THE EFFECT OF IMPROVED SOLUBILITY AND UPTAKE OF LIME BY THE USE OF TRIPLE SUPER PHOSPHATE FERTILIZER AND SLUDGE ON CROP PRODUCTION

By

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DECLARATION

Declaration by student

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DEDICATION

This thesis is dedicated to my entire family that is, Bethwuel Kimutai (Husband) and children (Kipyator, Jeptepkeny, Jebiwot, Kigen, Jepkorir, Kiptoo, and Jepchumba) for their support and encouragement.

ABSTRACT

Soil acidity is one of the major problems that limit agricultural productivity. Improving fertilizer uptake is a key issue to sustainability of crop production. Fertilizer efficiency by most crops and farming systems is still very poor. Calcium carbonate, the chief component of limestone, is widely used for amendment of soil acidity and to supply calcium for plant nutrition. Since agricultural lime is more soluble in acid soils than in neutral or alkaline soils, its solubility can be improved in acidic conditions, using triple superphosphate (TSP) fertilizer which has a pH of 2.47 and therefore when used with sludge can improve lime uptake. This study aimed finding how crop production can be improved using TSP, lime and sludge, and the research was conducted at the University of Eldoret over a period of two seasons, 2006 and 2007 during long rains. Treatment combinations were; control, lime + sludge, TSP + lime, TSP + sludge, TSP + sludge +lime. Randomized complete block design was adopted with treatments being replicated twice in each block. The test crops used were; maize **(**H614), wheat (Mwamba), beans (Rose coco). The treatments were replicated two times and applied in plots measuring 4 m x 4 m. planting was done in early May after onset of long rains. Lime was applied in plots one week before planting the crops at 1.5 tons per hectare. Nitrogen was applied one month after planting the crops. All crops were harvested after reaching full maturity. Data collected included laboratory solubility test data for the fertilizer material formed from combinations of lime, TSP and sludge. All samples (lime, TSP and sludge) were mixed in different proportions and their pH and phosphorous content analyzed. Soil available P was determined by Olsen method while total soil nitrogen was done using the Kjedahl method. Measurement of pH was done using glass electrode meter and water as a reagent. In addition; grain yield and stover biomass measurements were taken. Analysis of variance and mean separation were done on the grain yields and stover biomass to establish best treatment combinations. All fertilizer treatment combinations' effect on grain yield and biomass were statistically different form each other ($p<.001$). The combination of (TSP + lime + sludge) gave highest grain yields and stover biomass in maize of over 21 kg and 45 kg, respectively. The combination of TSP and lime produced highest grain yield and biomass in wheat and beans. There was no significant difference between a combination of (TSP + lime) and (TSP + lime + sludge) on wheat grain yields. The combination of (lime + sludge) gave the lowest yields for both grain and stover biomass for the 3 crops. There was, however, no significant difference in production (both grain and biomass) of the 3 crops for different growing seasons or years ($p<.367$). It is recommended that the combination of (TSP + lime + sludge) should be used in maize production while (TSP and lime) production of wheat and beans as this will increase productivity by improving soil fertility and health of the crops.

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LIST OF ABBRIEVIATIONS/ACRONYMS

ANOVA	Analysis of variance
C.A.N	Calcium ammonium nitrate fertilizer
CV	Coefficient of Variation
Df	degrees of freedom
Ms	mean square
P	phosphorus
PR	Phosphate rock
SS	sum of squares
TSP	Triple super phosphate
V.r.	Variance ratio
D.A.P	Diammomium phosphate
M.A.P	Monoammonium phosphate
CEC	Calcium equivalent content

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CHAPTER ONE

INTRODUCTION

1.1 Background information

Improving fertilizer uptake by crops is very important in sustainability of crop production. Fertilizer uptake by most crops and farming systems is still very poor due factors like pH. Due to lack of local production of agricultural chemicals, Kenya imports most of them. Manufactured fertilizers are nonrenewable resources hence sustainability is needed. Calcium carbonate, the chief component of limestone, is widely used to amend soil acidity and to supply calcium (Ca) for plant nutrition. Agricultural lime is more soluble in acid soils than in neutral or alkaline soils.

Agriculture is the backbone of the economy of Kenya and it contributes up to about 25% of the domestic product and about 60% export earning mainly from cash crops such as tea, coffee pyrethram and horticulture products (Alila and Atieno, 2006). It is a great source of employment for many people especially in rural areas (Wokabi, 2007). The sector faces great challenges such as soil chemical degradation from continuous use of inorganic fertilizer which lowers soil pH which then affects the uptake of major nutrients which are pH dependent for their solubility in the soil. Also changes in climatic conditions, leading to prolonged drought hence failure of the crops. A lot of flooding can also cause destruction of the produce.

To increase production of food, it is necessary to identify both short term and long term needs of the soil. This can only be obtained through proper research on different plants. To determine these needs, frequent soil analysis is necessary (Quresh, 1990) and once the needs are identified proper measurements or better ratios of fertilizers can be used.

Loss of fertilizer input by way of leaching and fixation can be reduced in two ways; through enriching the soil with inorganic matter which increases the cation exchange capacity and reduces leaching. In addition, it can be improved through applying fertilizers particularly N and K in split doses rather single dose (Taja and Zaag, 1991).Generally the production of the land in Kenya has declined. This is majorly because of reduction of the soil fertility. This has caused a great challenge to the country since agriculture is the main source of food and foreign exchange earner. Low soil fertility could be attributed to the soil pH due to high acidity. This prevents some plant nutrients from being assimilated. TSP (pH 2.47) which makes soil acidic is used by most farmers causing low productions. Low pH can be increased by use of lime. However, the solubility of lime is low but can be improved in acidic environment and therefore T.S.P fertilizer becomes suitable. Another beneficial strategy is the use of a combination of fertilizing technique for example, green manure fallow plus modest quantities of chemical fertilizing (Smaling *et al.*, 1992).

The high and medium zones of maize productions have the highest potential for productivity of 5 t/ha if farmers overcome production constraints like poor soil fertility, acidity soil erosion and moisture stress (Smaling *et al.*, 1993). The annual maize production in Kenya is about 2.7 million tonnes and slightly lower than the domestic consumption needs (KARI, 1999). About one million more tonnes of maize grains could be added to the current domestic production if farmers improve their soil fertility and this will meet annual domestic demand.

Of the major plant nutrients, world sources of P are the smallest and thus, on a global scale, P should be used as efficiently as possible in order to conserve the resource base and to maintain and increase, where necessary, agricultural productivity. Possible options for improving the efficiency of soil and fertilizer P use include: modifying surface soil properties to increase P availability; managing surface soil to minimize losses of P in surface runoff; managing P sources (both fertilizers and organic manures); and investment to optimize soil P status(FAO , 2007).

The production yield of food crops in Kenya is beginning to decrease. This could be attributed to poor soil fertility resulting from continuous application of inorganic fertilizers which include; diamonium phosphate (D.A.P), monoammonium phosphate (MAP), urea which make soils more acidic due to presence of hydrogen when the fertilizer is broken down (Kherallah *et al*., 2002). Acidity of the soil has the following effects; low pH and base mineral saturation, plant mineral saturation, plant mineral nutrient deficiencies and mineral toxicities. Acidity of soil can be promoted by the nature of the parent rock/mineral or by leaching of the bases from the soil profiles (Buresh *et al*., 1997).

Food shortage in Kenya led to starvation that of over 10 million citizens and government appealing for assistance for instance, 32 billion appeal fertilizers, U.K donations of Kshs 605 million for food aid to world program, among the many the country required 5 million more bags of maize. With the use of T.S.P with lime, the pH obtained will be suitable for food production (Buresh *et al*., 1997).

1.2 Problem Statement

Food crisis is alarming in the whole world and Kenya is not exempted. This has been contributed to by the low production of food crops due to low soil pH which is corrected mainly by lime, but due to low solubility, its application causes some challenge. The plants are not able to get the required nutrients quickly for example, calcium. Although T.S.P by itself makes soil acidic, dissolving lime in it produces a richer fertilizer combination leading to release of the required nutrients to the plants. Soil pH can be increased by use of agricultural lime. The solubility of lime is low but can be increased in acidic conditions, therefore to increase the solubility of lime, T.S.P and sludge can be used.

1.3 Justification

The continuous application of inorganic fertilizer like D.A.P, MAP and urea has caused a lot of acidity to the soil. Lime also is known to be insoluble enough for plants to acquire nutrients from it. Since T.S.P is able to dissolve lime faster, calcium ions will be available to plants for assimilations. Also low production of food crops in the country has been associated with the infertility of the soil due to low soil pH and also due to the cost of fertilizers which has continued to rise (Baligar *et al*., 2001).

There is a need to increase the use of P fertilizers in most developing countries in order to ensure food security for their growing populations. Soils containing insufficient amounts of plant-available P not only produce economically unacceptable yields, but other inputs, particularly N, are also used less effectively (FAO, 2007).

This project therefore was meant to investigate both the solubility of lime and to improve TSP uptake use by plants hence providing a cheaper and richer fertilizer. As a result, many farmers will be able to farm and grow enough food crops.

1.4 Objectives

1.4.1 General Objectives

To study the solubility and the uptake of lime using triple superphosphate (T.S.P) fertilizer and sludge for increased crop production

1.4.2 Specific Objectives

1. To investigate the solubility of lime for assimilations of nutrients by plants
2. To investigate effect of pH of T.S.P for assimilations of nutrients by plants
3. To study the production of food by varying fertility of soil through combination of lime and TSP.

1.5 Hypotheses

H_0: Triple superphosphate does not increase solubility of lime

H_0: The use of lime does not improve solubility of T.S.P

H_0: Crop production obtained by using TSP and lime is not high and the soil fertility is not enhanced

CHAPTER TWO

LITERATURE REVIEW

2.1 Status of Fertilizer and agrochemical industry in Kenya

Kenya imports virtually all of its agricultural chemicals since there is no significant local production. Unlike many sub-Saharan African countries, Kenya's fertilizer use has almost doubled since the liberalization of the market in the 1990s and removal of government price controls and import licensing quotas. The growth of fertilizers in use has been noted especially among the smallholder farmers in growing of both food crops (maize, domestic horticulture) and cash crops (tea, coffee). Growth in the industry is largely due to huge private investment in both importation and retailing of fertilizers. The agrochemical imports average about 450,000-480,000 metric tons every year. The main types of fertilizers consumed in Kenya are compound fertilizers that provide both nitrogen and phosphate.

Fertilizers that are used for planting grain like DAP and NPK comprise the majority of the fertilizer consumed in Kenya, while direct use of nitrogenous fertilizers such as CAN and urea are used for top-dressing. DAP is used on maize, MAP on wheat, NPK is used on tea, NPK and MOP (Muriate of Potash) on coffee, and other fertilizers are used on horticultural crops particularly in the flower industry. Cereal production consumes the bulk with 150,000 tons closely followed by horticulture, which takes up to 65,000 tonnes. Coffee and tea take up to 40,000 and 30,000 tonnes, respectively while the remainder is taken up by other crops. In 2007, there was a drop in imports due to several factors including a rise in overall prices and a prevailing drought in the country. In 2009, there was a huge spike on fertilizer and agrochemical import. This was due in large part to a new initiative by the Government of Kenya that saw the largest import program of fertilizer in years (Sheahan, 2011).

The program, dubbed the "National Accelerated Agricultural Input Access Program" (NAAIAP) is aimed at offering farm input subsidies and distributing free fertilizer to small scale farmers so as to reduce poverty and "kick-start" agricultural productivity that was greatly affected by the post election violence and poor rainfall. The bulk purchase of fertilizer was also expected to bring down the price of fertilizers that have steadily increased, and thereby bring down food prices. According to the Ministry of Agriculture report of March 29, 2012, Kenya imported 520,000 tons of fertilizer valued at US$263 million, thus continuing with the upward growth in imports. (Sheahan, 2011).

Sludge acts as buffer for nutrient concentration in the soil when applied in combination with inorganic fertilizer whereby nutrients are not released immediately to crops. This causes relatively low yields especially in crops with short growing cycles. However, with time, this will change making this combination the best fertilizer material for crops with longer growing seasons like maize in cold and high altitude areas. Research in soya beans by Serafim *et al* (2013) revealed that manure and lime significantly reduced exchangeable acidity and increased soil pH. Application of manure alone or combined with lime or P fertilizer also increased Mg and K. In addition, lime alone or lime combined with manure and manure combined with P applied gave a significant increase in exchangeable Ca. Soybean responded well and significantly to application of manure either alone or combined with lime, P or both.

The application of manure significantly has an impact on the chemical, physical and biological properties of the soil due to an increase in the levels of soil organic matter (Shirani *et al*., 2002; Liang *et al*., 2011; Bakayoko *et al*., 2009) resulting from manure application. Mwangi *et al*. (2001) indicated that agricultural lime reduced soil acidity while farmyard manure did improve soil pH but the change was not as instant as was for lime.

Kidanemariam *et al*. (2013) indicated that yield and yield attributes of wheat showed significant response to lime and inorganic fertilizer applications. In addition, a fertilizer-lime interaction was significant in grain yield, total biomass and N and P uptakes, as shown by the results in table 7. According to a study conducted in the mid and highlands of Ethiopia, application of lime with fertilizer generally increased maize production. This also is in agreement with Okalebo *et al*., 2009) who stated that combined application of lime with nitrogen and phosphorus significantly increased maize yield in Kenya.

2.2 Fertilizer use efficiency and sustainability

Improving fertilizer efficiency is key to sustainability. Manufactured fertilizers are non renewable resources since reserves of raw materials for P and K fertilizer manufacture are finite. Based on the presently identified supply base, reserves of potash are sufficient for at least another 250 years whilst those of phosphate are sufficient for 300–400 years (Roberts, 2008). N fertilizers are manufactured using natural gas as an energy source to transform atmospheric N_2 into ammonia, the raw material for N fertilizer manufacture. About 3–5% of world natural gas use or 1–2% of the world’s energy supply is used to manufacture N fertilizers. Fertilizer use efficiency by most crops and farming systems is still very poor. For example, it has been estimated that two-thirds of the nitrogen fertilizer applied in irrigated rice systems is not taken up by rice plants to produce biomass and fulfill physiological functions but is instead lost due to leaching, volatilization and denitrification. To increase the efficiency of mineral fertilizers it is essential to adopt an integrated crop management approach to manage all growth-limiting or growth-reducing factors as well as possible.

2.3 Wheat

Triticumaestivum (L.) is a cereal of the Gramineae family, a family that also includes important cereals as rice, maize, oats and sorghum. It is an herbaceous annual plant up to 1.2 m in height. Most of the world`s wheat production is aimed for feeding. Almost 75% of this production is used for the production of wheat flour. Most of these flours, especially those from soft wheat varieties are used for the production of bread. The flours from hard wheat are used mainly for making cakes, biscuits, to name a few. Wheat is cultivated in almost all parts of the world. It is the product to which more proportion of arable land is destined. In the year 2000 it was estimated that about 230 million hectares world area were devoted to this crop. China is the largest producer in the world. This is followed by the United States, Russia, Ukraine and France (Poulton & Kanyinga, 2014).

2.3.1 Wheat production yields in Kenya

Wheat production has been fluctuating with time. In 2006, production was 3000MT which declined and increased in 2009 at 512MT. Since then, production has reduced with only 300MT in 2012 (Shen *et al.,* 2004)

2.4 Maize (*Zeamays*)

Maize is the most important of the cereals after wheat and rice. It is very widely distributed and it is one of the highest yielding grain crops. The most likely ancestor of corn is believed to be a grass called teosinte (*Zea Mexicana*) native to Mexico and Central America. The grain is the feed of choice for most domestic monogastric animals such as pigs and poultry. Maize is grown from 58^0 N to 40^0 S, from sea levels to altitudes greater than 3000 m, and in areas with 250 mm to more than 5000 mm of rainfall per year (Arntzen, 1994).

Different varieties of maize are adapted to a range of climates and growing seasons. Growing seasons are mainly within the range of 90-120 days. There is a general increase in the growing season of about 20days for each 100m increase in altitude above 1500m, or for each 0.5^0C fall in mean temperature below 20 ^{0}C. Rainfall requirements vary with the variety and range from 200 mm to 900mm in the growing season. Maize is an important component of cropping systems in the tropics especially Kenya where rainfall is in the range of 750mm-1750mm per year. Maize grows well on a wide variety of soils, but best on intermediate textures (sandy-loams to clay-loam), with a good structure and aeration (Arntzen, 1994).

2.4.1Maize production yields in Kenya

In 2006, production was 3000MT a 12.6% increase from previous year. Production declined until 2010 when it rose to 3222MT. In 2012, production was 3200 and it has been projected to remain the same in 2013 (Kherallah *et al.*, 2002).

2.5 Common Beans (*Phaseolus vulgaris)*

It is scientifically known as *Phaseolus vulgaris* and belongs to family Papilionaceae (Legumininosae). It’s believed to have originated from central and south America. It is a major food crop in both urban and rural areas of Kenya where it’s used as the main protein source. Commonly, beans are nitrogen fixing legumes. In tropical areas like Kenya, it thrives well in altitudes of 1200-2200 m, temperatures of 15-30 ^{0}C with average rainfall greater than 400mm. common bean prefers medium textured, well drained soils and sensitive to both aluminum and manganese toxicities with optimum pH of 6-7.5 (Serafim et al., 2013).

2.6 Lime: Calcium oxide (CaO). Manufacture and Uses

Calcium oxide is a white crystalline solid with a melting point of 2572°C. It is manufactured by heating limestone, coral, sea shells, or chalk, which are mainly $CaCO_3$, to drive off carbon dioxide, temperature of 500–600°C is required

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

This reaction is reversible; calcium oxide will react with carbon dioxide to form calcium carbonate. The reaction is driven to the right by flushing carbon dioxide from the mixture as it is released.

Lime is mixed with water and sand to form mortar, which is used in construction to secure bricks, blocks, and stones together. Mortar is initially a stiff paste that is laid between the bricks. It gradually hardens, cementing the bricks together. At room temperature, the reaction of lime with carbon dioxide is very slow. It is speeded by mixing lime with water. When lime is mixed with water, it forms calcium hydroxide, called slaked lime.

$$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$$

The reaction of calcium hydroxide with carbon dioxide is faster, producing a mortar that hardens more quickly.

$$Ca(OH)_2(s) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$$

The most commercially important property of lime is its ability to form solutions with silicates. When lime is heated with silica sand (SiO_2) and sodium carbonate (Na_2CO_3), a solution is formed that does not crystallize when it is cooled. Instead it hardens to an amorphous, clear, and nearly colorless solid, namely glass. Because it is a mixture and not a pure compound, glass does not have a distinct melting point; it gradually softens as it is heated. Therefore, it can be molded and blown into many useful shapes. The production of glass from lime is another of the ancient uses of lime.

The most important modern use of lime also relies on its ability to form solutions with silicates. Nearly 45% of lime is used in the steel industry. Steel and iron are produced from ores, which are rocks that contain iron oxides. Many of these ores also contain a large amount of silicates. When lime is mixed with the ore and the mixture melted, these silicates combine with the lime, forming a liquid solution called slag. Slag is immiscible with molten iron, so the silicates can be removed from the iron by draining of the slag. Approximately 80 kg of lime is used in the production of each metric ton (1000 kg) of iron. Lime is also used in the production of other metals. For example, it is used to remove silicates from alumina (Al_2O_3) before the alumina is reduced to aluminum metal

Lime is also an important material in the manufacture of chemicals like production of calcium carbide, CaC_2. Calcium carbide is manufactured by heating lime with coke.

$$2\ CaO(s) + 5\ C(s) \rightarrow 2\ CaC_2(s) + CO_2(g)$$

Calcium carbide reacts with water, releasing acetylene, C_2H_2.

$$CaC_2(s) + 2\ H_2O(l) \rightarrow C_2H_2(g) + Ca(OH)_2(aq)$$

Acetylene is an important fuel for welding and is also a starting material for a range of organic compounds, including vinyl chloride, neoprene, and acrylonitrile, all of which are raw materials for polymers.

Pollution control is a rapidly expanding consumer of lime. Lime is used in stack gas scrubbers to reduce sulfur dioxide emissions from power plants. Sulfur dioxide reacts with lime to form solid calcium sulfite.

$$SO_2(g) + CaO(s) \rightarrow CaSO_3(s)$$

Lime is also added to sewage to remove phosphates.

$$3\ CaO(s) + 3\ H_2O(l) + 2\ PO_4^{3-}(aq) \rightarrow Ca_3(PO_4)_2(s) + 6\ OH^-(aq)$$

The pretreatment of water supplies involves the use of lime to decrease the acidity, to soften, and to clear drinking water.

A variety of other industrial processes also make extensive use of lime. It is used as an opacifier in plastics. The paper industry uses it in pulping wood; because lime is highly alkaline, it dissolves the lignin that binds the fibers together in wood. In the refining of sugar, lime causes coagulation of plant material, allowing it to be more easily separated from the sugar syrup.

Calcium oxide no longer produces the limelight in theaters. The theatrical use of lime has disappeared, leaving only its name, suggesting the romance of a bygone era. Because lime has a very high melting point, it can be heated to a very high temperature without melting. Substances with such high melting points can be heated to white heat, a temperature so high that the light they emit is white. Before the advent of electric lighting, white stage lighting was produced by heating lime in the flame of a torch, and this light was called limelight (Serafim et *al.*, 2013).

2.6.1 Reactions of limestone with water

Limestone ($CaCO_3$) reacts with hydrogen ions in water since water undergoes autoprotolysis: $H_2O(l) \rightarrow H^+(aq) + OH^-(aq)$ The more acidic the water is, the more limestone will react, and erode. The erosion of marble sculpture and inscriptions exposed to the elements is one of the consequences of acid rain (Plummer and Busenberg, 2014).

The equilibrium solubility of limestone (and marble) exposed to the atmosphere is dominated by the following reactions:

$CaCO_3(s) + H_3O^+(aq) \rightarrow Ca^{2+}(aq) + HCO_3^-(aq)$

$HCO_3^- + H_3O^+(aq) \rightarrow CO_2(aq) + 2\ H_2O(l)$

$H_3O^+(aq) + CO_3^{2-}(aq) \rightarrow HCO_3^-(aq) + H_2O(l)$

Only about one percent of the total dissolved CO_2 present is actually in the form of carbonic acid, so the formation and acid dissociation equilibria are worth mentioning, but are frequently overemphasized:

$CO_2(aq) + H_2O(l) \rightarrow H_2CO_3(aq)$

$H_2CO_3(aq) + H_2O(l) \rightarrow H_3O^+(aq) + HCO_3^-(aq)$

Calcium forms a *carbonato* complex $CaCO_3^0(aq)$.

$Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3^0(aq)$

The log of the equilibrium constant for this reaction has been determined to be 3.22 +/- 0.14. This is important for very concentrated calcium and carbonate solutions, (Plummer and Busenberg 2014).

. There is also a calcium hydrogen carbanato complex $CaHCO_3^+(aq)$:

$Ca^{2+}(aq) + HCO_3^-(aq) \rightarrow CaHCO_3^+(aq)$

2.7 Lime (Calcium Carbonate)

Calcium carbonate, the chief component of limestone, is a widely used amendment to neutralize soil acidity and to supply calcium for plant nutrition. The term “lime” can refer to several products, but for agricultural use it generally refers to ground limestone. Limestone is a common sedimentary rock found in widespread geologic deposits. It has been used throughout much of recorded history as a building material, a cementing agent, and in agriculture to improve acid soils. An agricultural liming material (ag lime) is broadly defined as any substance containing calcium or magnesium and capable of neutralizing acidity.

Many materials can be classified as agricultural lime. It is extracted from quarries or mines and usually requires mechanical crushing. The fineness of the agricultural lime is important in determining how quickly it reacts with soil acidity. Limestone of a smaller particle size reacts quickly since there is more exposed surface area for chemical reaction. Larger particles are slower to react, but provide a sustained, longer term source of acid neutralization.

A measurement of particle size is typically reported on the product label (Rajan *et al*., 1996; Robinson *et al*., 1992).

Other materials in the agricultural lime, such as clay, will reduce its purity and diminish the acid-neutralizing capacity. Ag lime effectiveness is rated based on its comparison with pure calcium carbonate, a value that is expressed as the percent calcium carbonate equivalent (CCE). Agricultural lime is more soluble in acid soils than in neutral or alkaline soils. The presence of $CaCO_3$ in soil is detected by the effervescence or 'fizz' when a drop of strong acid is applied (Liang *et al*., 2011).

2.7.1 Agricultural Use of Lime

The primary use of agricultural lime is to raise the pH of acid soils and reduce the concentration of aluminium in soil solution. Poor crop growth in acid soils is largely due to soluble Al, which is toxic to the root system of many plants. Lime will reduce soluble Al by two reactions:

1) $CaCO_3 + H_2O \rightarrow Ca^{2+} + 2OH^- + CO_2$

2) Al^{3+} (soluble) + $3OH^- \rightarrow Al(OH)_3$ (insoluble)

Additions of agricultural lime also supply valuable Ca (and possibly Mg) for plant nutrition. Some secondary benefits of neutralizing soil acidity with agricultural lime include:

• Increased phosphorus (P) availability

• Improved nitrogen (N) fixation by legumes (Palm et al., 2001)

• Enhanced N mineralization and nitrification

• Better water use, nutrient recovery, and plant performance with a healthier root system.

2.7.2 Chemical Properties of Lime

Limestone/calcite is calcium carbonate ($CaCO_3$), which is mostly insoluble in water, but solubility increases in acid conditions (contains a maximum of 40% Ca). Dolomite is calcium magnesium carbonate ($Ca.Mg(CO_3)_2$) and is mostly insoluble in water, but solubility increases in acid conditions (contains between 2 to 13% Mg). Hydrated/slaked lime is calcium hydroxide ($Ca(OH)_2$)which is relatively insoluble in water; forms a solution of pH >12. Burned lime or quick lime is calcium oxide (CaO) which reacts with water to form hydrated lime (Serafim *et al.*, 2013).

2.7.3 Neutralizing effect of lime in the soil

The quality of lime varies significantly with neutralizing values and particle size distribution. Neutralising value compares a lime's ability to neutralize acidity with that of pure calcium carbonate, which is assigned a standard value of 100. The laboratory determination of a lime's neutralizing value does not always reflect its capacity to change soil pH. This is why particle size distribution is the second key measure of lime quality. Lime dissolving is a chemical reaction and smaller particles of lime are more easily dissolved in the soil. Lime particles react and neutralize acidity immediately adjacent to them. When this has occurred there is insufficient acidity near the particle for further neutralization (Pluske, 2005).

2.7.4 Factors considered in Evaluation of Agricultural Lime

1. Degree of Fineness

The relationship between increasing limestone fineness and reactivity is caused by having a larger surface area exposed to chemical reaction.

The surface area of liming material increases proportionately with decreasing particle size, for example, the exposed area of a cube of 1 cm is 6 cm^2: decreasing the particle size to 2 mm (10 mesh), or 0.05 mm (300 mesh) increases the exposed area to 30 and 1200 cm^2, respectively (Lierop and Kelowna, 2013).

2. Neutralizing Capacity

Another factor which influences the efficiency of a limestone is its neutralizing capacity. This is determined by reacting limestone with strong acids, either hydrochloric or sulphuric acid. The limestone's neutralizing capacity is expressed as a percentage value of pure calcium carbonate, which has a neutralizing value of 100%. Commercial limestones may have neutralizing capacities greater or lesser than pure $CaCO_3$. Dolomitic limestone (a mixture of magnesium and calcium carbonates) has a theoretical neutralizing value of 108%. Generally, limestones have neutralizing values below 100%. Impurities such as clays in limestone reduce their relative neutralizing capacities (Lierop and Kelowna, 2013).

3. Solubility and Magnesium Content

Limestone solubility is not frequently evaluated by routine tests (analysis of soil pH, P, K, Ca, Mg, Zn, Mn, Cu, Fe and B), but also the influence it has the neutralizing rate of soil acidity. The crystaline structure and chemical composition of limestones vary due to their geological formation.

Dolomitic limestones, having a combination of magnesium and calcium carbonates, are less soluble than either calcitic limestones ($CaCO_3$) or magnesium carbonate. Dolomite is, however, useful on acidic soils low in magnesium(Lierop, and Kelowna ,2013).

4. Other Liming Materials

At low liming rates, around 2 tonnes/ha, calcium hydroxide (slaked lime) can be substituted for limestone by multiplying the recommended rates by 0.84. The main advantage in using calcium hydroxide [$Ca(OH)_2$] is its quick neutralizing capacity, which is due to being very finely pulverized. The disadvantages are that it costs substantially more, may cause overliming problems, and is unpleasant to handle in large quantities due to its caustic nature, Lierop and Kelowna (2013).

2.8 Factors Affecting Phosphorous Availability

2.8.1 Soil pH

As the soil pH increases above about pH 8.0, soil P is increasingly "fixed" into less Soluble/available forms by excess calcium. As the soil pH decreases below about pH 6.0, soil is increasingly "fixed" into less soluble/available forms by excess soluble aluminium (Baligar *et al.,* 2001)

2.8.2 Soil Compaction

Phosphorous moves very little in the soil. Because of this, plant roots must be healthy and actively explore new areas of the soil daily in order to obtain adequate P nutrition. Anything that inhibits aggressive root growth is likely to reduce P uptake, even in high P soils.

Interestingly, it was found out that increased uptake of P following incubation of low quality materials such as maize stover with phosphorus rock.

More recently, the reported decline in crop yields was attributed to the result of combination of OMS and insoluble PR (Smithson, 2014)

2.8.3 Soil Aeration

Inadequate soil aeration is often related to soil clay content, soil drainage, and soil compaction. Most cultivated plants require adequate oxygen (O_2) in the soil atmosphere. A lack of adequate soil O_2 can reduce P uptake by as much as 50% (Hue *et al.,* 1994).

2.8.4 Soil Moisture

As moisture stress increases, P availability and uptake decrease. Higher levels of soil P result in higher P uptake at all moisture levels. However, as soil moisture begins to exceed field capacity, the excess water excludes the needed oxygen from the soil and P uptake begins to suffer due to the lack of O_2 in the soil (Liang *et al.,* 2011).

2.8.5 Soil Temperature

Cold soil reduces P uptake, as well as most other chemical and biological activity in the soil. This is the reason that many fields respond to row-placed fertilizer. During warm seasons, uptake efficiency of both the plants and the soil improve. However, permanent yield losses can occur from early season P shortages.

2.8.6 Soil Texture

Generally, low CEC soils require higher soil P tests to supply equivalent amounts of P to a crop. Such soils typically hold less water at any point in time, which slows P diffusion to the roots. These soils also have less particle surface area and that current soil testing procedures may extract a higher percent of the total P in lower CEC soils.

This would lead to less capacity to quickly replenish the P in solution (buffering power) and require a proportionately higher soil P level for equivalent P supplying power. Some clay types have a high P fixation capacity. These types of clay are more common in tropical soils. In these cases, it would logically be expected a higher CEC to require a proportionately higher soil P level for adequate soil fertility (Liang *et al.*, 2011).

2.8.7 Soil Organic Matter

The organic matter (OM) in soil may account for anywhere from 3% to 75% of the total P in a soil (not necessarily the same as "available P"). Generally, the increase in OM results in greater fixation of Fe and Al, resulting in less P fixation by these elements, and more labile (available) P. Such reactions also tend to reduce the fixation of applied P as well. Typically, in soils developed in temperate climates, the contribution of P by OM is relatively small and the main source of P for plants is the inorganic forms (Smithson, 2014).

2.8.8 Crop Residues

Incorporation of large amounts of crop residues can result in immobilization of available P by microbes. As they decompose the residue, they grow and reproduce, thus creating their own need for available P. During the decomposition of crop residue, soil microbes are effectively in competition for nutrients with higher plant for the nutrients.

Microbially immobilized P will gradually become available as decomposition is completed, the microbes die, and they are re-cycled. Factors such as temperature, moisture, soil pH, soil aeration, and the availability of other nutrients have a direct bearing on the level of microbial activity in the soil and the rates of immobilization and mineralization.

While this cycle is present in all soils, it is not thought to be a cause for major adjustments in fertilizer recommendation programs.

2.8.9 Plant Root Systems

As mentioned earlier, soil P is essentially immobile, and the portion of soil P that is soluble and immediately available to plants is exceptionally small. Therefore, plant roots must constantly explore large volumes of soil to satisfy their need for P. There are significant differences between species in the relative size and effectiveness of their root systems. There can also be significant differences of this type between hybrids and varieties within the same species. This is one factor in explaining why some plants or crops require different soil P levels for a given level of performance (Baligar *et al.,* 2001).

2.8.10 Mycorrhizae

Mycorrhizae are soil fungi that form a symbiotic association with plant roots. The thread-like hyphae of the fungus connect with plant roots and extend into the soil. The hyphae act like extensions of the plants root system by absorbing nutrients and transporting them back to the plant roots. A major benefit in this respect is an increase in P uptake (Singh and Reddy, 2006). In exchange, the mycorrhizae receive sugars manufactured by the plant. While mycorrhizae can infect most plants, they typically are more of a benefit to trees than agricultural crops.

It has been demonstrated with agricultural crops that the benefits of mycorrhizae decrease as the soil P level increases. Soil P levels adequate for good yields of most crops essentially eliminate the benefits of mycorrhizae (Singh and Reddy, 2006).

2.9 Triple superphosphate (TSP) Ca $(H_2PO_4)_2$

It contains 44-52% P_2O_5, 1-1.5% sulfur, and 13% Ca. It is made by the action of phosphoric acid on raw rock phosphate (apatite). It typically contains 46% P_2O_5, soluble in neutral ammonium citrate and water. Of this, 90% is soluble in water. It contains 12-14% calcium. TSP does not have a great effect on soil pH (Tisdale *et al.*, 2012).

Triple superphosphate fertilizer (TSP) grade 0:46:0. T.S.P is made by the action of phosphoric acid on raw rock phosphate (apatite). It typically contains 46% P_2O_5, soluble in neutral ammonium citrate and water. Of this, 90% is soluble in water. It contains 12-14% Ca. Rock phosphate generally contains about 32% P_2O_5, compared to manufactured P fertilizers such as TSP, which contains 46% P_2O_5, and single superphosphate (SSP), which contains 20% P_2O_5. Whilst phosphate rock is sparingly soluble, manufactured P fertilizers are fully soluble in the soil, Serafim *et al.*, (2013).

2.10 Chemical reactions of common phosphatic fertilizers

The most common phosphatic fertilizers in kenya are: diammonium phosphate, mono-ammoniumphosphate(MAP), and triple superphosphate (TSP) of which are dry materials with ortho-phosphate as the primary form of P. Taken together the results indicate that for most situations, the amount of P supplied to the crop is far more significant than the source of that P. There are still some questions about different P sources, and there are some actual differences that can be important in specific situations. (Stoorvogel *et al.*, 1993).

Of primary importance is how efficiently P in the fertilizer is converted into the forms that a plant can use. As stated earlier, plants can absorb only the primary ($H_2PO_4^-$) and secondary (HPO_4^{--}) ortho forms of P. Therefore, P sources must be efficiently converted to one of these two forms, if they are to benefit the crop. The primary ortho-phosphate form dominates in mildly acid soil can be absorbed about 10 times as efficiently as the secondary ortho form.

The chemical breakdown of the major commercial P fertilizers can be illustrated as follows. (Stoorvogel *et al.*, 1993).

DAP $(NH_4)_2HPO_4 + H_2O \rightarrow 2NH_4^+ + HPO_4^{2-} \rightarrow HPO_4^{2-} + H^+ \rightarrow H_2PO_4^-$

MAP $NH_4H_2PO_4 + H_2O \rightarrow NH_4^+ + H_2PO_4^-$

TSP $Ca(H_2PO_4)_2 + H_2O \rightarrow CaOH^+ + H_2PO_4^-$

APP $(NH_4)_2H_2PO_7 + H_2O \rightarrow 2NH_4^+ + H_2P_2O_7^{2-} \rightarrow H_2P_2O_7^{2-} + H_2O \rightarrow 2H_2PO_4^-$

2.11 The Nature of TSP fertilizer and its application in the soil

TSP (Triple Super Phosphate) represented as 0-46-0, is normally applied where plants are grown in soils with low or average levels of phosphorus. Its importance can be measured by the fact that in absence of it, the root development is weak, growth is stunted, productivity drops, the leaves or the edges of the leaves turn purple and in plants like tobacco and cotton, the leaves turn an abnormal color of dark green; potato tubers develop brown spots among others. Because it is a fertilizer with slightly acidic composition, its effect is limited in neutral or alkali soils. Because the phosphorus in its composition dissolved easily in water, it shows its effects rapidly. TSP is used as a base fertilizer. If it's applied too early, the phosphorus in it combines with the lime and other elements in the soil and loses its effectiveness. If it is applied after the planting or seeding, it remains on the surface and has little effect. For these reasons, it should be applied either during or immediately after planting, seeding for maximum effect. TSP is made by reacting wet-process phosphoric acid with phosphate rock. Typically it contains 46% P_2O_5. TSP is produced in granular and non-granular form and is used both in fertilizer blends (with potassium and nitrogen fertilizers) and by itself, (TSP Bohr industries, 2013).

2.12 Formation of phosphatic fertilizer from lime material

In a process for the production of monocalcium phosphate by reaction of phosphoric acid and a material selected from the group consisting of lime, limestone and dolomite, the improvement which comprises:

(1) Adding said material to a dilute dispersed solution of phosphoric acid containing 22-38% P_2O_5 by weight with vigorous agitation while maintaining a temperature of 100 degrees Celsius to produce directly granulatable slurry;

(2) Granulating the resulting slurry;

(3) Drying the resultant granulated slurry at a temperature not exceeding 200 granulated monocalcium phosphate (Houlbrooke et al., 2011).

Substantial efforts have been made in the recent past to improve soil fertility status targeted to decrease levels of poverty among farmers in Kenya (Okalebo *et al*., 2004).

A knowledge about the maize growth, as an agricultural crop and its production cycle constitute initial indispensable information for yield agroclimatic modeling, and yield prediction studies (Mello *et al.,* 2014). Some growth analysis studies have been developed for agricultural crops, with a number of applications in mind, such as fertilization management (Simões *et al*., 2005). However, there has not been any study on precision farming in East Africa particularly Kenya, whilst it is documented that in Kenya, the geographic region with favorable climate conditions for cereal production (especially maize) are limited and rapid population growth has resulted in more intense land use pattern (Achieng *et al*., 2001).

Plant growth analysis provides an excellent opportunity to monitor the independent interactive affects of various factors affecting maize yield and opens the way to managing these factors in integrated systems (Kherallah *et al.*, 2002).

2.13 The interaction of lime material and manure in the soil

The solution of the question whether quick lime ought to be applied to a soil depends upon the quantity of inert vegetable material that it contains. The solution of the question whether marl, mild lime or powdered limestone ought to be applied in the soil depends upon the quantity of calcareous material already in the soil. All soils are improved by mild lime and ultimately by quick lime which do not effervesce in acid soils and sands more than clay. When, a soil deficient in calcareous, contains more soluble vegetable manure, the application of quick lime should always be avoided, as it either tends to decompose to soluble matters by uniting to their carbon or oxygen so as to become mild lime, or it combines with the soluble matters and forms compounds having less attraction for water than the pure vegetable substance (Mengel *et al*., 2001).

2.14 Application of Animal Manure and its effect on the soil

Application of animal manure to the land is an efficient utilization alternative because of its lower costs compared to treatment and the nutrient benefits derived by crops from them. Manure nutrients help build and maintain soil fertility. Manure can also improve soil tilth, increase water-holding capacity, lessen wind and water erosion, improves aeration, and promotes beneficial organisms, (Johnson and Eckert, 2013).

According to Macgregor & Warren (2006), the material is classified as farm dairy effluent (FDE) which is defined as animal excreta and water captured by the working surfaces associated with a farm dairy shed. This liquid fertilizer is capable of being pumped and sprayed through irrigation equipment.

There are two principal objectives in applying animal manure to land:

1) Ensuring maximum utilization of the manure nutrients by crops to avoid having excess than required by the plants.

2) Minimizing water pollution hazard. This is because of the effect of the excess nutrients in to the water bodies.

Surface spreading and subsurface injection are two of the most common land-application methods. Several guidelines should be followed to achieve maximum nutrient use with minimal environmental hazard:

2.15 Guidelines for efficient application and use of animal manure

- Soil is tested to establish existing soil-fertility levels.
- Manure and wastewater are tested to determine nutrient content.

- An application rate that does not exceed crop nutrient requirements is selected and soil contamination, crop damage, run off and contaminated tile flow avoided.
- Soil moisture is checked before applying liquid wastes, and application rates adjusted to avoid runoff. Soil moisture is estimated based on soil feel and appearance. To avoid runoff, manure application is not done to frozen or saturated soils.
- Raw or untreated manure is incorporated to reduce odour and nitrogen losses.

Available land for manure application is an important consideration for existing livestock operations as well as new or expanding operations. Typically, if enough land is available in an operation to produce feedstuffs for the animals, there is enough land to apply manure nutrients to minimize environmental effects. Land application of plant nutrients, including manure, must take into account both crop needs and the potential for environmental degradation. Nutrients should not be applied in quantities that exceed the amount needed for adequate plant nutrition. All nutrient sources from commercial fertilizer, manure, and sludge application must be considered. Excess application may induce nutrient deficiencies in the soil and increase the potential for excess nutrients to enter waterways. High nutrient concentrations can accelerate eutrophication, a condition that reduces dissolved oxygen in the water, increasing plant growth and limiting animal life (Eckert, 2013)

2.16 Animal manure and Soil phosphorus management

In animal manure management, phosphorus (P) is the nutrient of major concern on soils with high phosphorus fertility levels. Phosphorus applied to fields as manure or commercial fertilizer can move into bodies of water during erosion and runoff events. It accumulates in soils if applied in quantities greater than those removed by crops. Accumulation of phosphorus in the soil can be measured by accepted soil test procedures. Concentrations of algal-available phosphorus (the phosphorus responsible for eutrophication) increase as soil-test phosphorus levels increase, meaning that as soil concentrations of phosphorus rise, the potential increases for soils to degrade the environment through runoff and erosion (Johnson and Eckert, 2013).

Therefore, recommended strategies for manure applications to land are based on the following principles:

- There is no agronomic justification for raising soil phosphorus levels above those that provide adequate nutrition to the crop.
- Increasing soil test phosphorus levels at the soil surface increases a field's pollutant potential.
- Site characteristics, application methods and management, cropping system, and erosion/runoff abatement practices all affect the quantity of manure that can be safely applied to a given field.

2.17 Factors Controlling Application Rate

The factors that most often limit the amount of manure that should be applied to crop land are existing soil-fertility levels, manure nutrient content, crop nutrient needs, site limitations, slope, runoff potential, and leaching potential. Nitrogen and/or phosphorus is usually the limiting nutrient for manure application. All manure contains measurable amounts of both. Applying levels that exceed crop nutrient requirements may lead to nutrients entering surface waters or leaching into ground water (Eckert, 2013).

The amount of nutrients available in raw manure varies with the type and size of animal. The nutrient composition of waste is affected by housing and the waste-handling system. Bedding and additional water can dilute manure, resulting in less nutrient value per pound. Nutrient losses from storage and handling reduce the amount of nutrient available for land application. Phosphorus and potassium losses are usually negligible, but nitrogen losses can be significant. Land application methods also affect the amount of nutrients available for crop uptake. Most losses occur within 24 hours of application. Manure should be incorporated into the soil as soon as possible after application. Injecting, chiseling, or knifing liquid manure into the soil minimizes odours and nutrient losses to the air or as surface runoff. The amount of nitrogen available in the soil depends on the method of application and time of incorporation. The phosphorus and potassium applied to the soil will be available unless removed by surface runoff and soil erosion. Nearly 100 percent of total phosphorus and potassium from manure application are considered available the first growing season (Johnson and Eckert, 2013).

Table 1: Approximate nutrient value of animal manure applied in liquid state

			Nutrient Content			
Type of Livestock	**Bedding vs. No Bedding**	**Dry matter**	**Total N(b)**	**NH_4^+(c)**	**P_2O_5(d)**	**K_2O(e)**
		(%)	**(lb/ton)**			
Swine	Liquid pit	4	36	26	27	22
	Lagoon (f)	1	4	3	2	4
Beef	Liquid pit	11	40	24	27	34
cattle	Lagoonf	1	4	2	9	5
Dairy	Liquid pit	8	24	12	18	29
cattle	Lagoonf	1	4	2.5	4	5
Veal calf	Liquid pit	3	24	19	25	51
Poultry	Liquid pit	13	80	64	36	96
(a) Application conversion factors: 1,000 gal = about 4 tons; 27,154 gal = 1 acre-inch						
(b) Ammonium N plus organic N, which is slow releasing.						
(c) Ammonium N, which is available to the plant during the growing season.						
(d) To convert to elemental P, multiply by 0.44						
(e) To convert to elemental K, multiply by 0.83.						
(f) Includes feedlot runoff water and is sized as follows: single cell lagoon - 2 cu ft/lb animal weight; two-cell lagoon - cell 1, 1-2 cu ft/lb animal weight and cell 2, 1 cu ft/lb animal weight.						

SOURCE: Ohio State University Extension Department of Horticulture and Crop Science

2.18 The Biochemistry of manure decomposition in the soil

Manure break down is accomplished by a mixed population of anaerobic bacteria, which is commonly grouped into acid-forming or methane-producing classes.

Acid formers are responsible for the initial break down of complex molecules into short-chain compounds, including organic acids. Methane bacteria further reduce organic acids to methane and carbon dioxide.

The breakdown of protein proceeds to ever-simpler proteoses, peptones, peptides, amino acids and finally, to ammonia and volatile organic acids such as formic, acetic, propionic, and butyric acids. Due to the presence of sulfur in certain amino acids (sulfur averages about 1 percent of most proteins), various sulfides and mercaptans can be expected as a result of protein catabolism. Carbohydrates in animal waste include sugars, starch, and cellulose. Starch and cellulose are broken into glucose (sugar) units as the first step of decomposition. Under anaerobic conditions, sugars are broken into alcohols, aldehydes, ketones, and organic acids. These intermediate compounds are odorous and can be further metabolized and transformed into methane, carbon dioxide, and water (non-odorous end-products) if conditions allow the methane-producing microorganisms to function (Susanti *et al.*, 2014).

2.19 Related studies

A long-term studies on continuous winter wheat used to illustrate the risk of liming while fertilizer is routinely applied showed that, soil pH gradually decreased over time for all the fertilizer treated plots. The higher the N rates of absorption, the lower the soil pH. This is because higher N rates produced higher wheat yields in the early years and removed more base cations from the system. Some acidity is also as a result of the acid forming nature of the fertilizer. When soil is getting more acidic, the aluminium is more soluble. High soluble and exchangeable Al in the soil is harmful to plant growth. Al saturation (the relative abundance of Al on the exchange sites to cation exchange capacity) has been shown to be a better indicator for Al toxicity. Al saturation is well correlated with soil pH. In general, the lower the pH is, the higher the Al saturation. Wheat grain yields have been gradually decreasing in the last decade for high N rate treatments due to soil acidity rather than nutrient supply. This is the risk faced if continuous fertilizer application is done without liming to correct soil acidity problem (Adetunji ,1992).

Effect of different rates of hydrated lime and zeolite tuffs, as lime materials, mineral and organic fertilizers upon the yield of maize and winter wheat grain was studied. Out of this, the soil shows acid reaction very low supplies of phosphorus, moderate supplies of potassium and high saturation of the soil cation –exchange capacity. The highest yield of maize was recorded in the variant with the higher mineral fertilizer rate in combination with the higher rate of solid farmyard manure. A significantly lower yield was recorded in the check treatment, and a significantly higher yield was recorded in the variant with the higher mineral fertilizer rate in combination with higher doses of hydrated lime, as well as in variants in which a combination of the lower mineral fertilizer rate and the higher dose of hydrated lime and organic fertilizer was applied. This point to a conclusion that the level of maize yield in variants involving the combination of mineral fertilization and liming materials was conditioned by the interaction of mineral and liming. In conclusion, the downward trend of effective soil fertility was caused by the reduced soil content of calcium. Calcium deficiency led to degradation of the physical, chemical and biological properties of soil, and thereby also soil fertility. This was confirmed by Travnik *et al*. (2003) .

According to Shepherd *et al*. (1997), nitrogen and phosphorus are the main limiting nutrients in food production. They found out that, continuous use of mineral fertilizer can have detrimental effects on soil properties. On strongly weathered, poorly buffered soils of the tropics, using inorganic fertilizer as the main source of nutrients can lead to rapid decline in crop yields because of acidification and soil compaction. High rates of lime and phosphatic fertilizers are required to improve crop yields on highly acidic soils. A study conducted in western Kenya also confirmed this. It also confirmed that, plant population is a direct influence of many factors including source of seed, condition of soil tilth at sowing, row spacing, soil condition and type of fertilizer used at the time of planting.

Nekesa, (2007) and Kisinyo *et al*. (2009) found out that, the generally accepted method to reduce soil acidity is the application of agricultural lime or limestone. Lime applied to acid soils raises the pH of soils, resulting in enhanced availability of nutrient, such as P, Ca, Mg, Mo and others, and improved crop yields.

According to Kisinyo *et al*. (2012), soil acidity is widespread in the tropics and is partially responsible for low beans and maize yield in several parts of Kenya. Atiwag (1992) concluded that, ways of improving crop output from such soils includes application of nitrogenous and phosphatic fertilize, liming and addition of organic manure. From the study conducted in Got Nanga in Ugunja and in Kakamega North districts, Soil acidity is a major problem in maize growing regions as low responses have been observed even after application of inorganic fertilizer on acid soils. There is great potential of increasing cereal and legume production following amelioration of the soil acidity problems. The use of legumes in the system can also help increase productivity of the systems. It was also discovered that the farmers in the region were not aware of the soil acidity problems as well as the use of lime to solve the problem. Hence the need for extensive demonstrations to educate farmers on the potential of liming, and judicious use of other resources to address the problem of soil acidity. This was illustrated in the figure 2.1 below;

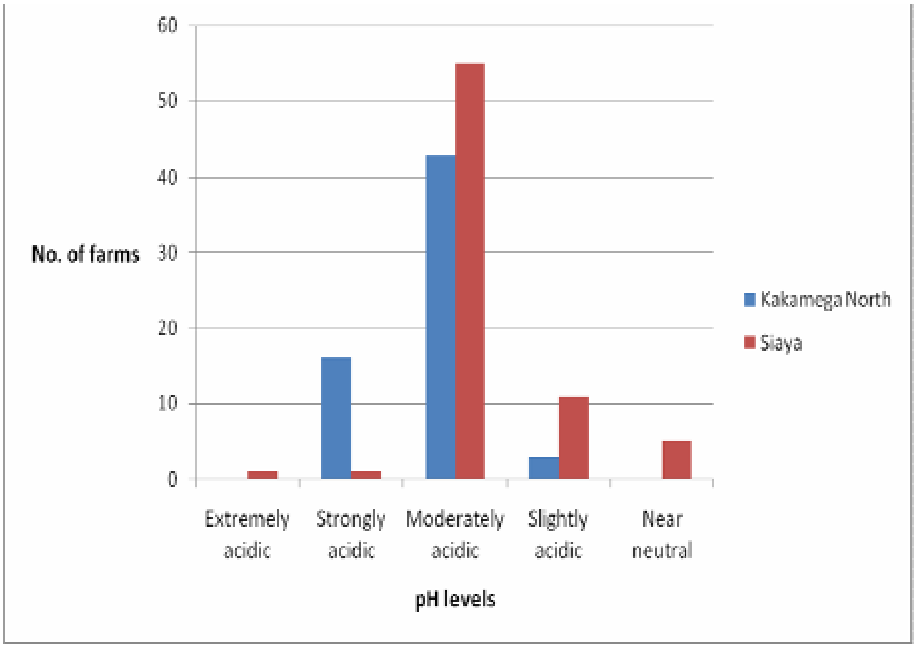

Fig 1: Frequency distribution of soil pH across North Kakamega and Ugunja districts.

According to the studies conducted in south central Kansa, well-drained productive soils under good management usually become acidic over time as natural result of high crop production. This makes long-term continuous production of wheat vulnerable. Strongly acidic soils may present several problems for wheat production. These include; aluminium toxicity and in some cases manganese toxicity, as well as deficiencies of phosphorus, calcium magnesium molybdenum. These problems are referred to as the acid soil.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site

The study was conducted at the University of Eldoret farm, which is classified as lower highlands zone 3 (LH3) Jeatzold and Schmidt (2006). The site is positioned at (0 30E, 35 15E) at elevation of 2185 m with precipitation of 900-1100 mm p.a. The field experiments were carried out during the long rains of the year 2006 and 2007.

3.2 Materials

The agricultural lime with calcium carbonate as the active ingredients on average Ca 30%, Mg 5%, K 0.23%, and S 0.11%, was obtained from Koru mining Company. Sludge made from dairy cattle manure was sourced from the University of Eldoret Farm.

3.3 Treatments

Table 2: Treatments carried out during the experiment

Maize	**Wheat**	**Beans**
Control (No treatment)	Control(No treatment)	Control (No treatment)
Lime + sludge	Lime + sludge	Lime + sludge
TSP + lime	TSP + lime	TSP + lime
TSP + sludge	TSP + sludge	TSP + sludge
TSP + sludge +lime	TSP + sludge +lime	TSP + sludge +lime

3.4 Experimental Design

Randomized complete block design was adopted with treatments being replicated in each block. This was important to control nuisance factors. Nuisance factors included specific treatment and time of application. Randomization was done to reduce contamination or mixing of the treatments. There were five (5) treatments applied to three (3) test crops which were maize, wheat and beans. This made to a total of 30 plots per block. The experiment had two (2) blocks.

3.5 Rate of application of treatments

The treatments were replicated twice and applied in plots measuring 4 m x 4 m. planting was done in early May after onset of long rains. Lime was applied in plots one week before planting the crops at 0.00237 tonnes per plot. Sludge was applied at 0.00316 tonnes per plot.

3.5.1 Maize

The maize variety used was H614 with spacing of 75 cm by 30 cm planted in holes at seed rate of 22 kg/ha. Sludge and TSP were mixed with the soil in the hole before sowing seeds. TSP was applied at 20 kg P per hectare.

3.5.2 Wheat

Muamba, a local variety was used. Seeds were planted in rows with spacing of 15 cm apart at seed rate of 170 kg/ha.TSP was applied at 20 kg P per hectare.

3.5.3 Beans

The common bean variety used was Rose coco as known locally. Hole planting was used with spacing of 60 cm by 15 cm. TSP was applied at 15 kg P per hectare.

3.6 Field management

3.6.1 Maize

Seed bed was well prepared to medium tilth before planting. Weeding was done twice; after 20 days and at knee high stage before the plants flower.

3.6.2 Beans

Seed bed was well prepared to medium tilth before planting. Weeding was done twice; after 20 and 40 days after planting. Fungicides were used for disease control.

3.6.3 Wheat

Seed bed was well prepared to fine tilth. Weeding was done once after one month. Fungicide was applied for disease control.

3.7 Data collection and analysis

Data collected included; grain yield and stover biomass measurements. Analysis of variance and mean separation, this is to say a comparison of every pair was done on the grain yields and stover biomass to establish best treatment combinations.

3. 8 Harvesting

All crops were harvested after reaching full maturity. Grain yield and stover biomass were measured for the 3 crops. Maize was harvested when cobs had ripened and dried with moisture content of less than 15%. Wheat was harvested manually using sickle when grain moisture content of less than 14%. Bean pods were harvested early in the morning when they were still turgid to avoid shattering and dried to moisture of less than 20% before weighing.

3.9 Laboratory analyses

Soil available phosphorus was determined by Olsen method, whereby 1gram of air dried soil was scooped and 20 ml 0f 0.5M sodium bicarbonate solution are shaken for 30 minutes. Blue colour in the filtrate is developed with ascorbic acid reagent, measure with colorimeter at 880 nm and results reported in ppm phosphorus. Total soil nitrogen was done using the Kjedahl method, where a substance is heated with Sulphuric (IV) acid to decompose it by oxidation, to liberate nitrogen as ammonium sulphate. Solution is then distilled with sodium Hydroxide to convert it to ammonia which is equivalent to nitrogen present. Measurements of pH were done using glass electrode meter using water as a reagent as per Okalebo *et al*., (2002).

3.10 Field layout

The illustration below shows how the field arrangements of the plant were made.

4m

Control Maize	2m	Lime+TSP Beans	2m	Lime+TSP Wheat	2m	TSP+Sludge Beans	2m	Sludge +lime Maize
2m								
Lime+sludge+TSP Beans		TSP+Sludge Maize		Sludge +lime wheat		TSP+Sludge Wheat		Lime+sludge +TSP Wheat
2m								2m
Control Wheat		Sludge +lime beans		Lime+TSP maize		Lime+sludge+TSP maize		Control Beans

Figure 2: Field arrangements of the plots

-Control; Only the grains are planted without applying any treatment

-lime+sludge,lime+TSP,lime+TSP+sludge,TSP+sludge ;Each of these was applied to each plot of the three plant

CHAPTER FOUR

RESULTS AND DISCUSION

4.1 Results

4.1.1 Soil fertility

Use of lime increased phosphorus content in the soil from pH of 7.32 to 17.3 for Maize, 7.32 to 20.4 for Wheat, 7.32 to 21.7 for Beans. In addition, its increased solubility due to combination with TSP increased phosphorus soil content leading to higher yields in maize, wheat and beans. Soil pH was also found to have increased from 4.65 to 6.0 as indicated in Tables 4, 5 and 6. Soil available phosphorus was more after crop harvest than at planting time while soil nitrogen content did not change (Tables 3, 4, 5 and 6).

Table 3: Initial characterization of lime, TSP and soil

Parameter	**Value**	**Method**
lime Ph	11.3	Glass electrode
TSP Ph	2.47	Glass electrode
soil pH	4.65	Glass electrode
P (ppm)	7.32	Olsen method
Total %N	0.09	Kjeldahl method
% OC	1.26	Walkly-Black method
Bulk density (g/cm)	1.75	Core sampler

Table 4: Soil phosphorus and nitrogen content after harvest of Maize

Treatments	soil available P (ppm)	Total %N
Control	6.9	0.07
Lime + sludge	17.3	0.14
TSP + lime	41.3	0.09
TSP + sludge	13	0.12
TSP + sludge +lime	32.6	0.15
Soil pH 6.0		

Table 5: Soil phosphorus and nitrogen content after harvest of Wheat

Treatments	soil available P(ppm)	Total %N
Control	6.53	0.07
Lime + sludge	20.4	0.12
TSP + lime	39.4	0.11
TSP + sludge	17.8	0.09
TSP + sludge +lime	37.4	0.17
Soil pH 6.0		

Table 6: Soil phosphorus and nitrogen content after harvest of Beans

Treatments	soil available P (ppm)	Total %N
Control	7.4	0.09
Lime + sludge	21.7	0.13
TSP + lime	16.4	0.1
TSP + sludge	10.3	0.12
TSP + sludge +lime	34.6	0.15
Soil pH 6.0		

Table 7: Critical soil test data for the ratings of P and N

Ratings for P and N		
Ratings	**Available P (ppm)**	**% N Content**
Very low	< 2	< 0.1
Low	(2-10)	0.1 – 0.2
Medium	(10-20)	0.2 – 0.5
High	(20-40)	0.5 – 1.0
Very high	> 40	> 1.0

Source: Landon, (1991)**.**

4.1.2 Crop productivity: Grain yield

The effect of different Soil treatments as per Table 1 on grain yield for maize, wheat and beans was highly statistically significant (*p<.001*). A combination of TSP and lime was significantly different from a combination of (TSP, lime and sludge) in maize but not for wheat and beans (Fig 3, 4, 5 and 6). Combination of (TSP, lime and sludge) gave highest yields in maize (Fig 3) while combination of (TSP, lime) gave highest yields in wheat and beans (Fig 4 and 5). A combination of (lime and sludge) and that of (TSP and sludge) was statistically significant in maize but not for wheat and beans.

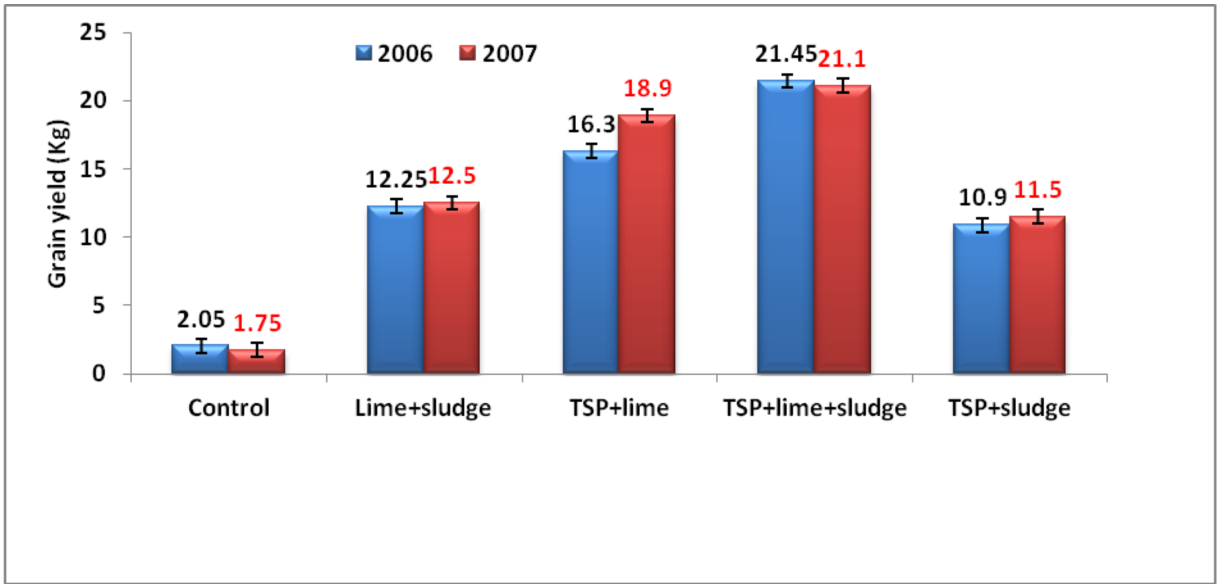

Figure 3: Maize grain yields (kg) for 2006 and 2007 seasons

TSP +lime +sludge combination gave highest maize grain yield followed by TSP + lime then lime +sludge and finally TSP +sludge. The absolute control gave the least grain yield. There was significant difference between TSP +sludge and finally lime +sludge (Figure 3). The difference in grain production over the two growing seasons was not statistically different. Productivity was ten (10) times more in TSP +lime +sludge combination than the control (Figure 3).

Wheat grain yield productivity followed the same trend like that of maize. TSP + lime was the best treatment but not significantly different from TSP + lime + sludge combination. TSP + sludge and lime + sludge were far much behind but giving grain yields more than double that of control. TSP + sludge and lime + sludge were not statistically different in terms of productivity Figure 4.

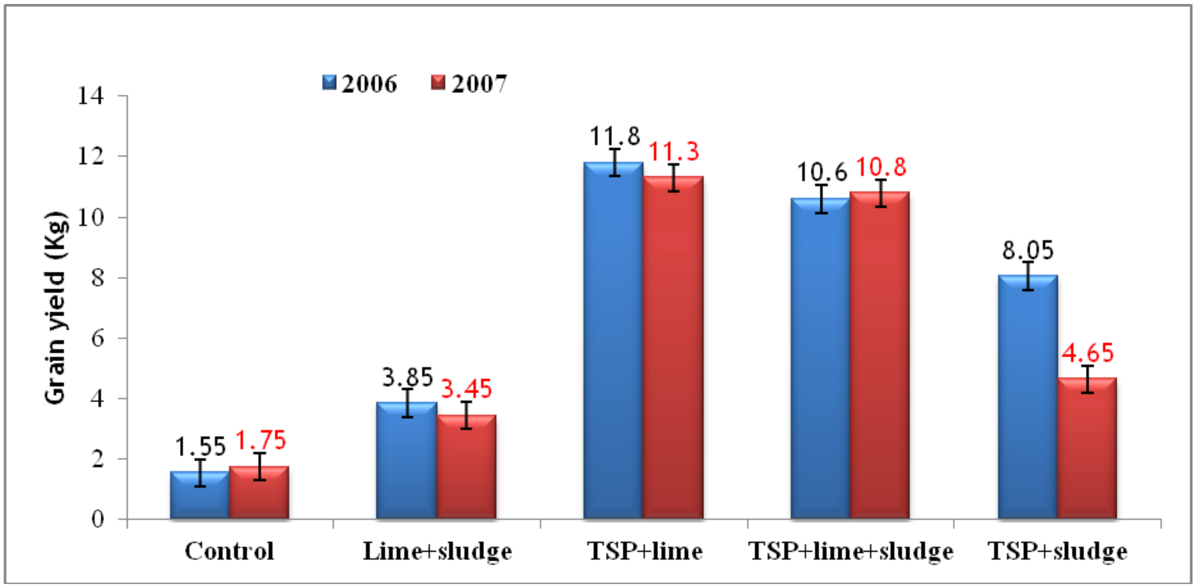

Figure 4: Wheat grain yields (kg) for 2006 and 2007 seasons

Unlike in maize and wheat, TSP + lime combination gave the highest yields followed by TSP + lime + sludge but the productivity between the two treatments was not statically significant. In addition, the productivity from the two treatments was five (5) times more than that produced without use of fertilizer (control). TSP + sludge and lime + sludge were different and gave more than double compared to that of control.

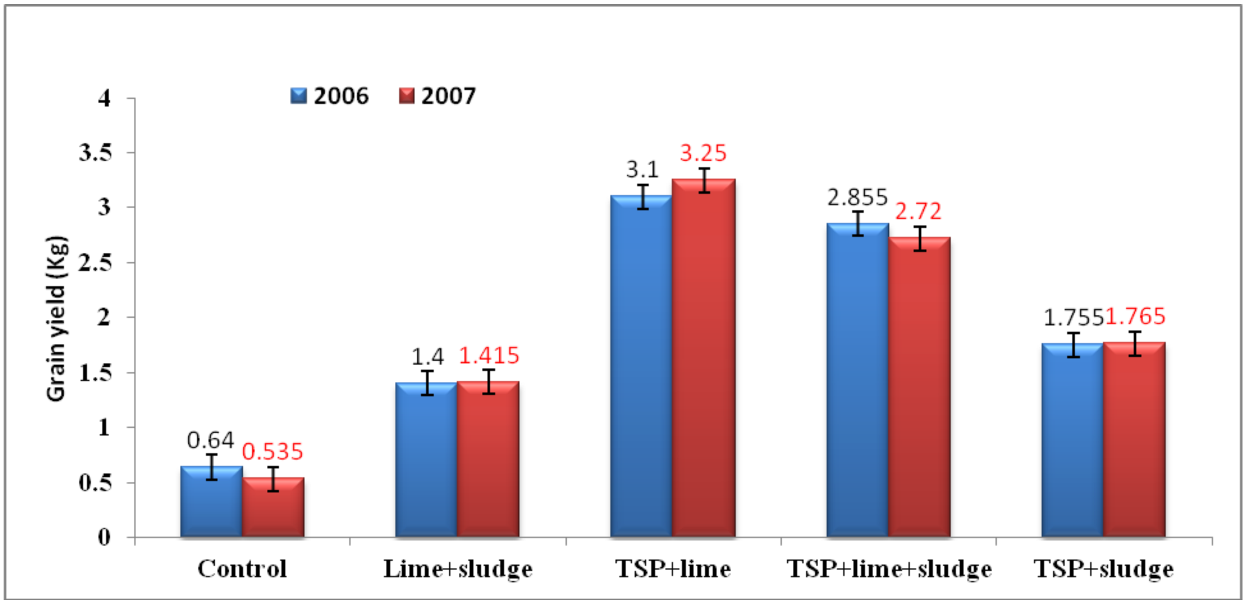

Figure 5: Bean grain yields (g) for 2006 and 2007 seasons

4.1.3 Crop productivity: Biomass

The effect of different treatments as per Table 1 on biomass for the 3 crops (maize, wheat and beans) was highly statistically significant ($p<.001$). A combination of TSP and lime was significantly different from a combination of TSP, lime and sludge) for the 3 crops (Fig 6, 7, and 8). Combination of TSP and lime gave highest biomass in all the 3 crops followed by the combination of TSP, lime and sludge. A combination of TSP and sludge and that of lime and sludge were not statistically significant on bean biomass but significant on maize and wheat biomass.

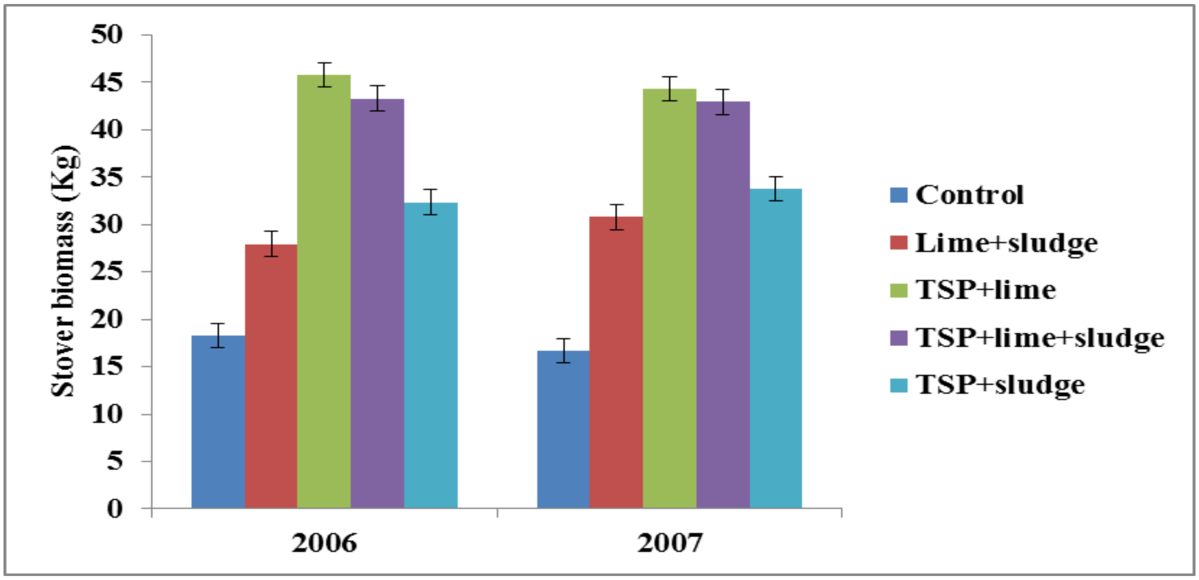

Figure 6: Maize stover biomass (kg) for 2006 and 2007 seasons

The effect of different treatments on maize biomass was highly significant (*p<.001*). The biomass produced from TSP and lime treatment was highest and was nearly triple that of absolute control. This was followed by TSP, lime and sludge) but the difference was not statistically significant between the treatments. Combining TSP + sludge and lime + sludge did not give statistically different results for the two seasons as shown in Figure 6. The difference in the two years (growing seasons was not significant). The reason for the using two growing seasons was to cater for any environmental changes like change in amount of rains.

The effect of different fertilizer materials on wheat biomass gave the same trend as in maize. A TSP and lime combination gave highest straw biomass which was double that of absolute control. TSP, lime and sludge combination gave second highest biomass yields followed by TSP and sludge and then lime and sludge. The control gave the least biomass (Figure 7).

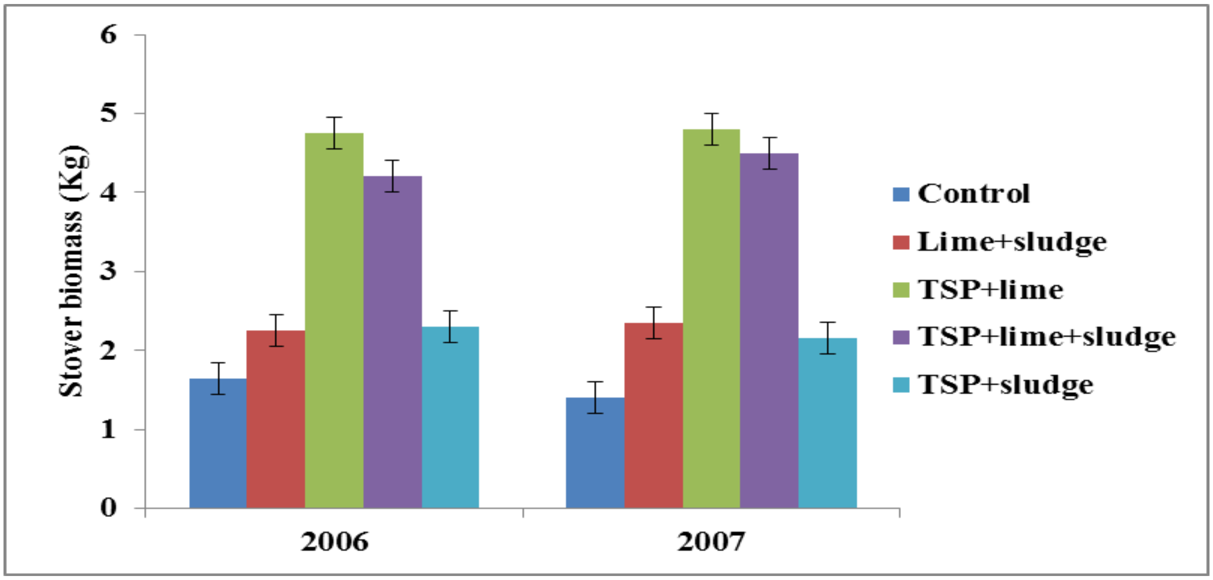

Figure 7: Wheat straw biomass (kg) for 2006 and 2007 seasons

Bean biomass was greatly affected by treatments. A TSP and lime combination was the best and five (5) times more than control. TSP and sludge was second followed by lime and sludge while absolute control was the least (Figure 8). The difference between TSP and sludge and lime and sludge was significant statistically unlike in maize and wheat.

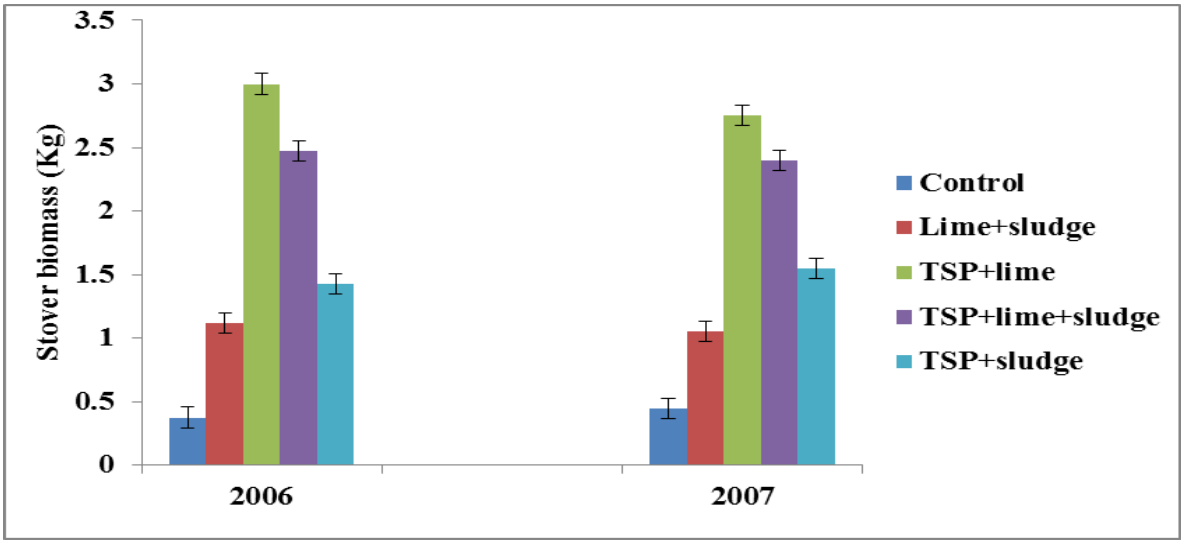

Figure 8: Bean biomass (kg) for 2006 and 2007 seasons

4.2 Discussion

The effect of combined use of lime, TSP and sludge on crop productivity differs with the type of crop and even the type of soil. Maize and wheat are cereals while common bean is a legume that fixes nitrogen in the soil. Deep rooted crops like maize mines more nutrients from the soil than wheat. TSP fertilizer is soluble in the soil and it releases phosphorus immediately after application to the soil for plant use compared to lime or sludge. This is confirmed by the results in the table 3, 4 and 5. Sludge, as a fertilizer releases nutrients very slowly because it's an organic material that has to undergo mineralization before enriching the soil. Mineralization is a process that is a function of various environmental factors like; soil moisture, the type of the decomposing agents. In addition, the source and storage conditions of the organic material used to make manure sludge greatly influences nutrient content of sludge. Lime as a soil amendment improves several conditions of a given soil. It improves the soil structure due to the effect of Ca which improves the aggregate structure. In addition, lime increases soil pH hence improving the fertility although on a slow basis. The main use of lime in agriculture is to raise the pH of acid in soils and reduce the aluminium hence making phosphorus available to crops. According to Sawyer, (2003), lime corrects problems from excessive acidity ranging from reduced Al and other metal toxicities, improved soil physical condition, increased microbial activity like the symbiotic bacteria that fix N to improving availability of essential nutrients such as Ca and Mg for plants. This was confirmed by the study conducted in western Kenya.

Combining lime, TSP and sludge for use as a fertilizer material seemed the best choice as it gave the highest yields. This was confirmed from the yield obtained as per table 7. Lime is basic (pH 11.2) while TSP is acidic (pH 2.47) in solution. Combination of the two gave a pH of 6.0, hence the acidic conditions of TSP increases the solubility of lime in the soil therefore improving the efficiency of lime. When the two are applied in the soil, TSP releases phosphorus immediately for better root development hence good crop establishment, and Table 3, 4 and 5 confirm this.

Lime will cater for phosphorous needs at later stages of growth besides providing calcium. The pH increase caused by lime will create favourable soil conditions for crops to absorb and utilize essential cations like K and Mg. This combination lime + TSP will need additional nitrogen source to cater for nitrogen deficiencies as done in this experiment where CAN fertilizer was applied in all treatments. Using a combination of lime and sludge as a fertilizer was less effective as both are slow nutrient releasers and limited in terms of quantity or amount of nutrient required by the crops. Sludge as an organic matter is a good option to manage problems associated with soil acidity as it increases the cation exchange capacity of the soil mostly increasing the base saturation. In addition, sludge forms strong bonds, known as "chelating effect," with aluminum which reduces the solubility of aluminum and soil acidity, Kabata-pendias, (2010).

Since Sludge acts as buffer for nutrient concentration in the soil when applied in combination with inorganic fertilizer, whereby nutrients are not released immediately to crops, relatively low yields are obtained especially in crops with short growing cycles. However, with time, this will change making this combination the best fertilizer material for crops with longer growing seasons like maize in cold and high altitude areas. In this regard, the combination of lime + TSP + sludge would be preferred to that of lime + TSP. Research in soya beans by Serafim *et al* (2013) revealed that manure and lime significantly reduced exchangeable acidity and increased soil pH. Application of manure alone or combined with lime or P fertilizer also increased Mg and K. In addition, lime alone or lime combined with manure and manure combined with P applied gave a significant increase in exchangeable Ca. Soybean responded well and significantly to application of manure either alone or combined with lime, P or both.

Studies done at the same site for this experiment but in French beans by Barasa *et al*. (2013) indicated lime having significantly increased soil pH from 5.5 to 6.3 and 5.4 to 6.0, respectively at the end of the study period. P alone had no significant effect on soil pH, but increased soil available phosphorus. This was found out at the end of the production as indicated by the results in table 4, 5 and 6.

According to Kidanemariam *et al*. (2013), yield and yield attributes of wheat showed significant response to lime and inorganic fertilizer applications. In addition, a fertilizer-lime interaction was significant in grain yield, total biomass and N and P uptakes, as shown by the results in table 8. Therefore .instead of applying only fertilizer on acidic soil, it is better to integrate it with lime for better production of maize.

Fertilizer material made from combining lime and sludge gave low yields for these plants because of its slow release of nutrients for plant use. The nutrient composition is limited and it will require huge amounts of both lime material and sludge for successful crop production and therefore starter inorganic fertilizer would be needed to supply essential nutrients to crops at early stages of growth. The residual effect of both lime and sludge are very important in soil fertility sustainability as both can be applied in soils and provide nutrients for many growing seasons without additions, residual effects last for several years before application again. The fineness of lime is important in determining how quickly it reacts with soil acidity. Smaller particle size reacts quickly since there is more exposed surface area for chemical reaction. Larger particles are slower to react, but provide a sustained, longer term source of acid neutralization. In addition, lime is more soluble in acid soils than in neutral or alkaline soils. According to studies done by international plant nutrition institute (IPNI), lime made of calcium carbonate ($CaCO_3$) is insoluble in water but its solubility increases in acid conditions, Adetunji (1992). These studies further suggest that poor crop growth in acid soils is largely due to soluble Al that affects the root system of plants making them stubby. The effect of lime reducing Al from the soil is due to Ca and is given below:

1) $CaCO_3 + H_2O \rightarrow Ca^{2+} + 2OH^- + CO_2$

2) Al^{3+} (soluble) + $3OH^- \rightarrow Al(OH)_3$ (insoluble).

Hue and Ikawa, (1994) explain that when lime (that is CaCO3) is added to a moist soil, the following reactions will occur:

(1) Lime is dissolved slowly by moisture in the soil to produce Ca^{2+} and OH^-

$CaCO_3 + H_2O$ (in soil) $\rightarrow Ca^{2+} + 2OH^- + CO_2$ (gas)

(2) Newly produced Ca^{2+} will exchange with Al^{3+} and H^+ on the surface

of acid soils

$2Ca^{2+}$ + soil-Al $\rightarrow$ soil-Ca + Al^{3+} + soil-H $\rightarrow$ soil-Ca + H^+

(3) Lime-produced OH^- will react with Al^{3+} to form $Al(OH)_3$ solid and with H^+

to form water.

$Al^{3+} + 3OH^-$ ===> $Al(OH)_3$ (solid), $H^+ + OH^-$ ===> H_2O

Thus liming eliminates toxic Al^{3+} and H^+ through the reactions with OH^-. Excess OH^- from lime will raise the soil pH, which is the most recognizable effect of liming. Another added benefit of liming is the supply of Ca^{2+} and Mg^{2+} if dolomite [$Ca,Mg(CO_3)_2$] is used. Because soils differ widely in mineralogy, organic matter and clay content, they require different amounts of lime to raise soil pH to a given value.

Moreover, there are other indirect benefits of liming the acid soil and these ranges from; increased P availability, better N fixation by legumes like the common bean, enhanced N mineralization and nitrification, increased water and nutrient use efficiency, and plant performance with a healthier root system. Combination of TSP and lime increases the efficiency of each nutrient because industrial manufacture of phosphatic fertilizer by lime material is now possible that is reacting phosphoric acid with any kind of lime material like limestone ($CaCO_3$ or dolomite $MgCO_{3.}CaCO_{3,}$ Uchida, *et al.* (2000). According to Sawyer, (2003), lime corrects problems from excessive acidity ranging from reduced Al and other metal toxicities, improved soil physical condition, increased microbial activity like the symbiotic bacteria that fix N to improving availability of essential nutrients such as Ca and Mg for plants.

CHAPTER FIVE

CONCLUSION AND RECOMENTATIONS

5.1 Conclusions

All fertilizer treatment combinations effect on grain yield and biomass were statistically different form each other. The combination of TSP + lime +sludge gave highest grain yields and stover biomass in maize. The combination of TSP and lime produced highest grain yield and biomass in wheat and beans. There was no significant difference between a combination of TSP+ lime and TSP + lime + sludge on wheat grain yields. The combination of Lime +sludge gave the lowest yields for both grain and stover biomass for the 3 crops. The fertilizer material from combining TSP+ lime + sludge gave more grain yields in maize while a combination of TSP +lime produced higher Stover biomass in the same crop.

There was no significant difference in production of both grain and biomass of the 3 crops for these growing seasons or years of 2006 and 2007. The productivity of the two food crops (maize and wheat) was enhanced greatly by the combined use of lime, TSP and sludge as a fertilizer material. To improve the combination lime and TSP, additional nitrogen source is required to cater for nitrogen deficiencies. Sludge when used alone acts as buffer for nutrient concentration in the soil but when applied in combination with inorganic fertilizer, nutrients are not released immediately to crops which cause relatively low yields especially in crops with short growing cycles. In this regard, the combination of lime, TSP and sludge would be more preferable to that of lime and TSP.

The application of only TSP fertilizer in the agricultural soils reduced the plant available phosphorus but when lime was added to the TSP before application, the plant available phosphorus content in the soil increased. In contrary, the total % nitrogen didn’t change a clear indication that N is less affected by soil pH than.

5.2 Recommendations

The combination of (TSP + lime + sludge) should be used in maize production as this will increase productivity by improving soil fertility and health. In addition, this combination (TSP + lime + sludge) should be used in long term strategy cropping systems while the combination of (TSP and lime) should be adopted for short term strategies for crops grown.

The use of TSP and lime should be adopted in production of wheat and beans as it gave highest yields. TSP will provide instant phosphorus for better root establishment while increased lime solubility will provide calcium and additional phosphorus needed for better grains.

A combination of TSP + lime + sludge would be preferred for growing maize for grain yields while TSP and lime for growing maize for Stover for use as animal feeds either as fresh fodder, silage or hay especially in dairy farming systems.

This study was limited to only three crops .Therefore more studies on other crops should be done so as to establish how they respond to the same treatment.

REFERENCES

Achieng", D.F., Odongo, O. and Odendo, O.(2001). Sustainability of fertilizer use on maize production in western Kenya through provision of credit. Seventh eastern and southern Africa, regional maize conference.;428-431.

Adetunji, M.T.(1992). Effect of lime and phosphorus on the sulphate adsorption capacity of south western Nigerian Soils. *Indian Journal of Agricultural Science* 43:488-493. Agriculture, German Agriculture Team (GTZ). Nairobi, Kenya. Volume IIIB

Alila, P. O., and Atieno, R. (2006,) March. Agricultural policy in Kenya: issues and processes. In *Future Agricultures, A paper for the Future Agricultures Consortium workshop, Institute of Development Studies* (pp. 20-22).

Arntzen, C. (ed) (1994). Soil-water-plant relationships Encyclopedia of Agriculture science Vol 4ISBN: 9780122266706 *http://store.elsevier.com/Encyclopedia of Agricultural Science 2012.*

Atiwag, J. A. (1992). Response of snap bean (Phaseolus vulgaris Linn.) to lime and phosphorus in acid soil. *Philippine Journal of Crop Science (Philippines)*.

Singh, H., & Reddy, M. S. (2011). Effect of inoculation with phosphate solubilizing fungus on growth and nutrient uptake of wheat and maize plants fertilized with rock phosphate in alkaline soils. *European Journal of Soil Biology*, *47*(1), 30-34.

Bakayoko, S., Soro, D., Nindjin, C., Dao, D., Tschannen, A., Girardin, O. and Assa, A. (2009). Effects of cattle and poultry manures on organic matter content and adsorption complex of a sandy soil under cassava cultivation (*Manihotesculenta*, Crantz). *Afric. J. Environ. Sci. Technol., 3*(8): 190-197

Baligar, V. C., Fageria, N. K., & He, Z. L. (2001). Nutrient use efficiency in plants. *Communications in Soil Science and Plant Analysis*, *32*(7-8), 921-950.

Barasa, J.N. Omami, E.N., Okalebo, J.R., Othieno, C.O. (2013). Effect of lime and phosphorus fertilizer applications on performance of french beans in Uasin Gishu district, Kenya.

Brink, M., & Belay, G. (2006). *Plant resources of tropical Africa 1. Cereals and pulses*. Programme PROTA.

Mengel, K., Kosegarten, H., Kirkby, E. A., & Appel, T. (Eds.). (2001). *Principles of plant nutrition*. Springer Science & Business Media.

Buresh, R. J., Smithson, P. C., & Hellums, D. T. (1997). Building soil phosphorus capital in Africa. *Replenishing soil fertility in Africa*, (replenishingsoi), 111-149.

Macgregor, C. J., & Warren, C. R. (2006). Adopting sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland: the view from the farm. *Agriculture, ecosystems & environment*, *113*(1), 108-119.

FAO (2007). *Efficiency of soil and fertilizer phosphorus use bulletin.* FAO Fertilizer and Plant Nutrition Bulletin

Houlbrooke, D., Longhurst, B., Orchiston, T. and Muirhead, R. (2011). *Ag Research. Characterising dairy manures and slurries*. Report prepared for Surface Water Integrated Management (SWIM) October 2011

Hue, N. V. and Ikawa, H. (1994). *Acid Soils in Hawaii: Problems and Management*. Department Institute, Nairobi Kenya. 44p.

Jaetzold, R., & Schmidt, H. (1983). Farm management handbook of Kenya. *Natural conditions and farm information*, *11*.

Johnson, J., & Eckert, D. (1995). Best management practices: Land application of animal manure. *Ohio State University Extension Publication AGF-208-95 (Available online at http://www. ag. ohio state. edu/~ ohioline/agf fact/0208. html)(Verified 8 September 2004).*

Okalebo, J. R., Palm, C. A., Lekasi, J. K., Nandwa, S. M., Othieno, C. O., Waigwa, M., & Ndungu, K. W. (2004). Use of organic and inorganic resources to increase maize yields in some Kenyan infertile soils: A five-year experience. *Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa. AfNet-CIAT, Nairobi*, 359-372.

Kabata-Pendias, A. (2010). *Trace elements in soils and plants*. CRC press.

KARI, (1999). *Strategic plan for cereals in kenya (1993-2013).* Kenya Agricultural Research

Kherallah, M., Delgado, C. L., Gabre-Madhin, E. Z., Minot, N., & Johnson, M. (2002). *Reforming agricultural markets in Africa: Achievements and challenges*. Intl Food Policy Res Inst.

Kidanemariam, A., Gebrekidan, H., Mamo, T., & Fantaye, K. T. (2013). Wheat crop response to liming materials and N and P fertilizers in acidic soils of Tsegede highlands, northern Ethiopia. *Agriculture, Forestry and Fisheries*, *2*(3), 126-135.

Kisinyo, P. O., Gudu, S. O., Othieno, C. O., Okalebo, J. R., Opala, P. A., Maghanga, J. K., ... & Ogola, B. O. (2012). Effects of lime, phosphorus and rhizobia on Sesbania sesban performance in a Western Kenyan acid soil.

Landon, L.R. (1991). *Brooker Tropical Soils Manual. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics.* John and Wiley and Sons, Inc.New York, U.S.A. p. 474

Lester, G.E., (2005). *Impact of Potassium Nutrition on Food Quality of many Horticultural crops*. Retrieved 13th April 2014 from http://www.textbookalmonds.com/media.

Liang, W., Wu, X., Zhang, S., Xing, Y., Wang, R. (2011). *Effect of organic amendments on soil water storage in the aeolian sandy land of northeast China*. Proceedings of the Electrical and Control E Engineering (ICECE), International Conference on 16th – 18th Sept. 2011. pp. 1538-1540.

Lierop, W. and Kelowna, S. (2013). *Evaluation of Agricultural Limestone, SOIL FACTSHEET* Ministry of Agriculture and Food, British Columbia.

Simões, M. D. S., Rocha, J. V., & Lamparelli, R. A. C. (2005). Growth indices ans productivity in sugarcane. *Scientia Agricola*, *62*(1), 23-30.

Mwangi, T. J., Ngeny, J. M., Wekesa, F. and Mulati, J. (2001). *Acidic soil amendment for maize production in Uasin Gishu district, North Rift Kenya*. Kenya Agricultural Research Institute, National Agricultural Research Centre, P.O. Box 450, Kitale, Kenya.

Nekesa, A.O. (2007). *Effect of Minjingu phosphate rock and agricultural lime on maize ,groundnuts and soybean yields on acidic soils of western Kenya*. M.Phil Thesis Moi Unversity, Eldoret, Kenya.

Ohito, D. (2009). US fury over maize handling delay. *The Standard Online* [internet] 12th March. Available at: *http://www.eastandard.net/InsidePage. 2013*

Okalebo, J. R., Gathua, K. W, and Woomer, P. L. (2002). *Laboratory methods of soil and plant analysis:* A working manual. TSBF-CIAT and SACRED Africa, Nairobi.

Okalebo, J. R., Othieno, C. O., Nekesa, A. O., Ndungu-Magiroi, K. W., Kifuko-Koech, M. N., Tenywa, J. S., ... and Nampala, M. P. (2009). Potential for agricultural lime on improved soil health and agricultural production in Kenya. In *9th African Crop Science,Conference Proceedings, Cape Town, South Africa, 28 September-2 October 2009* (pp. 339-341). African Crop Science Society.

Okalebo, J. R., Palm, C. A., Lekasi, J. K., Nandwa, S. M., Othieno, C. O., Waigwa, M., & Ndungu, K. W. (2004). Use of organic and inorganic resources to increase maize yields in some Kenyan infertile soils: A five-year experience. *Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa. AfNet-CIAT, Nairobi*, 359-372.

Kisinyo, P. O., Gudu, S. O., Othieno, C. O., Okalebo, J. R., Opala, P. A., Maghanga, J. K., ... & Ogola, B. O. (2012). Effects of lime, phosphorus and rhizobia on Sesbania sesban performance in a Western Kenyan acid soil.

Palm, C.A., Gachengo, C.N., Delve, C.N., Cadisch, G., Giller, K. (2001). Organic inputs for *Philippines journal of crop Science (Philippines).*17 (Supplement No.1),21

Plummer, L. N. and Busenberg, E. (2014). The solubilities of calcite, aragonite, and vaterite in CO_2-H_2O solutions between 0 and 90°C, and an evaluation of the aqueous model for the system $CaCO_3$-CO_2-H_2O. *Geochim. Cosmochim. Acta*, ***46(*23)**, 1011-1040.

http://www.General Chemistry Online/ what is the reaction of limestone with water.

Pluske, W. (2005). *How lime or gypsum can improve pH or soil structure*. Farming, ahead No. 158

Poulton, C., & Kanyinga, K. (2014). The politics of revitalising agriculture in Kenya. *Development Policy Review*, *32*(s2), s151-s172.

Susanti, D., Wong, J. H., Vensel, W. H., Loganathan, U., DeSantis, R., Schmitz, R. A., ... & Mukhopadhyay, B. (2014). Thioredoxin targets fundamental processes in a methane-producing archaeon, Methanocaldococcus jannaschii. *Proceedings of the National Academy of Sciences*, *111*(7), 2608-2613.

Qureshi, J.N. (1990). The cumulative effect of fertilizers, manure and crop residues on maize and bean yields and some soil chemical properties at Kabete. Second KARI Annual Scientific Conference, Nairobi, Kenya. *www.fao.org/docrep/012/i1220e/i1220e.pdf 2013*

Rajan , S.S.S., Watkinson, J.H. and Sinclair, A.G. (1996). Phosphate rock for direct application to soils. *Adv. Agron.* 57:78-159.

Robinson , J .S., Syers, J.K., and Bolan, N.S. (1992). Influence of calcium carbonate on the dissolution of Sechura phosphate rock in soils. *Fert.Res.* 32:91-92.

Mello, M. P., Atzberger, C., & Formaggio, A. R. (2014, July). Near real time yield estimation for sugarcane in Brazil combining remote sensing and official statistical data. In *Geoscience and Remote Sensing Symposium (IGARSS), 2014 IEEE International* (pp. 5064-5067). IEEE.

Sawyer, J. E. (2003). *Soil pH and Liming*. Iowa State University, University Extension. Sciences Oklahoma State Unversity

Serafim, B.V., Danga, O. B. and Njeri , J. M. (2013). Effects of manure, lime and mineral P fertilizer on soybean yields and soil fertility in a humicnitisol in the Central Highlands of Kenya. *International Journal of Agricultural Science Research* Vol. 2(9), pp. 283-291, September 2013 Available online http://academeresearchjournals.org/journal/ijasr ISSN 2327-3321 ©2013 Academe Research Journal.

Sheahan, M.B. (2011). Opportunities in the Fertilizer and Agrochemicals sub-sector. An Expert's View about Fertilizers and Nitrogen Compounds in Kenya *2012* http://www.Fertilizersand Nitrogen Compounds in Kenya. Opportunities in the Fertilizer and Agrochemicals sub-sector 2013.

Shen, J., Li, R., Zhang, F., Fan, J., Tang, C., & Rengel, Z. (2004). Crop yields, soil fertility and phosphorus fractions in response to long-term fertilization under the rice monoculture system on a calcareous soil. *Field Crops Research*, *86*(2), 225-238.

Sherpherd, K.D., Ndufa , J.K., Ohlsson, E., Sjogren, H., and Swinkels, R. (1997). Adoption potential of hedgerow intercropping in maize based cropping systems in the highlands of western Kenya .I. Background and agronomic evaluation. *Exp, Agric.* 33, 197-223.

Shirani, H., Hajabbasi, M.A., Afyuni, M., Hemmat, A. (2002). Effects of farmyard manure and tillage systems on soil physical properties and corn yield in central Iran. *J. Soil Till. Res., 68*(2): 101-108

Smaling, E. M. A., Stoorvogel, J. J., & Windmeijer, P. N. (1993). Calculating soil nutrient balances in Africa at different scales. *Fertilizer Research, 35*(3), 237-250.

Smaling, E. M. A., Nandwa, S. M., Prestele, H., Roetter, R., & Muchena, F. N. (1992). Yield response of maize to fertilizers and manure under different agro-ecological conditions in Kenya. *Agriculture, ecosystems & environment*, *41*(3), 241-252.

Smaling, E.M.A. (1990). Two scenarios for sub-saharan. *Ceres,* 126: 19-24.

Smithson, P. (1999). Interactions of organic materials with phosphate rocks and triple soil fertility management in tropical agroecosystems: *Application of an organic resource database.Agric.Ecosyst.Environ*.83:27-42.

spectral models. *Remote Sensing and Environment*,33:183-192.

Stoorvogel, J.J. and Smaling, E.M.A., Janssen, B.H. (1993). Calculating soil nutrient balances in Africa at different scales. *I. Supra-national scale. Fertilizer Research*, 35, 227–235.

Taja, H. and Zaag, P.V. (1991). Organic residue management in the hot tropics: Influence on growth and yield of *Solanum* and maize. *Trop. Agric. (Trinidad)* Vol. 68 No.2.

Roberts, T. L. (2008, October). Global potassium reserves and potassium fertilizer use. In *INPNI 2008 Joint Annual Meeting*.

Trávník, K., Petrasek, K., Vanek, V., & Nemecek, R. (1998). The effect of long-term fertilizing and liming on soil pH and crop yields. *Rostlinna Vyroba-UZPI (Czech Republic)*.

Uchida, R., and Hue, N. V. (2000). *Soil acidity and liming. Plant nutrient management in Hawaiian soils, approaches for tropical and subtropical agriculture*. Edited by JA Silva, and R. Uchida. University of Hawaii, Honolulu, 101-111.

United States department of agriculture (USDA). Kenya Corn Production by Year (1000 MT) 2013.*www.indexmundi.com/agriculture/?country* 2013.

United States department of agriculture (USDA) (2013). Kenya Wheat Production by Year (1000 MT) 2013. Wheat plant study 2012. Online: *www.botanical-online.com.2013.*

Wokabi, S. M. (2007). *Sustainability of Maize Production in Kenya.* Kenya Agricultural Research Institute, Nairobi, Kenya.

APPENDIX

Appendix I: Maize grain yields (kg) for 2006 and 2007 seasons

Treatment	2006	2007	Mean
Control	2.05	1.75	1.9
Lime+sludge	12.25	12.5	12.375
TSP+lime	16.3	18.9	17.6
TSP+lime+sludge	21.45	21.1	21.275
TSP+sludge	10.9	11.5	11.2
Mean	12.59	13.15	12.87
	LSD	SED	CV%
			5.3
Treatments	1.082	0.486	
Year	0.685	0.307	

Appendix II: Wheat grain yields (kg) for 2006 and 2007 seasons

Treatment	2006	2007	Mean
Control	1.55	1.75	1.65
Lime+sludge	3.85	3.45	3.65
TSP+lime	11.8	11.3	11.55
TSP+lime+sludge	10.6	10.8	10.7
TSP+sludge	8.05	4.65	6.35
Mean	7.17	6.39	6.78
	LSD	SED	CV%
			8.3
Treatments	0.881	0.396	
Year	0.557	0.25	

Appendix III: Bean grain yields (kg) for 2006 and 2007 seasons

Treatment	2006	2007	Mean
Control	0.64	0.535	0.5875
Lime+sludge	1.4	1.415	1.4075
TSP+lime	3.1	3.25	3.175
TSP+lime+sludge	2.855	2.72	2.7875
TSP+sludge	1.755	1.765	1.76
Mean	1.95	1.937	1.9435
	LSD	SED	CV%
			7
Treatments	0.2156	0.0968	
Year	0.1364	0.0612	

Appendix IV: Bean biomass (Kg) for 2006 and 2007 seasons

Treatment	2006	2007	Mean
Control	18.3	16.65	17.475
Lime+sludge	27.95	30.8	29.375
TSP+lime	45.8	44.35	45.075
TSP+lime+sludge	43.3	42.95	43.125
TSP+sludge	32.35	33.8	33.075
Mean	33.54	33.71	33.625
	LSD	SED	CV%
			4.6
Treatments	2.456	1.102	
Year	1.553	0.697	

Appendix V: Wheat straw biomass (Kg) for 2006 and 2007 seasons

Treatment	2006	2007	Mean
Control	1.65	1.4	1.525
Lime+sludge	2.25	2.35	2.3
TSP+lime	4.75	4.795	4.7725
TSP+lime+sludge	4.2	4.5	4.35
TSP+sludge	2.3	2.15	2.225
Mean	3.03	3.039	3.0345
	LSD	SED	CV%
			8.5
Treatments	0.4051	0.1818	
Year	0.2562	0.115	

Appendix VI: Bean biomass (Kg) for 2006 and 2007 seasons

Treatment	2006	2007	Mean
Control	0.375	0.445	0.41
Lime+sludge	1.12	1.055	1.0875
TSP+lime	3	2.75	2.875
TSP+lime+sludge	2.475	2.395	2.435
TSP+sludge	1.425	1.55	1.4875
Mean	1.679	1.639	1.659
	LSD	SED	CV%
			6.2
Treatments	0.1623	0.0728	
Year	0.1026	0.0461	

Appendix VII: ANOVA of Grain yield for the three types of crops

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Year	1	0.2761	0.2761	0.84	0.367
Crop	2	1177.562	588.781	1788.29	<.001
Treatment	4	815.6962	203.9241	619.38	<.001
year.crop	2	1.6868	0.8434	2.56	0.094
year.treatment	4	1.5146	0.3787	1.15	0.352
crop.treatment	8	372.9933	46.6242	141.61	<.001
year.crop.treatment	8	4.8996	0.6125	1.86	0.104
Residual	30	9.8772	0.3292		
Total	59	2384.506			

Appendix VIII: ANOVA of different treatments for maize grain yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Year	1	1.568	1.568	3.32	0.098
Trtment	4	865.567	216.3918	458.46	<.001
year.trtment	4	5.827	1.4568	3.09	0.068
Residual	10	4.72	0.472		
Total	19	877.682			

Appendix IX: ANOVA of different treatments for wheat grain yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Year	1	3.042	3.042	9.72	0.011
Trt	4	297.672	74.418	237.76	<.001
year.trt	4	9.008	2.252	7.19	0.005
Residual	10	3.13	0.313		
Total	19	312.852			

Appendix X: ANOVA of different treatments for bean grain yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Year	1	0.00084	0.00084	0.05	0.836
Treatment	4	17.55453	4.38863	234.37	<.001
year.treatment	4	0.05123	0.01281	0.68	0.619
Residual	10	0.18725	0.01872		
Total	19	17.79385			

Appendix XI: ANOVA of Biomass for the three types of crops

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Year	1	0.0322	0.0322	0.04	0.846
Crop	2	13063.31	6531.653	7815.43	<.001
Treatment	4	976.7767	244.1942	292.19	<.001
year.crop	2	0.1207	0.0604	0.07	0.93
year.treatment	4	5.454	1.3635	1.63	0.192
crop.treatment	8	1074.269	134.2836	160.68	<.001
year.crop.treatment	8	9.8462	1.2308	1.47	0.209
Residual	30	25.0722	0.8357		
Total	59	15154.88			

Appendix XII: ANOVA of different treatments for maize biomass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Year	1	0.144	0.144	0.06	0.812
Treatment	4	2002.16	500.54	205.94	<.001
year.treatment	4	15.028	3.757	1.55	0.262
Residual	10	24.305	2.43		
Total	19	2041.638			

Appendix XIII: ANOVA of different treatments for wheat straw biomass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Year	1	0.00041	0.00041	0.01	0.939
Treatment	4	32.89822	8.22456	124.42	<.001
year.treatment	4	0.18662	0.04666	0.71	0.606
Residual	10	0.66105	0.0661		
Total	19	33.7463			

Appendix XIV: ANOVA of different treatments for bean stover biomass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Year	1	0.008	0.008	0.75	0.406
Treatment	4	15.98743	3.99686	376.71	<.001
year.treatment	4	0.08565	0.02141	2.02	0.168
Residual	10	0.1061	0.01061		
Total	19	16.18718			