STUDIES ON POTASSIUM REQUIREMENTS FOR MAIZE IN
NYAMIRA COUNTY, KENYA

BY

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Award of the Degree of Master of Science (Chemistry) in the School of Pure and
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DECLARATION

I hereby declare that this is my original work and has not been presented for a degree in any other University.

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DEDICATION

The research is dedicated to my loving wife Janet, my daughter Olive, my mother Paskaliah, my sister Mary and my late father Alfred Kenyanya Ong’era who loved me and whom I miss.
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### ABBREVIATIONS AND ACRONYMS

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<tr>
<td>AAS</td>
<td>Atomic absorption spectrophotometer</td>
</tr>
<tr>
<td>ATP</td>
<td>Adenosine triphosphate</td>
</tr>
<tr>
<td>CEC</td>
<td>Cation exchange capacity</td>
</tr>
<tr>
<td>EC</td>
<td>Electrical conductivity</td>
</tr>
<tr>
<td>EMF</td>
<td>Electromotive force</td>
</tr>
<tr>
<td>KARI</td>
<td>Kenya Agricultural Research Institute</td>
</tr>
<tr>
<td>PBC</td>
<td>Potassium buffering capacity</td>
</tr>
<tr>
<td>SI</td>
<td>International system of units</td>
</tr>
<tr>
<td>UV – VIS</td>
<td>Ultraviolet-Visible spectrophotometer</td>
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ABSTRACT

In Kenya, maize is a key cereal crop and a major staple food in most Kenyan families. Most maize farmers mainly apply nitrogenous and phosphorus fertilizers to improve on maize yields in the country and Nyamira County in particular. However, acreage yields have been declining yearly despite their use. Application of potassium (K) fertilizers in the region is limited yet it is the third major nutrient required by maize crop in large quantities for optimum growth and yields. Consequently, it is no longer wise to assume that the soils in the region have enough K levels for good maize growth and yields. The present study was planned to determine the soils nutrient status and evaluate whether K fertilizers use can play a role to improve maize yield in the region. The field experiments were set and conducted in Gachuba location in Nyamira County. Equilibria K concentrations were determined by flame photometry from filtrate of 2.5 g soil in 25 mL solutions of various potassium concentrations (0, 25, 50, 75, 100, 125, 150, 175, 200, 225 and 250 mgL⁻¹) after stirring the mixtures for 24 hours to achieve steady state condition. Adsorption data obtained from the various soil solutions of K were fitted into Langmuir, Freundlich, Temkin and Van Hauy equations. The data fitted best in Freundlich isotherm model and was farther used to calculate acreage doses. Maize was grown under same doses of nitrogenous and phosphorus fertilizer and ten different doses of potassium in plots of 6 m by 5 m at two farm sites, that is, Gachuba (farm site 1) and (Kiang’ende farm site 2). Maize performances with site and dosage application were determined and growth parameters as well as yield parameters recorded. 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 144.76 kg ha⁻¹ giving yields of 3315.27 kg ha⁻¹ and 3340.50 kg ha⁻¹ for farm sites 1 and 2 respectively. The concentration levels of available potassium in the soils ranged from 57 to 70 mg kg⁻¹ and with a mean value of 60±5.542 mg kg⁻¹. The water soluble potassium ranged from 1.8 to 2.2 mg kg⁻¹ and gave a mean of 2.02±0.16 mg kg⁻¹. Nitric acid extracted potassium had a mean of 149±2.306 mg kg⁻¹. The mean value of energy of replacement, ΔF, was found as −3572±44.98 cal mol⁻¹. The study indicated insufficiency of potassium in the soils for optimum maize production in the region. Also, it established that potassium doses significantly affected concentrations of phosphorus and nitrogen in the tissues. The findings of this research would create awareness the extent to which potassium has been depleted in soils in the region to both farmers and policy makers and hence appropriate action taken. Also, the information is expected to help extension officers and farmers to use correct K doses for optimum maize yields.
CHAPTER ONE

INTRODUCTION

1.1 Background information

Food security remains elusive so far to many low income groups of Kenya. Studies have found that 88% of Kenya’s households consume maize as staple food (Olielo, 2013). Despite the importance of maize in Kenya, acreage yields have continued to decline. A major contributing factor to low agricultural yields in developing countries is low soil fertility (Dereje et al., 2002). This has mainly led to the decline in crop productivity in Kenya (Ayaga et al., 2004). Soil fertility has been declining because of continuous use of the agricultural land without adequate replenishment of utilized nutrients (Kiiya et al., 2006) and planting more nutrient demanding crops which produces high yield. This leads to a drop in nutrient stocks in the soil (Loes and Ogaard, 2003). For instance, in Kisii and Western Kenya, annual depletions of 112 kg ha\(^{-1}\), 31 kg ha\(^{-1}\) and 70 kg ha\(^{-1}\) have been reported for nitrogen, phosphorus and potassium nutrients respectively (Smaling, 1993).

The nutrients depletion is as a result of poor agricultural practices. Some of the poor agricultural practices include: removal of crop residue for livestock, overgrazing and burning of stock to ease land preparation (KARI, 2009). Other factors that have led to a decline in crop productivity are: limited usage of inorganic fertilizers, lack of knowledge on types of fertilizers and insufficient information on fertilizer usage (Gikonyo et al., 2000). Economic hardship has also led to high cost of farm inputs for peasant Kenyan farmers to afford (Nandwa et al., 2000).
Potassium is the third major primary essential nutrient after nitrogen and phosphorus. It is required by plants and animals in large quantities (Oborn et al., 2005). Potassium is a main requirement for maximum plant growth and yield, especially maize crop (White, 2003). The nutrient plays a key role such as regulation of the uptake of nitrates from the soil and balancing effect on phosphorus uptake. Potassium strengthens stalks of plants thus helping plants resist fungal and bacterial attacks as well as lodging. The nutrient promotes the formation of good quality seeds and fruits. It also influences very many physiological processes in plants such as transpiration, synthesis of carbohydrates, proteins and translocation of the synthesized food. However, excess K levels may not be of any economic and environmental importance (Hannan, 2008).

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 (Bukhsh et al., 2012). The crop has extremely wide range of environmental adaptability and large number of varieties differing in period to maturity. Despite the increase of any available land for maize cultivation, 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 depletion in the soils; hence need for adequate supply of nutrients 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 et al., 2012).

Different approaches are used to evaluate soil nutrient requirements of crops for optimum growth in which adsorption isotherm technique 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 soil accurately. 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 of these facts, the present study was aimed at determining 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 in intensive agricultural soils of Nyamira County, Kenya.

1.2 Statement of the problem and justification

Maize is a key cereal crop and a major staple food in most Kenyan families. However, its acreage yields in Nyamira County, Kenya have been decreasing yearly despite application of nitrogenous and phosphorus fertilizers to improve on yields. Potassium rich fertilizer usage in the region is limited yet it is the third major nutrient required by maize crops in large quantities. So, it is no longer wise to assume that the soils in
the region have enough K levels, a key nutrient requirement for good maize growth and yields. Consequently, there is need to not only determine soil nutrients in the region but also work out the external and internal K requirements for maize crops for optimum yield which is crucial.

1.3 Hypothesis
Soils in Nyamira county do not contain adequate potassium for maize production.

1.4 Objectives

1.4.1 General objective
To determine nutrient concentration levels and work out the external and internal K requirements for maize crops in Gachuba region of Nyamira County for optimum maize yield.

1.4.2 Specific objectives
(i) To determine fertility indices of the soil that include: organic carbon, cation exchange capacity, exchangeable cations, soil pH, available nitrogen, total and available phosphorus.
(ii) To determine the K buffering capacity of the soils.
(iii) To determine the optimum soil K fertilization dosage by using adsorption isotherms for optimum maize yield.

1.5 Significance of the study
The data or results from this study will be integral in providing more knowledge, verify and update soil test potassium fertilizer recommendations for maize crop to farmers and relevant authorities who influence policy implementation such as KARI
and Ministry of Agriculture. The results of this work will assist in strategies to increase food production and food security in the country.
CHAPTER TWO
LITERATURE REVIEW

2.1 Soil and soil fertility

Soil is not a lifeless zone but a dynamic layer in which many chemical, physical and biological activities go on constantly. Soil is made up of the three states of matter, that is, solids, liquids and gases that coexist together for better existence of living organisms (Tisdall, 1994). Soil fertility is a general term that defines various factors that promote and support plant growth. Components of soil fertility include: biological, nutrient factors, formally called chemical fertility and physical factors. Physical fertility of soil comprises capacity of soil to control disintegration of soil structure which refers to size, shape and arrangement of the aggregates formed when primary particles are clustered together into larger separate units called peds. Soil and soil fertility are important components of crop production.

2.2 Chemical soil nutrients

Chemical soil nutrients are mainly divided into two groups, that is, macro and micro nutrients. Macronutrients are divided into primary and secondary nutrients. The primary nutrients are required by plants in large amounts for their growth and survival. They are taken by plants in large amounts and are always inadequate in the soils. The nutrients include: nitrogen (N), phosphorus (P) and potassium (K). Secondary nutrients such as calcium (Ca), magnesium (Mg) and sulphur (S) are usually enough in the soils and as a result fertilization is not always needed. Further, large amounts of Mg and Ca are added when lime is applied to acidic soils. On the other hand, micro- nutrients are those elements essential for plant growth which are
needed in very small quantities. They include boron, copper, iron, chlorine, manganese, molybdenum and zinc (Ahmed et al., 1992).

2.2.1 Potassium

Potassium is a soil mineral nutrient which does not form any structural component of plants but required in large quantities for various metabolic activities as well as physiological functions. Soil K varies from soil to soil. Similarly, the response to K fertilizer added differs significantly. The added fertilizers differ because responses of crops to applied K are erratic. This unpredictability is due to different adsorption characteristics of K by different types of soils. For example, when K fertilizer is applied in the soils, some portion are adsorbed on interlayer sites and become non-exchangeable thus non available for immediate uptake by plants (Harter and Naidu, 2001).

2.2.1.1 Roles of potassium in plants

The main role of K in plants is to provide the appropriate ionic environment in the cells and regulator of physiological processes. Plants require K ions for opening of the stomata which is regulated by the proton pumps which makes the surrounding guard cells either turgid or flaccid. Potassium helps in the regulation of the uptake of nitrates from the soil and brings a balancing effect on phosphorus uptake. Potassium strengthens stalks of plants thus helping plants resist fungal and bacterial attacks as well as lodging. The nutrient promotes the formation of good quality seeds and fruits. It also influences the rate of transpiration and synthesis of carbohydrates and proteins and translocation of the synthesized food. But deficiency of potassium ions can impair plants ability to maintain these processes (Bukhsh et al., 2012). On the other hand,
application of excess K dosage levels in soils are unwanted because of economic and environmental pollution problem that are harmful to crops. For instance, high K rates do not improve yield but impair grain quality, damage salt, depress magnesium and boron ions uptake by roots and damage seeds as they germinate (Chapman et al., 1992).

2.2.1.2 Symptoms of potassium deficiency

Typical symptoms of potassium deficiency in plants include brown scorching and curling of leaf tips as well as chlorosis. Potassium deficiency on old lower leaves because K is a mobile nutrient. This means that a plant can allocate K to younger leaves when it is deficient. Plant growth, root development, seed and fruit development are normally reduced in potassium deficient plants (Pravinchandra and Kotecha, 2006).

2.2.1.3 Prevention and cure of potassium deficiency in soils

Potassium deficiency can be cured by adding K specific fertilizers referred as potash. Long term methods of prevention and cure of K deficiency in soil include use of organic fertilizers and adding plenty of rotted composted plants remains into soils such as banana peels because they are rich in K nutrient. This improves soil structure. Adequate moisture is necessary for effective K uptake; low soil moisture reduces K uptake by plant roots. Also, liming acidic soils will also increase K retention in the soils by reducing leaching (Datnoff, 2007).
2.2.2 Soil organic matter

This is the portion of the soil which consists of plants and animal tissues at different stages of decomposition. The particles include cells and tissues of soil organisms and substances synthesized by the soil organisms. Soil organic matter has positive effects on soil physical and chemical properties as well as the soils capacity to provide regulatory ecosystem. Optimum organic matter improves: soil structure, aggregation of water retention, soil biodiversity absorption and retention of pollutants, buffering capacity, recycling and storage of plant nutrients. It also acts as a major sink and source of carbon (Brady and Weil, 1999).

2.2.3 Nitrogen

Nitrogen is the major mineral component of all proteins. In many agricultural farms, nitrogen is the main limiting nutrient for high growth and yield. Most of the nitrogen taken up by plants from the soil is in the form of nitrates but in other areas it is absorbed as ammonium ions (Lowenfel et al., 2011). Other soluble forms are transported in form of ammine and amides.

2.2.4 Phosphorus

This is a very important nutrient for root development, key element for plant cell membrane and all energy functions within the plant. Phosphorus fertilization has been shown to increase plant uptake of magnesium. Phosphorus is most available to plants when the pH ranges from 6-7 and rapidly becomes tied up in other elements such as aluminium, and iron in very acidic soils making it unavailable to plants.
2.2.5 Soil pH

The term is used to express the acidity or alkalinity of the soil. The soil pH is very important because it affects the availability of nutrients in the soil necessary for plant growth. According to Okaleb et al, (2000) the availability of most plant nutrients in soils is best at pH range of 5.5-6.8. When the pH is higher, micronutrients such as iron, manganese copper and zinc becomes less available due to precipitation and leaching. This is because soil pH affects solubility of plant nutrients in the soil. Soil pH can be raised by adding lime or lowered by adding iron sulphite or sulphur.

2.2.6 Cation exchange capacity (CEC)

The CEC is the maximum quantity of total cations of any class a soil is capable of holding at a given pH value available for exchange with the soil solution. It is a measure of fertility, nutrient retention capacity and the capacity to protect ground water from cation contamination. It measure of the capacity of the soil to hold nutrients with a positive electrical charge such as calcium, magnesium and K. Soils with high CEC can supply large amounts of nutrients. However, may also require large amounts of fertilizer to be fertile. On the other hand, a soil with low CEC such as sand has low nutrient holding capacity. As a result, more frequent applications of low rates of fertilizers are required (Hannan, 2008).

2.2.7 Magnesium

Magnesium is an essential mineral element in very many biological systems (Marschner, 1995). For example, adenosine triphosphate (ATP), the main source of energy in cell must be bound to a magnesium ion in order to be biologically active in
the form Mg-ATP. The nutrient is very important in the synthesis of chlorophyll and photosynthesis.

2.2.8 Calcium

Normally, calcium regulates transport of other nutrients into the plant, strengthens structural systems and plays a role in activation of certain plant enzymes. Calcium deficiencies may lead to stunted growth and rotting of parts of plant (Brady and Weil, 1999).

2.3 Forms of K in soil

None of the activities in assessing the K supplying capacity of the soil can be achieved without elaborate understanding of various forms and behavior of K in the soils (Hannan, 2008). There are four forms of soil potassium. They include: solution, fixed, exchangeable and mineral K. The forms in order of ease of availability to plants are: solution, exchangeable, fixed (non-exchangeable) and mineral (Sparks, 2000). The equilibrium and kinetic reactions between the four forms of soil K affects the level of soil solution K at any particular time, and thus, the amount of readily available K for plants. Exchangeable K and non-exchangeable K levels comprise a small fraction of the total K. The largest portion of total soil K is in the mineral fraction which is about 98% (Sparks and Huang, 1985).

2.4 Importance and agro-ecological requirements of maize production

Based on the area and production, maize is the third most important cereal crop after wheat and rice in the world (Tollenaar and Dwyer, 1999). In Kenya, almost every household consumes maize with an annual per capita consumption of about 125 Kg of
Maize is a nutritious stable food and richest source of carbohydrates, proteins, iron, vitamin B, and minerals among many families in Kenya. It is the major source fodder for livestock feed, raw material for industry for starch and oil extraction. Maize residues are important in soil conditioning (Pangali and Pandey, 2001).

Maize is a versatile crop grown across a wide range of agro-ecological zones and climatic conditions throughout the year. The crop has large number of varieties differing in period to maturity. The varieties can be grown in a wide range of rainfall from average rains of about 250 mm to 2000 mm for a season. The varieties require an altitude ranging from sea level to about 3000 m at the equator and well drained soils with a pH of about 6 to 7. Maize has a wide range of tolerance to temperature condition. It is a crop of essentially of warm regions where moisture is adequate. They require an average temperature of at least 20 ºC. The optimum temperature for good yield is about 30ºC. Production of maize is affected by factors such as poor soil fertility, drought and diseases (Eltelb et al., 2006). The crop is sensitive to moisture stress a round and at the time of tasselling and cob formation. It needs optimum moisture condition at the time of planting. Maize can be grown in many soil types but preferred best in well drained soils, well aerated deep soils containing adequate organic matter and well supplied with nutrients. High maize yield is depended on high soil nutrients.
2.5 Potassium adsorption isotherms

Adsorption isotherms describe the relationship between the amount of substances that are adsorbed by an absorbent and the equilibrium remaining concentration amounts in soil solution phase. Adsorption affects nutrient availability to crops in the soil. Adsorption studies can be done on essential elements such as P, K, S and Cu (Hunter, 1980). They help in determining whether the applied nutrient can react, be fixed or form complexes with the soil matrix. The approach involves fertilizer optimization for maximum crop production. The approach provides safe levels of any one nutrient in the soil since it is adjusted in available pool of the soil level in which it is neither deficient nor toxic (Hunter, 1980). The approach can be used to evaluate the ability of soil to supply K to plants and to describe the exchange of K from soils by other ions such as Ca$^{2+}$ (Neiderbudde, 1986).

Models equations can be used to describe and monitor nutrient adsorption behaviors in soils and their availability to plants. Some of the model equations used include Langmuir, Freundlich, Gunary and Temkin model equations. They can be used in prediction of fertilizer requirements of crops. The model equations involve the development of adsorption isotherms. The technique is superior since it takes into account intensity, quantity and capacity factors which are very important for predicting the amount of soil nutrients required for maximum plant growth. It helps in predicting how the nutrient status of soils may change upon cropping provided the critical solution level for a particular plant is identified. It helps in estimating the fertilizer that may needed to adjust soil solution to level optimum for maximum yield for particular crops.
2.5.1 Langmuir adsorption isotherm

The isotherm model fits monolayer reactions. The experimental data is fitted into the linearized form of the equation 2.1 (Pal et al., 1999).

\[
\frac{c_e}{q_e} = \frac{1}{kb} + \frac{c_e}{b} \tag{2.1}
\]

The constants in the isotherm equation have their usual meaning, in which \( C_e \) is the equilibrium solution K concentration (mg L\(^{-1} \)), \( q_e \) is the mass of K adsorbed per unit mass of soil (mg kg\(^{-1} \)), \( k \) is a constant related to bonding energy of K to the soil, and \( b \) is the maximum K adsorption capacity of the soil.

2.5.2 Temkin adsorption isotherm

The linearized form of the isotherm is shown by equation 2.2 below.

\[
q_e = a + b \ln C_e \tag{2.2}
\]

Where \( q_e \) is the mass of K adsorbed per unit mass of soil (mg kg\(^{-1} \)), \( C_e \) is equilibrium solution K concentration (mg L\(^{-1} \)), \( a \) and \( b \) are constants obtained from the intercept and the slope respectively.

2.5.3 Freundlich adsorption isotherm

Freundlich isotherm model gives a closer description of the real adsorption phenomena in the soil. The un-linearised form of the isotherm is shown in equation 2.3

\[
q_e = aC_e^b \tag{2.3}
\]
By rearranging and log transforming equation 2.3, the linearised form of the isotherm will be as shown in equation 2.4. For fitting experimental data, equation 2.4 below is used.

\[ \log q_e = \log a + b \log C_e \]  

Where \( q_e \) is the mass of K adsorbed per unit mass of soil \( (\text{mg kg}^{-1}) \), \( C_e \) is the equilibrium solution K concentration \( (\text{mg L}^{-1}) \), \( a \) and \( b \) are constants obtained from the intercept and slope respectively.

2.6 Analytical techniques

Many of analytical methods used for environmental samples are methods approved by federal agencies and organizations such as the National Institute for Occupational Safety and Health.

2.6.1 Atomic absorption spectroscopy (AAS)

The AAS make use of the fact that free atoms of an element absorb light at wavelength characteristics of the element. The technique is used in analysis of most heavy metals and in some cases magnesium and calcium. The extent of absorption is the measure of the number of atoms in the light path. As illustrated in the figure 2.1 below, an AAS requires: a source of light, a flame to decompose the sample into its constituent atoms, that is, flame atomizer, a monochromator to isolate the required wavelength, a photomultiplier detector and readout device.
The light emitted from hollow cathode lamp is characteristic of the metal lining in the cathode lamp. The light is passed through the flame, into which a fine mist or aerosol of the sample solution is sprayed by a pneumatic nebulizer. The flame desolvates the sample mist and decomposes the resulting droplets into atoms of the analyte. Only atoms of elements in the flame similar to those lining the hollow cathode absorb the spectral radiation from the hollow cathode lamp. The characteristic wavelength is isolated by the monochromator. The decrease in the amount of light reaching the detector when sample atoms are present in the flame is a measure of the concentration of metal analyte. Thus the absorbance is obtained by equation 2.5.

\[ \text{Absorbance} (A) = \log \frac{I_o}{I_T} = \varepsilon cl \]  

\( I_o \) is the intensity of the incident beam, \( I_T \) is the intensity of the beam transmitted by the atoms, \( c \) is the concentration of metal analyte in the atomizer and \( \varepsilon \) is molar absorptivity and \( l \) is path length (Alloway, 1995).
2.6.2 Ultraviolet-visible spectroscopy

Ultraviolet-visible spectroscopy is the most common technique for the quantitative molecular analysis and determination of different analytes, such as transition metal ions, highly conjugated organic compounds, and biological macromolecules. Also it is used for qualitative analysis to provide valuable information through absorption spectrum which is unique for a given compound. Ultraviolet-visible spectrophotometer consist a dual light source, tungsten lamp for visible range and deuterium lamp for ultraviolet region, grating and monochromator, a photodetector, mirrors and glass or quartz. It involves the absorption of electromagnetic radiation by substances in the ultraviolet and visible region of the spectrum. This will result to changes in the electronic structure of ions and molecules through the excitation of bonded and non-bonded electrons. Spectroscopic analysis is commonly carried out in solutions but solids and gases may also be studied (Fified and Kealey, 2000).

2.6.3 Flame photometry

Flame photometry also referred to flame atomic emission spectrometry is a quick, economic and simple way of detecting metal ions primarily sodium, K, and lithium in solutions. A flame photometer is an instrument used for measuring the spectral intensity of lines produced by metal ions present in ionic compounds. Measuring flame emission of solution containing metal salts is done to perform a quantitative analysis of these substances.

Flame photometry relies on the principle that alkali metal salts drawn into a non-luminous flame will ionize, absorb energy from the flame and then emit light of characteristic wavelength as the excited atoms decay to unexcited ground state. The
intensity of the emission is proportional to the concentration of the element in the solution. A photocell detects the emitted light and converts it to voltage which can be recorded. Since each element in question emits light of different wavelength, by use of appropriate coloured filters the emission due to the elements can be used to measure their specific concentration (UNEP and WHO, 1996).
CHAPTER THREE
MATERIALS AND METHODS

3.1 Experimental site

The experiment was carried out in Gachuba location in Nyamira County, Kenya. The soils are mainly classified as nitosols which are well drained. The area has a mean annual rainfall of about 1700 mm - 1800 mm. Due to high population and pressure on land; all land is under cultivation with very small portion under pasture. The main crops grown in the area include: maize, beans, bananas, sugarcane, coffee, cassava, finger-millets, kales and cabbage.

3.2 Sample collection

The study involved five farms that have been consistently under cultivation. The farms locations were Gachuba (site 1), Kiang’ende (site 2), Kiomonso (site 3), Girango (site 4) and Keboba (site 5) villages. Top soil samples were collected from the farms 0 - 30 cm depth. The depth was used since most soil nutrients and maize roots concentrate in the region. Grid sampling was employed due to uniform soil characteristics of the area under study in which samples were randomly collected from the locations. With the help of a soil auger 15 - 20 cores (a core was an individual boring or coring spot in a field) were collected from each farm at random. The cores from each farm were mixed thoroughly in clean plastic pails to make composite soil samples. The bulk composite samples were air dried, ground, passed through a 2 mm sieve, packed in clean polythene bags, kept cool and were ready for use in the study.
3.3 Reagents

Reagents used throughout the research were of high quality analytical grade. The water used was distilled in an all pyrex distiller. The particular reagents included:

Concentrated nitric acid (70 % HNO₃) sd.fine Chem. Limited (MUMBAI)
Concentrated sulphuric acid (98 % H₂SO₄) BDH Chemicals Limited (UK).
Concentrated hydrochloric acid (assay 36-38 % specific gravity 1.18) BDH Chemicals Limited (UK).
Potassium chloride BDH Chemicals Limited (UK).
Magnesium chloride MgCl₂.6H₂O LAB TECH CHEMICALS
Calcium Chloride.6H₂O NOBIAN KENYA LTD

3.4 Instrumentation

The main instruments that were used included: flame photometer (Corning 410 - Japan), UV –Visible spectrophotometer (UV mini 1240 Shimadzu- Japan), atomic absorption spectrophotometer (AA – 630 - 12 Shimadzu) using single hollow cathode lamp, electrical conductivity meter, analytical weighing balance, electrical conductivity and the pH Meter located at Jomo Kenyatta University of Agriculture and Technology Horticultural Department Laboratories.

3.5 Cleaning of glassware, plastic ware and other containers

The glassware used in this research project included pipettes, volumetric flasks, round bottomed flasks, beakers, conical flask, filtering funnels and measuring cylinders. All glasswares, plastic ware, sample storage bottles and other containers were thoroughly cleaned. They were washed with soap and rinsed with tap water. Later they were soaked in ten percent nitric acid for 24 - 48 hours before rinsing thoroughly with
distilled water. The glassware were then put in an oven and dried overnight at 80°C. All volumetric glasswares were not oven dried to avoid loss of calibration. They were kept on the bench to dry.

3.6 Soil analysis

3.6.1 Soil pH
In the study, the pH of the soil was determined as follows: twenty grams of the soil samples were weighed into a plastic bottle and 50 ml of distilled water added. The resulting contents were shaken in shaker machine for 30 minutes after which it was allowed to settle for ten minutes. The pH of the soil-water paste was then measured by a calibrated pH meter (using known buffers i.e. buffer 7 and buffer 4 respectively).

3.6.2 Electrical conductivity (EC)
Twenty grams of the soil was placed in a conical flask and distilled water added to prepare a saturated soil paste which was allowed to stand for 30 minutes. The paste was then transferred to Buchner funnel for vacuum filtration. EC of the saturated filtrate was then measured.

3.6.3 Extraction of available Phosphorus: Olsen method
In this study, 2.5 g of soil was weighed into a 250 ml polythene shaking bottle. Then 50 ml of 0.5N solution of sodium bicarbonate added to each bottle. The contents were stoppered well and shaken on a reciprocal mechanical shaker for 30 minutes. The suspension was filtered after shaking; using the Whatman paper No. 42. A little
charcoal was added to the filtrate and re-filtered to obtain a clear filtrate. This filtrate was used for calorimetric measurements.

### 3.6.4 Calorimetric measurements of phosphorous

Each 10 ml of P standard solution, 10 ml of the sample filtrate and 2 reagent blanks were placed into 50 ml different volumetric flasks. 5 ml of 0.8M boric acid was added to each flask. Beginning with the standards, 10 ml of ascorbic acid reagent was added to each flask and then the flasks were filled to the mark. The contents in each flask were stoppered and shaken well. After one hour, the absorbance of the solution was measured at 880 nm wavelength using a UV–Vis spectrophotometer. The concentrations of P were obtained from the standard calibration curves. Boric acid was used to suppress fluoride interference from the extractant.

### 3.6.5 Digestion of soil for analysis of total nitrogen and phosphorus

A soil of 0.3 g was weighed and placed in clean digestion tubes. Then 5 ml of the digestion mixture was added and the reagent blank was treated the same way as the sample then placed in muffle furnace set at 330ºC for two hours. After two hours the sample digest was diluted to 50 ml volumetric flask after cooling. This is the stock where the aliquots were taken for analysis of total nitrogen and phosphorus.

#### 3.6.5.1 Determination of total nitrogen

The distillation apparatus was set. 10 ml of the digested aliquot sample were taken and added to 10 ml 40 % sodium hydroxide. The mixture is steam distilled immediately into 5 ml boric acid containing 4 drops of mixed indicator in 100 ml conical flask until the colour changed from red to green and the concentration of nitrogen determined by back titration.
3.6.5.2 Determination of total phosphorus

In this case, 10 ml of the digest solution was pipetted into 50 ml volumetric flask and 4 drops of 0.5 % of p-nitrophenol indicator added. Then 6 N ammonia solution was added drop wise until the colour turned yellow followed by addition of 1 N HNO₃ dropwise until the colour turned colourless after which ammonium molybdate was added. The volume was made to 50 ml with distilled water and after 30 minutes the the absorbance of the solution was measured at 880 nm wavelength using a UV–Vis spectrophotometer and amount of phosphorus present obtained from standard calibration curves.

3.6.6 Fractionation of potassium forms in the studied soils

3.6.6.1 Ammonium acetate extractable K

Two grams of soil were weighed into plastic bottle. Then 40 ml of 1 N ammonium acetate was added and the resulting contents were shaken in a reciprocal shaker machine for 30 minutes after which it was allowed to settle for ten minutes. Finally, the solution was filtered through a Whatman No. 42 and the concentration of the filtrate determined using a calibrated flame photometer

3.6.6.2 Water soluble potassium, magnesium and calcium

Soluble K, Mg and Ca were extracted by shaking 20.0 g of soil with 20 ml distilled water in a conical flask for one hour. From the water extract, activity of K, Mg and Ca in the filtrate were determined as the product of concentration of ions by their activity coefficient. Activity coefficient($f_i$) of the ions determined using extended Debye-Hückel (Graffin and Jurinak, 1993) as shown in equation 3.1
\[
\log f_i = \frac{-AZ_i^2(\mu^{\frac{1}{2}})}{(1 + Bd_i\mu^{\frac{1}{2}})}
\]  

Where: \( Z_i \) = valence of ion, \( A = 0.508 \) and \( B = 0.328 \times 10^8 \) are known constants, \( \mu = \) ionic strength and \( d_i = \) effective size of hydrated ions.

### 3.6.7 Cation exchange capacity (CEC)

A total of 2.5 g of the soil sample was weighed into a conical flask and 50 ml of 1N ammonium acetate solution added for replacement of cations and shaken in a mechanical shaker for 30 minutes. Excess ammonium acetate was washed with 25 ml 95 % ethyl alcohol from the soil sample by allowing it to drain until damp soil sample remained. The damp soil was then leached with 250 ml of 0.01N HCl to replace the exchangeable ammonium. 50 ml of the leachate was transferred to Kjeldahl flask, 3 g of sodium chloride and 40 % sodium hydroxide was added. Distillation was done until the colour of boric acid indicator turned from red to green. Then, back titration was done i.e. the boric acid solution with 0.01 N HCl from green to red. The same procedure was repeated with the blank.

### 3.6.8 Total Organic carbon

The 0.5 g of soil sample was measured into a 250 ml conical flask; then 10 ml of 1 N potassium dichromate was added followed by 15 ml of 98 % concentrated sulphuric acid. The flask was allowed to stand for 30 minutes followed by addition of 150 ml of distilled water, 5 ml of 96 % orthophosphoric acid and 10 drops of diphenylamine indicator. The mixture was titrated with 0.5 N ammonium ferrous sulphate solution until the colour changed from blue-violet to green. The blank was run the same way without soil but all other reagents added as the sample.
3.7 Adsorption studies

Adsorption studies were done as per the method described by Rowell (1994). In the study, 2.50 grams of the soil samples were put in 25 mL solutions of 0.01 M CaCl$_2$ that contained potassium concentrations of 0, 25, 50, 75, 100, 125, 150, 175, 200, 225 and 250 mg L$^{-1}$ and shaken for 24 hours at 25±1°C to achieve equilibration. The 0.01M CaCl$_2$ was used replace the exchangeable hence avoid extraction fixed potassium. The contents were filtered using Whatman filter papers No. 42. The potassium content in the filtrate was determined using a flame photometer. The amount of K adsorbed by the soil was calculated from the differences between the amounts found in filtrate from the initial amount that was in solutions using equation 3.2.

\[ \Delta K = (C_i - C_f) \times V / M \]  

Where $\Delta K$ is amount adsorbed by the solid phase of soil; $C_i$ and $C_f$ are the initial and equilibrium K concentrations in solution respectively; $V$ and $M$ are the solution volume and mass of the soil used. The K adsorption data was fitted into linearized forms of the Langmuir, Temkin, Freundlich and Van Hauy adsorption equations.

3.8 K fertilizer dosage for field experiments

From the adsorption studies, Freundlich isotherm best described the soils and hence was further used as shown in equations 3.3 and 3.4 to determine K fertilizer dosages. The K dosages obtained for the field experiments are shown (Table 3.1).

\[ \text{Fertilizer dose } q_e (\text{mg kg}^{-1}) = aC_e^b \]  

\[ \text{Fertilizer dose (kg ha}^{-1}) = \text{Fertilizer dosage } q_e (\text{mg kg}^{-1}) \times 2 \]  

Where $q_e$ is the amount of K adsorbed per unit mass of soil, $a$ and $b$ were constants obtained from the intercept and slope of Freundlich adsorption isotherms respectively.
Table 3.1  Freundlich K fertilizer doses applied to the maize crop for field experiments

<table>
<thead>
<tr>
<th>Treatment code</th>
<th>Concentration of K solution (mgL⁻¹)</th>
<th>Dosage of K (mgkg⁻¹)</th>
<th>Dosage of K (Kg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Site 1</td>
<td>Site 2</td>
</tr>
<tr>
<td>TR1</td>
<td>Control</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>TR2</td>
<td>2</td>
<td>14.97</td>
<td>13.51</td>
</tr>
<tr>
<td>TR3</td>
<td>5</td>
<td>44.54</td>
<td>40.97</td>
</tr>
<tr>
<td>TR4</td>
<td>8</td>
<td>77.92</td>
<td>72.38</td>
</tr>
<tr>
<td>TR5</td>
<td>11</td>
<td>113.82</td>
<td>106.55</td>
</tr>
<tr>
<td>TR6</td>
<td>14</td>
<td>151.56</td>
<td>142.54</td>
</tr>
<tr>
<td>TR7</td>
<td>17</td>
<td>191.08</td>
<td>180.32</td>
</tr>
<tr>
<td>TR8</td>
<td>20</td>
<td>231.84</td>
<td>219.54</td>
</tr>
<tr>
<td>TR9</td>
<td>23</td>
<td>273.80</td>
<td>260.03</td>
</tr>
<tr>
<td>TR10</td>
<td>26</td>
<td>316.80</td>
<td>301.65</td>
</tr>
</tbody>
</table>

3.9 Experimental design

Maize was grown under model K fertilization dosage in a complete randomized design in triplicates and in control plots potassium fertilizer was not applied. All the
plots received basic recommended nitrogenous and phosphorus fertilizer dosage. Maize performance was determined with respect to site and dosage.

3.10 Planting and measurement of growth parameters

The land was ploughed and harrowed to pulverize the soil. The experimental fields were marked into raised plots of 6 m by 5 m with a distance of 1 m between the plots. Round the edges of the plots mulches were placed to prevent soil erosion and mixing of nutrients from one plot to another. There were ten treatments of potassium fertilizer doses (Table 3.1) replicated three times. Plots without potassium fertilizer application were used as control experiment. Maize seeds of hybrid variety (H629) that are recommended for the area were used. They were purchased from Kenya Seed Company. Planting holes were spaced at 25 cm from plant to plant by 75 cm 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 75 kg ha\textsuperscript{-1} to ensure the nutrients did not cause a constraint over the growth period. The fertilizers were 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, 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.
3.11 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 3.3.

\[
\text{Relative yield (R.Y)} = \frac{\text{Actual grain yield}}{\text{Maximum grain yield}} \times 100 \%
\]  
(3.3)

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

3.12 Statistical analysis

The experimental data was 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.
CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Basic soil characteristics

The percentage of the total organic content was found to range between 1.10-2.07 % and a mean value of 1.82±0.41 % as shown in (Table 4.1). This falls within the moderate range that is considered to range from 1.5-3.0 %. The concentration levels of available phosphorus were found to range from 9.62 mg/kg to 9.77 mg/kg with a mean value of 9.71±0.056 mg/kg. These levels were below the critical level of 10 mg/kg (Okaleb et al., 2002). The low levels of available phosphorus obtained are illustrative of phosphorus deficiency that is endemic in many of the farms in the region. Phosphorus deficiency in many soils in Kenya is largely due to low occurrence of phosphorus containing minerals and inadequate phosphorus fixation (Buneman, 2003).

Concentration levels of total nitrogen content obtained in the study ranged from 0.173-0.196 % and had a mean of 0.179±0.017 %. This is below the recommended critical levels of nitrogen (Oborn et al., 2005). Low crop yields due to the low availability of soil phosphorus and nitrogen nutrients are expected from these findings in consistence with the FAO (2004) report. The concentration levels of available potassium obtained from ammonium acetate extracts ranged from 57-70 mg/kg with a mean of 60.2±5.541 mg/kg. The cation exchange capacity of the soil ranged from 17.25-28.05 Cmol/kg with a mean of 21.25±4.124 Cmol/kg. These medium values of cation exchange capacity indicate that the soils can moderately hold nutrients. The soil pH ranged from 4.81-5.61 with a mean of 5.19±0.28 indicating that the soils were strongly acidic. The electrical conductivity which is an indirect measure of total
amounts of soluble salts in soil was found to range from 0.20-0.31 mmhos/cm with mean of 0.25±0.05 mmhos/cm an indication these soils are non-saline.

### Table 4.1 Summary of some chemical properties of the studied soils

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Range</th>
<th>Mean values</th>
<th>Critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC</td>
<td>mmhos/cm</td>
<td>0.20-0.31</td>
<td>0.25±0.05</td>
<td>-</td>
</tr>
<tr>
<td>pH</td>
<td>-</td>
<td>4.81-5.61</td>
<td>5.19±0.28</td>
<td>-</td>
</tr>
<tr>
<td>Organic carbon</td>
<td>%</td>
<td>1.10-2.07</td>
<td>1.82±0.041</td>
<td>3</td>
</tr>
<tr>
<td>Total P</td>
<td>mg/kg</td>
<td>31.18-31.42</td>
<td>31.31±0.107</td>
<td>-</td>
</tr>
<tr>
<td>Available P</td>
<td>mg/kg</td>
<td>9.62-9.77</td>
<td>9.71±0.056</td>
<td>10</td>
</tr>
<tr>
<td>Total N</td>
<td>%</td>
<td>0.173-0.196</td>
<td>0.179±0.017</td>
<td>0.25</td>
</tr>
<tr>
<td>CEC</td>
<td>cmol/kg</td>
<td>17.25-28.05</td>
<td>21.25±4.124</td>
<td>-</td>
</tr>
<tr>
<td>Potassium ions</td>
<td>mg/kg</td>
<td>57.0-70.02</td>
<td>60.2±5.541</td>
<td>160</td>
</tr>
</tbody>
</table>

### 4.2 Fractionation of potassium forms in the studied soils

#### 4.2.1 Potassium from water extracts

The concentration levels of water soluble potassium in the soils ranged from 1.8-2.2 mg/kg and with a mean of 2.02±0.164 mg/kg (Table 4.2) and (Figure 4.1). This amount of potassium represents the amount present in solution form. The amounts obtained are very low when compared with the critical value of 19.5 mg/kg proposed by International Potash Institute (IPI, 2001). This indicates that a very small portion of available potassium is in solution form to support plant growth. This water soluble potassium was only about 3.36 percent of available potassium (potassium extracted by ammonium acetate). The low percentage is an indication that the equilibrium does not favor water soluble form of potassium.

#### 4.2.2 Ammonium Acetate K extract

The concentration levels of potassium obtained from ammonium acetate extracts ranged from 57 to 70 mg/kg and with a mean of 60.2±5.541 mg/kg as shown in (Table 4.2) and (Figure 4.1). Potassium levels from ammonium acetate extracts are
considered as estimates of the amounts in the soil that are available for plant uptake. The values obtained are below the critical value of 160 mg/kg (Al-zubaidi and Pagel, 1997). This shows that the available potassium in these soils is insufficient. These low values might be as a result of long-term continuous cropping without replenishing with potassium fertilizers. It may also imply that the soils positive response to potassium fertilization is highly probable.

4.2.3 Potassium saturation percentage

In soils, cations are held on the clay and organic matter and can be replaced by other cations thus, they are exchangeable. The total number of cations that soil can hold is related to its total negative charge and constitutes the soil's cation exchange capacity. The Percent Nutrient Saturation refers to a measure or estimate of the percent of the soil CEC that is occupied by a particular nutrient (nutrient saturation). The percentage portion of soil (CEC) that was occupied by potassium was found to range from 0.6399-0.8621 and had a mean of 0.7383±0.087 (Table 4.2). The values show that only a very small proportion of the CEC is occupied by potassium ions. This is far below the critical value of 2.3 (FAO-UNESCO, 1997).

4.2.4 Potassium extracted by nitric acid

The concentration levels of potassium found in nitric acid extracts ranged from 147-152 mg/kg and had a mean of 149.6±2.302 mg/kg as shown in (Figure 4.1) and (Table 4.2). This narrow range suggests that the soils may have similar mineralogy and parent rock. Potassium in this form is considered to represent the soil supplying power for potassium for long term cropping (Jackson, 1997). The values obtained are low compared with the critical value 400 mg/kg. This shows that the soils have poor
supplying power of potassium for future cropping and plant growth (FAO-UNESCO, 1997).

Table 4.2 Fractionation of potassium forms in the studied soils

<table>
<thead>
<tr>
<th>Forms of potassium</th>
<th>Unit</th>
<th>Range</th>
<th>Value n = 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water soluble –K</td>
<td>mg/kg</td>
<td>1.8-2.2</td>
<td>2.02±0.164</td>
</tr>
<tr>
<td>Ammonium acetate-K</td>
<td>mg/kg</td>
<td>57-70</td>
<td>60.2±5.541</td>
</tr>
<tr>
<td>Nitric acid-K</td>
<td>mg/kg</td>
<td>147-152</td>
<td>149.6±2.302</td>
</tr>
<tr>
<td>K-saturation percentage</td>
<td>%</td>
<td>0.64-0.86</td>
<td>0.738±0.087</td>
</tr>
<tr>
<td>Basal saturation percentage</td>
<td>%</td>
<td>0.1883-0.3246</td>
<td>0.2523±0.049</td>
</tr>
</tbody>
</table>

Figure 4.1 Distribution of some forms of potassium in the soils

4.3 Thermodynamic and chemical properties of Potassium in the studied soil

The thermodynamic determinants used to evaluate the levels of potassium in soils (Table 4.3) included Woodruff energy of replacement, activity ratio and ionic activity.
They give an indication on the rate at which potassium adsorbed on the solid phase can replenish the soil solution potassium (Rasnake and Thomas, 1976). This method can be used to determine fertilizer dosage required to obtain optimum concentration levels in soil solution.

Table 4.3  Thermodynamics and chemical properties of K in the studied soils

<table>
<thead>
<tr>
<th>Soil Sample</th>
<th>Electrical conductivity (EC)</th>
<th>Ionic strength (mmol/L)</th>
<th>K activity coefficient</th>
<th>K activity in mmol/L</th>
<th>∆F(Cal mol⁻¹)</th>
<th>Activity ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.28</td>
<td>3.61</td>
<td>0.9361</td>
<td>0.0528</td>
<td>-3523</td>
<td>0.00261</td>
</tr>
<tr>
<td>2</td>
<td>0.20</td>
<td>2.58</td>
<td>0.9452</td>
<td>0.0436</td>
<td>-3632</td>
<td>0.00217</td>
</tr>
<tr>
<td>3</td>
<td>0.24</td>
<td>3.10</td>
<td>0.9404</td>
<td>0.0506</td>
<td>-3548</td>
<td>0.00250</td>
</tr>
<tr>
<td>4</td>
<td>0.22</td>
<td>2.84</td>
<td>0.9427</td>
<td>0.0459</td>
<td>-3606</td>
<td>0.00227</td>
</tr>
<tr>
<td>5</td>
<td>0.31</td>
<td>4.00</td>
<td>0.9331</td>
<td>0.0502</td>
<td>3553</td>
<td>0.00248</td>
</tr>
<tr>
<td>Mean</td>
<td>0.25</td>
<td>3.23</td>
<td>0.9395</td>
<td>0.0486</td>
<td>3572</td>
<td>0.00241</td>
</tr>
<tr>
<td>SD</td>
<td>0.04</td>
<td>0.58</td>
<td>0.0049</td>
<td>0.00375</td>
<td>44.98</td>
<td>0.00018</td>
</tr>
</tbody>
</table>

4.3.1 The ionic strength (fi)

The values of the ionic strengths of potassium in the soils were tabulated as shown (Table 4.3). They were found to range from 2.58-4.00 mmol/L with a mean value of 3.23±0.58 mmol/L. This ionic strength is an indication that the potassium for maximum crop yields in the studied soils existed in active form in the soil solution (Al-zubaidi et al., 2008).
4.3.2 The activity ratio

The activity ratio of the soils was tabulated as shown (Table 4.3). They were found to range from 0.00217 to 0.00261 and with a mean value of 0.00241±0.00. The values of activity ratios normally reflect the chemical potential of the soil. High activity ratio value simply means more potassium available for plant absorption.

4.3.3 The Woodruff energy of replacement (ΔF)

Figure 4.2 shows a summary of energy of replacement. According to the classification, soils with lower than (ΔF) - 3500 cal.mol⁻¹ have poor supplying power of potassium and those with -3500 to -2000 cal.mol⁻¹ have medium supplying power of potassium. Finally, soils with greater than -2000 cal mol⁻¹ have high supplying power of potassium (Woodruff, 1995). The values obtained from the study ranged from -3632 to -3523 cal mol⁻¹ and with average value of -3572±44.98 cal mol⁻¹ (Table 4.3). This implies that the soils had poor supplying power of potassium.
4.4 Adsorption isotherms of the soils

Adsorption isotherms indicate how the adsorbate particles distribute between the liquid phase and the adsorbent phase when the adsorption processes reaches equilibrium state. The analysis of equilibrium adsorption data by fitting them to different isotherm models is an important step to finding a suitable model that can be
used for design purposes (Haghseresht and Lu, 1998). The applicability of the isotherm equation is compared by judging the $R^2$.

### 4.4.1 Langmuir adsorption isotherm

The adsorption isotherms were examined according to the linear form of the Langmuir equation. When adsorbed potassium data were plotted in Langmuir adsorption isotherm by taking $C/(x/m)$ against the equilibrium concentration a poor fit was obtained as indicated by $R^2$ (Table 4.5). The $R^2$ ranged from 0.006-0.743 and a mean of 0.359±0.278. The Langmuir adsorption isotherm did not fit well to the K adsorption data of the soils under study. This might be due to the fact that the Langmuir model assumes homogeneity of adsorption sites with a complete monolayer adsorption of solutes (Pal et al., 1999). It assumes a finite uniform number of adsorption sites of which no transmigration of adsorbate in the plane of surface (Fytianos et al., 2003).

### 4.4.2 Freundlich adsorption isotherms

A plot of log of adsorbed potassium against log equilibrium potassium concentration (EKC) gave linear graphs. The goodness of the fit was ascertained by looking at the values of $R^2$ which ranged between 0.927-0.985 as shown (Table 4.5) and gave a mean value of 0.957±0.021. This indicated high conformity of the adsorption data to Freundlich model, thus the Freundlich isotherm gave a better fit to the K adsorption data of the soils. Freundlich isotherms assume unlimited adsorption sites of heterogeneous medium and hence are expected to give better correlations for the mixed mineralogy contained in soils (Hannan, 2008). This is in agreement with cited literature. Chaudhry et al. (2003) and Hussain et al. (2006) reported that data obtained
from Freundlich equations was independent of time and temperature and the values depend on the concentration of potassium in soil solution.

The soils’ capacity to resist change in the concentration of potassium in soil solution is called potassium buffering capacity (PBC). It is also defined as the capacity of soil to maintain a given potassium level in soil solution. High values of buffering capacity are indicative of adequate potassium availability for long periods while low value simply implies that there is need for frequent fertilization (Sparks and Liebhardt, 1982). The (PBC) is obtained from the slope of the adsorption isotherms (Backett, 1964). The adsorption capacities of the soils ranged from 4.977-11.091 mg/kg with a mean of 6.993±2.378 mg/kg (Table 4.4). The value represents the amount of potassium held on un-specific sites and ready to be released for uptake by plants during a cropping season. Based on the data, the values of potassium adsorbed were low compared to available soil potassium. This suggests that part of exchangeable potassium is held on exchange sites by high bonding energy. The slopes values were found to range from 1.079-1.270 kg/mg and gave a mean of 1.171±0.0736 kg/mg.
Table 4.4 Comparison of Freundlich adsorption maximum and bonding energy constants for the five soil samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>K constants $b$ related to Bonding energy for soil L kg$^{-1}$</th>
<th>K adsorption capacity mg kg$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.190</td>
<td>6.561</td>
</tr>
<tr>
<td>2</td>
<td>1.211</td>
<td>5.834</td>
</tr>
<tr>
<td>3</td>
<td>1.270</td>
<td>4.977</td>
</tr>
<tr>
<td>4</td>
<td>1.079</td>
<td>11.091</td>
</tr>
<tr>
<td>5</td>
<td>1.195</td>
<td>6.501</td>
</tr>
<tr>
<td>mean±sd</td>
<td>1.171±0.0736</td>
<td>6.993±2.378</td>
</tr>
</tbody>
</table>

4.4.3 Temkin adsorption isotherm

The Temkin adsorption equations were obtained after plotting the adsorbed potassium \( \frac{x}{m} \) against \( \ln C \). It was observed that the Temkin equation showed a good fit compared to Langmuir equation but it is superiority was lesser than Freundlich and Van Hauy equations. The correlation coefficient $R^2$ ranged from 0.807-0.890 and with a mean of 0.839±0.0316 as shown (Table 4.5). Temkin buffering capacity (slope) was 0.001±0.00 L/Kg for the studied soil samples.
4.4.4 Van Hauy adsorption isotherms

Van Hauy adsorption isotherm was obtained by plotting adsorbed potassium \( \frac{x}{m} \) against \( \sqrt{C} \). It was observed that Van Hauy equations showed a good fit compared Temkin and Langmuir but not better than Freundlich isotherm Table 4.5. The \( R^2 \) of Van Hauy ranged from 0.895-0.947 with a mean of 0.923±0.021.

Table 4.5 Regression equation and \( R^2 \) values for the five soil samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>Model</th>
<th>Equations</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Freundlich</td>
<td>( y = 1.19x + 0.817 )</td>
<td>0.985</td>
</tr>
<tr>
<td></td>
<td>Langmuir</td>
<td>( y = -0.000x + 0.093 )</td>
<td>0.743</td>
</tr>
<tr>
<td></td>
<td>Temkin</td>
<td>( y = 0.001x + 2.892 )</td>
<td>0.847</td>
</tr>
<tr>
<td></td>
<td>Van Hauy</td>
<td>( y = 0.004x + 4.023 )</td>
<td>0.926</td>
</tr>
<tr>
<td>2</td>
<td>Freundlich</td>
<td>( y = 1.211x + 0.766 )</td>
<td>0.927</td>
</tr>
<tr>
<td></td>
<td>Langmuir</td>
<td>( y = -3E - 05x + 0.072 )</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>Temkin</td>
<td>( y = 0.001x + 2.734 )</td>
<td>0.827</td>
</tr>
<tr>
<td></td>
<td>Van Hauy</td>
<td>( y = 0.004x + 3.675 )</td>
<td>0.910</td>
</tr>
<tr>
<td>3</td>
<td>Freundlich</td>
<td>( y = 1.27x + 0.697 )</td>
<td>0.959</td>
</tr>
<tr>
<td></td>
<td>Langmuir</td>
<td>( y = -0.000x + 0.098 )</td>
<td>0.399</td>
</tr>
<tr>
<td></td>
<td>Temkin</td>
<td>( y = 0.001x + 2.885 )</td>
<td>0.890</td>
</tr>
<tr>
<td></td>
<td>Van Hauy</td>
<td>( y = 0.004x + 3.922 )</td>
<td>0.947</td>
</tr>
<tr>
<td>4</td>
<td>Freundlich</td>
<td>( y = 1.079x + 1.045 )</td>
<td>0.947</td>
</tr>
<tr>
<td></td>
<td>Langmuir</td>
<td>( y = -0.000x + 0.078 )</td>
<td>0.192</td>
</tr>
<tr>
<td></td>
<td>Temkin</td>
<td>( y = 0.001x + 2.8021 )</td>
<td>0.826</td>
</tr>
<tr>
<td></td>
<td>Van Hauy</td>
<td>( y = 0.004x + 3.887 )</td>
<td>0.895</td>
</tr>
<tr>
<td>5</td>
<td>Freundlich</td>
<td>( y = 1.195x + 0.813 )</td>
<td>0.968</td>
</tr>
<tr>
<td></td>
<td>Langmuir</td>
<td>( y = -0.000x + 0.092 )</td>
<td>0.454</td>
</tr>
<tr>
<td></td>
<td>Temkin</td>
<td>( y = 0.001x + 2.556 )</td>
<td>0.807</td>
</tr>
<tr>
<td></td>
<td>Van Hauy</td>
<td>( y = 0.004x + 4.098 )</td>
<td>0.935</td>
</tr>
</tbody>
</table>
The adsorption isotherm showed closely related equation for the five soil samples that might be attributed to uniform soil mineralogy and parent rock of the studied soils. Comparing the fitness of the four isotherms (Table 4.5) Freundlich, Van Hauy, Temkin and Langmuir equations fitted the data in that order respectively. Freundlich and Van Hauy provided the good fit for the data as shown by better $R^2$ but Freundlich equation was the best in describing the K adsorption of the soils with average $R^2$ value of 0.957±0.021, followed by Van Hauy equation $R^2 = 0.923±0.020$, Temkin equation $R^2=0.0829±0.0316$ and Langmuir equation $R^2=0.359±0.278$.

4.5 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.

4.5.1 Plant height

Table 4.6 shows the effect of varying doses of potassium to soils on growth parameters of maize. As shown in the table, the lowest mean plant heights of 191.81±0.49 cm (site 1) and 192.37±1.65 cm (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 cm and 234.87±0.21 cm at optimum dosages (Table 3.1) of 155.84 and 144.76 kg ha$^{-1}$ for site 1 and site 2 respectively. It was observed that further increase of K fertilizer dosage beyond the optimum values did not have a direct statistical significant effect on plant height. These indicate that the amounts of
potassium added to the soils for the plants to attain maximum heights constituted optimum doses which 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 the estimation rate of growth and describes the relationship between the growth vigor and chemical composition in plants. It plays a very important role in the determination of light interception in plants. Height is a primary determinant for high yield for individual plants (Winner and Fisherman, 1994). Plant height is depended on the genetic makeup of a plant but can be improved through balanced nutrition. Data regarding plant height (Table 4.8) indicates that the application of different levels of potassium fertilizer had a significant effect on maize height.
Table 4.6 Effect of different potassium dosages on growth parameters of maize

<table>
<thead>
<tr>
<th>Treatment code</th>
<th>Solution K in (mgL⁻¹)</th>
<th>Maize height (cm)</th>
<th>Stem girth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Site 1</td>
<td>Site 2</td>
</tr>
<tr>
<td>TR1</td>
<td>Control</td>
<td>191.81±0.49g</td>
<td>192.37±1.65g</td>
</tr>
<tr>
<td>TR2</td>
<td>2</td>
<td>194.06±0.89g</td>
<td>196.22±0.60g</td>
</tr>
<tr>
<td>TR3</td>
<td>5</td>
<td>199.22±0.21f</td>
<td>199.69±0.95f</td>
</tr>
<tr>
<td>TR4</td>
<td>8</td>
<td>234.46±0.71a</td>
<td>234.87±0.21a</td>
</tr>
<tr>
<td>TR5</td>
<td>11</td>
<td>219.02±0.30d</td>
<td>220.71±2.44d</td>
</tr>
<tr>
<td>TR6</td>
<td>14</td>
<td>233.27±0.55a</td>
<td>232.89±3.45b</td>
</tr>
<tr>
<td>TR7</td>
<td>17</td>
<td>230.53±1.60b</td>
<td>231.77±0.75b</td>
</tr>
<tr>
<td>TR8</td>
<td>20</td>
<td>212.39±1.42a</td>
<td>215.63±1.58e</td>
</tr>
<tr>
<td>TR9</td>
<td>23</td>
<td>221.74±0.87c</td>
<td>224.71±0.89c</td>
</tr>
<tr>
<td>TR10</td>
<td>26</td>
<td>232.82±3.27a</td>
<td>233.68±1.22b</td>
</tr>
</tbody>
</table>

Mean sharing the same letters in a column are statistically at par at 5 % level of probability Duncan’s multiple range test (DMRT)
4.5.2 Stem girth

As shown (Table 4.6), the lowest mean of stem girth of 6.34 cm (site 1) and 6.49 cm (site 2) were obtained in the control plots. These increased steadily as the doses were increased to optimum values of 10.52 cm and 10.44 cm at optimum doses of 155.84 and 144.76 kg ha\(^{-1}\) 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. The mean stem girth 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 \textit{et al.}, 1992). Potassium deficiency causes epidermis sclerenchyma tissues and xylem vascular cells to be thin (Syers, 2001).

4.6 Yield parameters

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

4.6.1 Grains yield

Grain yields were significantly affected by different levels of potassium fertilizer application (\(p<0.05\)). Data presented in tables 4.7 and 4.8 shows the effect of different potassium doses on the grains yields. For site 1, the mean grain yields increased significantly from 690.13 kg ha\(^{-1}\) to the highest mean yield of 3315.17±12.4 kg ha\(^{-1}\) obtained at an optimum potassium dose of 155.84 kg ha\(^{-1}\). Similarly the mean grain
yield for site 2 increased from 751.41 kg ha\(^{-1}\) to a maximum mean yield of 3340.50±64.9 kg ha\(^{-1}\) attained at an optimum potassium dose of 144.76 kg ha\(^{-1}\). The maize yields at different K dosages are summarized (Figure 4.3). These might be 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. Optimum potassium rates increases cell division, grains number per row, 1000 grains weight and grain yield according to Nesmith 1992. 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, that is, without nutrient constraint. 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 4.3 shows the effect of K fertilization dosages on maize grain yields.
Table 4.7  Effects of K dosages on yield parameters of maize site 1

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

Mean sharing the same letters in a column are statistically at par at 5 % level of probability (DMRT)
Table 4.8 Effects of K dosages on yield parameters of maize site 2

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

Mean sharing the same letters in a column are statistically at par at 5 % level of probability (DMRT)
Figure 4.3  Maize grain yields at different K fertilization dosages

4.6.2 Ear weight

The control plots gave the lowest mean ear weights of 155.49 g and 156.72 g for sites 1 and 2 respectively (Table 4.7 and 4.8). These increased to the highest mean values of 252.65 g and 254.52 g at optimum potassium doses of 155.84 kg ha\(^{-1}\) and 144.76 kg ha\(^{-1}\) for sites 1 and 2 respectively. The ear weight 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.

4.6.3 Ear girth and ear length

The control plots gave the lowest mean ear girth of 15.85 cm and 15.76 cm for sites 1 and 2 respectively. These increased to the highest mean values of 19.39 cm and 20.19 cm at optimum potassium doses of 155.84 kg ha\(^{-1}\) and 144.76 kg ha\(^{-1}\) for sites 1 and 2 respectively. There were significant differences in ear length in the treatments (Table 4.7 and 4.8). The highest ear length was recorded in treatment TR4. The average ear lengths ranged 15.57-19.07 cm for experimental site 1 and 17.07-22.25 cm for experimental site 2. From the results, ear girth and length with application of potassium fertilizers improved. These can be attributed to balanced nutrition which plays a key role in increasing crop production. In the region, farmers are not used to potassium fertilization in maize farming, imbalanced nutrition may be one of the yield limiting factors contributing to low productivity. Figure 4.4 shows the effect of different K fertilization dosages on maize grain yields.

4.7 Effect of K concentration (%) on 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 4.9 and 4.10) 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 of potassium in the tissues as potassium doses were increased. The potassium concentration in the stover ranged from 0.41 - 1.43 % for experimental site
1 and 0.33 - 1.34 % in experimental site 2. 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 - 0.82 % for site 1 and 0.52 - 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. This might be due to the fact that more potassium was trans-located to the cobs and grains during reproductive growth stage. In fact, potassium has a role in trans-location of photo-assimilates to storage organs (Romheld, 2010). Marchner, 1995 found potassium to be important in material transfer of leaf made assimilates to reproductive organs causing better seed filling, make hydrocarbons, proteins and quickly transfer the products towards the grains.
Table 4.9  K concentration (%) in maize grain, stover and cobs site 1

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

Mean sharing the same letters in a column are statistically at par at 5 % level of probability (DMRT)
Table 4.10  K concentration (%) in maize grain, stover and cobs site 2

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

Mean sharing the same letters in a column are statistically at par at 5 % level of probability (DMRT)
4.7.1 External 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 4.4). From the graph it was observed that K requirements in soil solution near maximum maize yield were 7.9 mg K L\(^{-1}\) for obtaining optimum maize yield in soils under study.

![Figure 4.4: External K requirements of maize](image)

4.7.2 Internal potassium requirement of maize

The internal K requirement refers to concentration of potassium in the plant 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 graph of K
concentration in the grain and optimum attainable 95% relative yield (figure 4.5).

The values for internal K requirement obtained for maize were 0.708% for site 1 and 0.729% for experimental site 2.

**Figure 4.5 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 its role in the transfer of photo assimilates to storage organs.
4.8 Effect of K concentration on nitrogen and phosphorus in maize tissues

4.8.1 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 4.11 and 4.12 contain data that shows the effect of increased potassium doses on nitrogen concentration in the tissues at site 1 and 2. The results show that the nitrogen concentration in the grains ranged from 0.06±0.01 - 0.14±0.00 %, in maize cobs it ranged from 0.12±0.02 - 0.27±0.00 % and in the stover ranged from 0.20±0.01 - 0.94±0.00 % for experimental site 1. In experimental site 2 (Table 4.14), nitrogen concentration in the grains ranged from 0.04±0.01 - 0.14±0.02 % in grains, 0.15±0.00 - 0.28±0.01 % in the cobs and 0.18±0.01 - 0.88±0.01 % in the stover. 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 nitrogen’s functions in structural development of plants especially in root development and protein synthesis.
Table 4.11  Effect of K concentration on nitrogen in maize tissues site 1

<table>
<thead>
<tr>
<th>Treatment code</th>
<th>Solution K levels</th>
<th>Grain N</th>
<th>Cobs N</th>
<th>Stover N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mg L⁻¹</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>TR1</td>
<td>Control</td>
<td>0.07±0.01c</td>
<td>0.26±0.02a</td>
<td>0.54±0.01c</td>
</tr>
<tr>
<td>TR2</td>
<td>2</td>
<td>0.07±0.00c</td>
<td>0.13±0.00c</td>
<td>0.41±0.02e</td>
</tr>
<tr>
<td>TR3</td>
<td>5</td>
<td>0.07±0.00c</td>
<td>0.19±0.01b</td>
<td>0.68±0.01b</td>
</tr>
<tr>
<td>TR4</td>
<td>8</td>
<td>0.06±0.01c</td>
<td>0.12±0.02c</td>
<td>0.46±0.01d</td>
</tr>
<tr>
<td>TR5</td>
<td>11</td>
<td>0.13±0.00ba</td>
<td>0.27±0.00a</td>
<td>0.94±0.00a</td>
</tr>
<tr>
<td>TR6</td>
<td>14</td>
<td>0.06±0.001c</td>
<td>0.21±0.02b</td>
<td>0.33±0.02f</td>
</tr>
<tr>
<td>TR7</td>
<td>17</td>
<td>0.14±0.00a</td>
<td>0.21±0.02b</td>
<td>0.54±0.00c</td>
</tr>
<tr>
<td>TR8</td>
<td>20</td>
<td>0.13±0.01b</td>
<td>0.26±0.01a</td>
<td>0.27±0.01g</td>
</tr>
<tr>
<td>TR9</td>
<td>23</td>
<td>0.06±0.01c</td>
<td>0.25±0.02a</td>
<td>0.34±0.00f</td>
</tr>
<tr>
<td>TR10</td>
<td>26</td>
<td>0.13±0.01ba</td>
<td>0.25±0.02a</td>
<td>0.20±0.01h</td>
</tr>
</tbody>
</table>

Mean sharing the same letters in a column are statistically at par at 5 % level of probability (DMRT)
Table 4.12  Effect of K concentration on nitrogen in maize tissues site 2

<table>
<thead>
<tr>
<th>Treatment code</th>
<th>Solution K levels</th>
<th>Grain N</th>
<th>Cobs N</th>
<th>Stover N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mg L⁻¹</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>TR1</td>
<td>Control</td>
<td>0.04±0.01f</td>
<td>0.28±0.01a</td>
<td>0.49±0.01d</td>
</tr>
<tr>
<td>TR2</td>
<td>2</td>
<td>0.05±0.01f</td>
<td>0.16±0.01g</td>
<td>0.44±0.01e</td>
</tr>
<tr>
<td>TR3</td>
<td>5</td>
<td>0.06±0.01e</td>
<td>0.18±0.00f</td>
<td>0.60±0.00b</td>
</tr>
<tr>
<td>TR4</td>
<td>8</td>
<td>0.08±0.00d</td>
<td>0.15±0.00h</td>
<td>0.39±0.00f</td>
</tr>
<tr>
<td>TR5</td>
<td>11</td>
<td>0.14±0.01a</td>
<td>0.27±0.00b</td>
<td>0.88±0.01a</td>
</tr>
<tr>
<td>TR6</td>
<td>14</td>
<td>0.10±0.00c</td>
<td>0.18±0.00f</td>
<td>0.34±0.01g</td>
</tr>
<tr>
<td>TR7</td>
<td>17</td>
<td>0.12±0.00b</td>
<td>0.19±0.00e</td>
<td>0.52±0.00c</td>
</tr>
<tr>
<td>TR8</td>
<td>20</td>
<td>0.14±0.02a</td>
<td>0.20±0.00d</td>
<td>0.25±0.00i</td>
</tr>
<tr>
<td>TR9</td>
<td>23</td>
<td>0.11±0.01b</td>
<td>0.22±0.00c</td>
<td>0.31±0.01h</td>
</tr>
<tr>
<td>TR10</td>
<td>26</td>
<td>0.08±0.01d</td>
<td>0.22±0.00c</td>
<td>0.18±0.01j</td>
</tr>
</tbody>
</table>

Mean sharing the same letters in a column are statistically at par at 5 % level of probability (DMRT)
4.8.2 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. This agrees with literature reports that K fertilizer significantly affects the concentration of P and N concentration in the tissues (Bahmanyar and Soodaeemashaee, 2010). From the results (Tables 4.13 and 4.14), 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 0.16 - 0.29 % in experimental site 1 and for experimental site 2 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 (Duivenbooden et 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 4.13  Effect of K concentration on phosphorus in maize tissues site 1

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

Mean sharing the same letters in a column are statistically at par at 5 % level of probability (DMRT)
Table 4.14  Effect of K concentration on phosphorus in maize tissues site 2

<table>
<thead>
<tr>
<th>Treatment code</th>
<th>Solution K levels Mg L(^{-1})</th>
<th>Grain P %</th>
<th>Cobs P %</th>
<th>Stover P %</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR1</td>
<td>Control</td>
<td>0.30±0.00d</td>
<td>0.17±0.01f</td>
<td>0.17±0.01c</td>
</tr>
<tr>
<td>TR2</td>
<td>2</td>
<td>0.22±0.01f</td>
<td>0.40±0.01a</td>
<td>0.14±0.01f</td>
</tr>
<tr>
<td>TR3</td>
<td>5</td>
<td>0.30±0.01d</td>
<td>0.30±0.01c</td>
<td>0.15±0.01f</td>
</tr>
<tr>
<td>TR4</td>
<td>8</td>
<td>0.28±0.00ed</td>
<td>0.29±0.01c</td>
<td>0.20±0.01d</td>
</tr>
<tr>
<td>TR5</td>
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<td>0.34±0.01c</td>
<td>0.24±0.01e</td>
<td>0.26±0.01a</td>
</tr>
<tr>
<td>TR6</td>
<td>14</td>
<td>0.30±0.01d</td>
<td>0.17±0.01f</td>
<td>0.24±0.01b</td>
</tr>
<tr>
<td>TR7</td>
<td>17</td>
<td>0.27±0.00e</td>
<td>0.32±0.01b</td>
<td>0.26±0.01a</td>
</tr>
<tr>
<td>TR8</td>
<td>20</td>
<td>0.44±0.00a</td>
<td>0.15±0.00g</td>
<td>0.24±0.01cb</td>
</tr>
<tr>
<td>TR9</td>
<td>23</td>
<td>0.40±0.01b</td>
<td>0.28±0.01d</td>
<td>0.23±0.01c</td>
</tr>
<tr>
<td>TR10</td>
<td>26</td>
<td>0.33±0.04c</td>
<td>0.30±0.00c</td>
<td>0.25±0.01ba</td>
</tr>
</tbody>
</table>

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

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Maize (Zea mays L.) occupies a key position as one of the most important cereals for both human and animal consumption. The present study was planned to determine the soils nutrient status and evaluate whether K fertilizers use can play a role to improve maize yield in the region.

The K levels in the soils were inadequate; water soluble K ranged between 1.8 - 2.2 mg kg$^{-1}$ an indication that a very small portion of soil solution K were available to support optimum maize growth and yields. The soils had low available K ranging from 57 - 70 mg kg$^{-1}$ an indication of potassium insufficiency in the studied soils. Potassium in nitric acid extracts were low ranging from 147 - 152 mg kg$^{-1}$. Woodruff energy of replacement of the studied soils ranged from -3532 – 3523 cal mol$^{-1}$ an indication of low supplying power of potassium in the studied soils.

Data on adsorption of K on the studied soils were fitted to Freundlich, Langmuir, Timkin and Van Hauy isotherms. The data fitted best into Freundlich isotherms with $R^2$ ranging from 0.927 – 0.98 an indication the soils were heterogeneous with mixed mineralogy and unlimited adsorption sites for K adsorption hence used in the determination of K fertilizer dosages.
Maize growth parameters of plant height and stem girth and its yield parameters of ear weight, ear length and grain yields significantly increased with increase of K fertilizer dosage to optimum rates of between 144.76 – 155.84 kg ha\(^{-1}\).

The soils had moderate amount of total organic carbon ranging from 1.10 - 2.07 %. Available phosphorus ranged from 9.82 - 9.77 mg kg\(^{-1}\). Total nitrogen ranged between 0.173 - 0.196 %. The cation exchange capacities of the soils were found to range between 17.25 - 28.05 cmol kg\(^{-1}\). The soils were strongly acidic with pH range of 4.81 - 5.61. The electrical conductivity of the soils ranged from 0.20 - 0.31 mmhos cm\(^{-1}\).

5.2 Recommendations

The findings of this research have shown the extent to which potassium has been depleted on soils in the region. Therefore, availability, awareness and education on K fertilizer use be emphasized to farmers and policy makers for maize production in the country.

Extension officers and farmers should emphasize on correct optimum K doses for maximum maize growth and yields.

With the low soil nutrients status, specifically nitrogen, phosphorus and potassium, balanced amelioration with respective fertilizers is necessary to boost on optimum maize production.
The soils are strongly acidic hence application of lime, composite organic fertilizer and farm yard manures are necessary to raise soil pH.

The research findings have shown medium cation exchange capacity and low K adsorption capacity of the soils hence need for split application of K fertilizers to minimize leaching and ensure efficient use the fertilizer in the soils during cropping season.

Adsorption isotherm techniques can be used effectively to develop K fertilizer recommendation and dosages with respect to soils and crops to overcome the problem of unpredictable crop responses to application K.

Further adsorption studies should be done on other key nutrients such as phosphorus for effective fertilizer use to minimize wastage and pollution and ensure optimum maize production in the country.
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Assessment of potassium levels in agricultural soils of Nyamira County, Kenya was necessitated by the observed progressive drops in maize acreage yields over the years despite use of phosphorus and nitrogenous fertilizers. In the study, concentration levels of potassium and other soil fertility indices such as, organic carbon, cation exchange capacity, exchangeable cations, soil pH, available nitrogen, total and available phosphorus were determined. Five composite soil samples were collected at depths of between 0-30 cm from five farms that have consistently been under intensive cultivation. Fractionation of potassium was achieved by sequential extraction of soil samples with distilled water, ammonium acetate and nitric acid in that order. Concentration levels of potassium in the extracts were determined using a flame photometer. Potassium concentration levels obtained from the water soluble soil extracts were used to calculate thermodynamic parameters such as free energy of replacement, potassium activity ratio and ionic strength of the soil solution. The relationship between the adsorbed and equilibrium potassium concentration, quantity/intensity was determined by plotting Freundlich adsorption isotherms. The isotherm was used to determine the buffering capacity of potassium and the concentration levels of potassium adsorbed on un-specific sites in the soil. The suitability of the adsorption equation was determined by applying the least square regression analysis. From the study available potassium in the soils ranged from 57 to 70 mg/kg and had amean value of 60±5.54.2 mg/kg (ammonium acetate method). The water soluble potassium ranged from 1.8 to 2.2 mg/kg with a mean of 2.02±0.16 mg/kg. Nitric acid extracted potassium had a mean of 149±2.306 mg/kg. The mean free energy of replacement, $\Delta F$, was found to be -3572±44.98 cal/mol indicating that the soils have low supplying power of potassium the potassium buffering capacity of the soils was found to have a mean of 1.189±0.06 mg/kg. The amount of potassium adsorbed on un-specific sites of the soils had a mean value of 6.993±2.378 L/kg. These findings reveal the extent of potassium depletion in the soils of this region and will form a baseline for working acreage potassium doses required for remediation.

**Keywords** Potassium Buffering Capacity, Adsorption, Freundlich Isotherm, Thermodynamics Parameters, Free Energy of Replacement, Soil Fertility Indices
Publication 2

International journal of multi-disciplinary academy (IJMRA)
Comparative Studies of Four Parametric Models for Potassium Adsorption in Soils of Nyamira County, Kenya

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ABSTRACT

Potassium is the third major nutrient after nitrogen and phosphorus. However, soil test for potassium often fail to reveal the true fertilizer demand in the field resulting to unreliable and inefficient fertilizer application to crops. This necessitated this field experiment to be carried out in soils of Nyamira county Kenya with an objective of fitting the experimental data into four parametric adsorption models and ascertain the most suitable adsorption isotherm which best fitted and described the studied soils. For adsorption studies 2.50 g soil samples were shaken with 25 ml 0.01 M CaCl₂ containing K concentration of 0, 25, 50, 75, 100, 125, 150, 175, 200, 225 and 250 mg L⁻¹ using potassium chloride for 24 hours at 25±1 °C to achieve equilibrium concentration. Langmuir, Freundlich, Temkin and Van Hauy adsorption models were applied to the data to check potassium adsorption in the soils. From the results, the physical-chemical properties of the soils revealed that the studied soils were acidic in nature with a mean pH of 5.19±0.2875. The soils were non-saline with electrical conductivity mean of 0.250 ± 0.04475 mmhos/cm. The cation exchange capacity of the soil was 21.254 ± 0.123 cmol/kg. Basic nutrients were low (Available K was 60.2±5.5408 mg/kg, available P (Olsen) was 9.71±0.056 mg/kg,and the organic carbon found to have a mean of 1.82±0.41%). By application of the models, potassium adsorption data revealed that Freundlich model showed a good fit of K adsorption (R²=0.957±0.021), then Van Hauy isotherm (R²=0.923±0.021), followed by Temkin model (R²=0.839±0.0316) and finally Langmuir model which did not fit well to the data (R²=0.359±0.278).

Key words: Potassium adsorption isotherms, Freundlich model, Van Hauy isotherm, Temkin model and Langmuir model.
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 ten different 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 144.76 kg ha\(^{-1}\) giving yields of 3315.27 kg ha\(^{-1}\) and 3340.50 kg ha\(^{-1}\) for farm sites 1 and 2 respectively. External potassium concentration of 7.9 mg L\(^{-1}\) 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