TR2 | 2 | 0.22±0.01f | 0.40±0.01a | 0.14±0.01f |
| TR3 | 5 | 0.30±0.01d | 0.30±0.01c | 0.15±0.01f |
| TR4 | 8 | 0.28±0.00ed | 0.29±0.01c | 0.20±0.01d |
| TR5 | 11 | 0.34±0.01c | 0.24±0.01e | 0.26±0.01a |
| TR6 | 14 | 0.30±0.01d | 0.17±0.01f | 0.24±0.01b |
| TR7 | 17 | 0.27±0.00e | 0.32±0.01b | 0.26±0.01a |
| TR8 | 20 | 0.44±0.00a | 0.15±0.00g | 0.24±0.01cb |
| TR9 | 23 | 0.40±0.01b | 0.28±0.01d | 0.23±0.01c |
| TR10 | 26 | 0.33±0.04c | 0.30±0.00c | 0.25±0.01ba |

Mean sharing the same letters in a column are statistically at par at 5% level of probability (DMRT)

This study has established that the soils in the region have moderate amount of total organic carbon content of range 1.87 - 2.03%, low phosphorus content ranging from 0.0970 - 0.0973mgkg$^{-1}$, low nitrogen content of between 0.154 - 0.196%. The available ranged from 57 – 70mgkg$^{-1}$,moderatecation exchange capacities of between 19.40 - 28.05Cmolkg$^{-1}$and a strongly acidic with pHthat ranged from 4.81 - 5.20. Data obtained from adsorption of K to the soils best fitted to Freundlich model followed by Van Hauy, Temkin and Langmuir. Therefore, Freundlich model was further used in the determination of specific soil K fertilizer dosages for field experiments.External K requirement for optimum maize yields was found at soil solution concentrations of7.9mgL$^{-1}$which corresponds to acreage doses of 155.84 and 144.76kgha$^{-1}$ for sites 1 and 2 respectively. On other hand, internal K concentration in plant tissues associated with 95% relative yield varied in maize grains, cobs and stover. Further, similar to literature reports, the K fertilizer dose significantly affects the concentration of P and N concentration in the tissues(Bahmanyarand Soodaee-Mashaee, 2010)

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