EFFECT OF SUGARCANE BAGASSE ASH AND MANURE AMENDMENTS ON SELECTED SOIL PROPERTIES AND MAIZE (*Zea mays* L.) YIELD IN WESTERN KENYA

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented in this university or any other for the award of a degree

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This thesis has been submitted with our approval as University supervisors

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DEDICATION

This work is dedicated to my mother, Eseroni Isaiah Payo Tanga.

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ABSTRACT

Soil acidity reduces soil quality and its ability to produce high crop yields. Soils in Kakamega, Western Kenya have pH values that range from strongly acid to slightly alkaline. The soils also have poor water infiltration capacities posing high risk of degradation by erosion. These conditions have contributed to low maize yields in the area. Integrated use of sugarcane bagasse ash and decomposed cattle manure can lead to complementary effects on soil physical, chemical and biological properties favourable for crop production. The use of the amendments can also solve waste disposal problems in a useful way. The objectives of this study were to determine the effects of application of sugarcane bagasse ash, lime and manure on (i) soil pH, (ii) soil cation exchange capacity (CEC) and available phosphorus, and (iii) maize growth and yield. The study was carried out in Kakamega Western Kenya in two seasons, the short rains (September – December) of 2019 and long rains (March – July) of 2020. Treatments consisted of a factorial arrangement of three levels of manure (0, 5 and 10 t ha^{-1}) and three levels of soil conditioners (0 and 5 t ha^{-1} bagasse ash, and 2 t ha^{-1} lime) in a randomized complete block design. The plot sizes were 4.83 m x 3.47 m and three replications of treatments were used. Soil pH, cation exchange capacity, and available phosphorus were measured at the beginning, at the end of the first and second seasons. Maize growth parameters; height, number of leaves, stem collar diameter and leaf area index were measured after 50% emergence at the interval of two weeks until 120 days after planting. Maize grain yield and dry matter content were measured at physiological maturity. The collected data were analysed using SAS software version 9.2. Normality was tested using Shapiro Wilk test and means were separated using Least Significant Difference (LSD) at ($P \leq 0.05$). Results showed that interaction of 5 t ha^{-1} manure with 2 t ha^{-1} lime increased ($P < 0.05$) soil pH from 5.39 to 5.85. Bagasse ash (5 t ha^{1}) significantly increased soil available P from 25 mg kg$^{-1`}$ to 29 mg kg^{-1} whereas 10 t ha^{-1} manure increased the soil CEC from 20 C mol kg^{-1} to 20.26 C mol kg^{-1} at the end of long rain season. Maize height of 2.65 m was attained in long rain due to the interaction of 5 t ha^{-1} manure with 2 t ha^{-1} lime. Significantly higher ($P < 0.05$) maize yield of 5178.5 kg ha^{-1} was obtained from the interaction of 5 t ha^{-1} manure with 2 t ha^{-1} lime. All treatments that received amendments were significantly different from treatments with nil amendments. To conclude, there were significant differences in the selected soil, maize growth and yield parameters because of the different treatments. Therefore, the incorporation of 5 t ha^{-1} manure with 2 t ha^{-1} lime can improve soil properties, maize growth and yield. Bagasse ash application is a good choice for improving soil available phosphorus.

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LIST OF ABBREVIATIONS AND ACRONYMS

BNF	-	Biological Nitrogen Fixation
DAP	-	Di-ammonium Phosphate
FAO	-	Food and Agricultural Organization of the United Nations
ITPS	-	Intergovernmental Technical Panel on Soils
LSD	-	Least Significant Difference
masl	-	Metres above Sea Level
MoALF	-	Ministry of Agriculture, Livestock and Fisheries
NAAIAP	-	National Accelerated Agricultural Input Program
NGOs	-	Non-governmental Organizations
SBA	-	Sugarcane Bagasse Ash
SSA	-	Sub-Sahara Africa
SWSR	-	Status of the World's Soil Resources

CHAPTER ONE

INTRODUCTION

1.1 Background information

Low soil fertility is linked to continuous cultivation without crop rotation or nutrient replenishment, loss of organic matter and low soil pH (Hartemink, 2017). Soil acidity contribution to soil infertility is well recognized in Africa among other constraints that encompass pests and diseases, droughts and inferior cultivars. Soils in Kakamega are classified predominantly as Acrisols, Nitisols and Ferralsols. They are strongly weathered with low pH, low cation exchange capacities and a base saturation of less than 50% (FAO, 2015). The pH of the soils range from 4.18 to 6.09 with the most limiting nutrients being phosphorus, potassium, calcium, and nitrogen (NAAIAP, 2014). Maize (*Zea mays*. L) yields of 1.87 t ha^{-1} are obtained which is low compared to a potential of 6.0 t ha^{-1} (Munialo *et al.*, 2019; Food and Agriculture Organization of the United Nations, 2020). Maize (*Zea mays* L.) is Kenya's staple crop (Muchena & Gachene, 1988). It grows best in well drained nutrient rich soils with pH ranging from 5.5 and 7.0. The use of inorganic fertilizers and lime to amend soil acidity, improve soil fertility and increase crop yields is still low with about 7% of the farmers applying lime in Western Kenya (Kenya market trust, 2019). The potential of using locally available sugarcane bagasse ash as soil conditioner and decomposed cattle manure as an amendment for acid soils in production of maize in Western Kenya have not been explored.

Sugarcane bagasse is a voluminous by-product in the sugar mills when juice is extracted from the cane. It is generally used as a fuel to fire furnaces in the same sugar mill and it yields about 8-10% ash (Sultana *et al.*, 2015). Sugarcane bagasse ash contains high amounts of un-burnt matter, silicon, aluminium, iron and calcium oxides. Its application to soil leads to an effective increase of soil pH because of the presence of high calcium oxides and carbonates in the sugarcane boiler ash (Das *et al.*, 2013). Sugarcane bagasse ash has high amounts of basic cations including Ca, Mg, K and P that can increase soil fertility. It has ability to modify soil moisture content, aeration and microbial activities (Islami *et al.*, 2017).

Application of sugarcane bagasse ash in combination with farm yard manure add nutrients directly to the soil and improve soil conditions, availing favourable environment for crop growth through better soil aeration, root activity and nutrient absorption (Reddy *et al.*, 2017). Farmyard manure refers to the decomposed mixture of dung and urine of farm animals along with their litter and left over material from roughages or fodder fed to the cattle. Farmyard manure can be easily accessed by farmers because 53.2% of the population of Kakamega County, Kenya rear cattle (MoALF, 2017) and their droppings can be decomposed for crop production. Farmyard manure has the capability to improve, maintain and sustain soil physical and chemical properties therefore supporting crop production. Application of manure can result to improved soil organic matter content, soil structure, soil water holding capacity, increased microbial activities and modification of soil cation exchange capacity (CEC), hence maintaining and sustaining soil properties for improved crop production (Thind *et al.*, 2016). Sugarcane bagasse ash, lime and manure are all soil conditioners due to their potential to improve soil quality and remedy its degradation, but manure is an excellent fertilizer among them because it contains all the primary macro nutrients which are nitrogen, phosphorus and potassium. Integrating the use of these amendments while using manure as a fertilizer, sugarcane bagasse ash and lime as soil conditioners can sustainably improve soil fertility and enhance crop growth and yield.

1.2 Statement of the problem

Soil acidity when ignored can limit crop production resulting in poor crop yield and quality even when high external input agriculture which uses inorganic fertilizers is used. Soils of Western Kenya are predominantly acidic, and deficient in nitrogen, phosphorus, and potassium. When soil pH is below 5.5 phosphorus is precipitated and becomes unavailable. Similarly, hydrogen and aluminium ions become toxic and may cause injuries to the plant's roots. These conditions have negative effects on plant nutrient availability, hindering maize production. The current maize yield in the study area is 1.8 t ha^{-1} in spite of the potential yield of 6.0 t ha^{-1}. This study assessed the effectiveness of the integrated use of bagasse ash and lime as soil conditioners and decomposed cattle manure as a fertilizer in amending soil pH, available P, cation exchange capacity, and maize growth and yields.

1.3 Objectives

1.3.1 General objective

To contribute to food security by enhancing soil fertility and maize yield through the use of bagasse ash and lime as soil conditioners and decomposed cattle manure in Western Kenya.

1.3.2 Specific objectives

(i) To determine the effect of bagasse ash and lime as soil conditioners and decomposed cattle manure application levels on soil pH in the field.

(ii) To determine the effect of bagasse ash and lime as soil conditioners and decomposed cattle manure application levels on soil available phosphorus and soil cation exchange capacity in the field.

(iii) To determine effect of bagasse ash and lime as soil conditioners and decomposed cattle manure application levels on maize growth and yields.

1.4 Hypotheses

(i) Bagasse ash and lime as soil conditioners and decomposed cattle manure applied at different levels have no significant effect on soil pH in the field.

(ii) Bagasse ash and lime as soil conditioners and decomposed cattle manure applied at different levels have no significant effect on soil available phosphorus and soil cation exchange capacity in the field.

(iii) Bagasse ash and lime as soil conditioners and decomposed cattle manure applied at different levels have no significant effect on maize growth and yields.

1.5 Justification

Low soil productivity problems are attributed to several factors but the major yield limiting factors are nutrient depletion, and soil acidity. Soil acidity, a soil condition resulting from low pH influences the availability of nutrients and their uptake by plants. Low pH soils lead to Aluminium toxicity and inhibit crop root growth, precipitates phosphorus rendering it unavailable for plants and molybdenum becomes deficient, limiting the functioning of soil microorganisms. On the other hand, nutrient depletion lead to low soil productivity as essential nutrients needed to support crop growth and yield become deficient. Soils in Kakamega are predominantly Acrisols, Ferralsols and Nitisols with the first two being inherently acid soils. While maize is the staple crop in this area, it is very sensitive to soil acidity. Maize is the most important crop in the Country with production area ranging from 2 to 2.4 million ha over the past five years. Its production ranges from 2.95 to 4 million metric tonnes. These productions however are deficit compared to the national requirement of 4.2 million metric tonnes. Hence there are annual imports of approximately 1 million metric tonnes to cover the gap. There is a need to find alternatives to amend the soil to an optimum pH that can optimize the production of this crop. The use of bagasse ash and lime as soil conditioners and decomposed cattle manure as a fertilizer would be a good choice to research on because bagasse is being produced in West Kenya sugar factory and would be easily accessible to the farmers, while lime is readily available in the market. Approximately an average of 2.4 million tonnes of bagasse is being produced by sugar mills in Kenya of which 25% (approximately 6 hundred thousand tonnes) is being used for cogeneration of heat and 10% (approximately 59868 tonnes) of ash produced and disposed. Utilizing the ash as soil amendments would minimize disposal issues. Similarly, decomposed cattle manure is being produced within as some of the farmers keep cattle and could be available to the small household farmers. In Kakamega County, the number of cattle kept by farmers per square kilometre range from 50 to 100 animals. However, few farmers utilise manure from these animals for the production of maize and cash crops like tea. These organic wastes such as sugarcane bagasse ash have high number of basic cations, phosphorus and micronutrients and can raise soil pH to optimum level that can support maize growth. Similarly, decomposed cattle manure contains macro and micronutrients, organic carbon and nitrogen, can improve soil physical, chemical and biological properties necessary for crop production. The use of sugarcane bagasse ash and lime as soil conditioners and decomposed cattle manure as fertilizer in an integrated way can render the amendments complimentary to each other. The low amount of nitrogen and organic carbon in sugarcane bagasse ash can be catered for in decomposed cattle manure while sugarcane bagasse ash high amounts of basic cations and phosphorus can lead to a quick realization of improvement in the soil chemical and physical properties, and lime can reduce soil acidity for improved absorption of nutrients found in the manure and soil. This can intern be sustainable amendment as both short term and long term effects due to the residual effects of decomposed cattle manure.

CHAPTER TWO

LITERATURE REVIEW

2.1 Soil fertility status and crop growth

Soil fertility is a term commonly used to indicate the potential of a soil to grow a crop or a series of crops whereas the productivity of a soil is the combined result of fertility and management (Finch *et al*., 2014). The low productivity in the agricultural sector of many parts of Sub-Saharan African countries is largely attributed to low and decreasing soil fertility due to many factors such as soil erosion, continuous cropping, soil acidity and inadequate sustainable soil fertility management (Nduwumuremyi *et al*., 2014). The exhaustion of nutrients in soil is raising alarm due to its direct connection to food insecurity in developing and least developing countries. In sub-Sahara Africa, soil fertility exhaustion has been recognized for deteriorating food production, with the original fertile soils crop yields scarcely sustaining the increasing population (FAO, 2015). Meanwhile, maize as a staple crop grows best in well drained, nutrient rich soils with pH 5.5 and 7.0 and has low tolerance to high acid soils (NAAIAP, 2014). In Kenya, main causes of low and declining maize yields are soil acidity, nutrient deficiencies and droughts. Low availability of water and nutrients within Agro-ecosystem inhibit soil crop productivity (Bashir *et al*., 2016). The unpredictable changes in weather which lead to delayed rainfall and frequent droughts during the long rains seasons cause moisture stress of maize in the field (MoALF, 2017). Inadequate moisture in the soil and in the maize plant reduces nutrient availability and plant uptake resulting in nutrient deficiencies, poor growth, low yields and failure of the soil to produce adequately. Improving or maintaining soil fertility at an adequate level is fundamental to produce maximum economic yield of crops on acid soils (Fageria & Nascente, 2014). The use of soil amendments, manures, and other organic wastes initiate improvement of soil fertility and plant nutrients (Cellier *et al*., 2013). Integrating the use of soil amendments and manure can supply essential nutrients for plants and act as soil moisture conservation strategies.

2.1.1 Soil reaction and crop growth

The term ‘reaction’ describes the degree or condition of acidity, alkalinity or neutrality whereas acidity and alkalinity are expressed by a pH scale on which pH 7 is neutral, numbers below 7 indicate acidity and those above 7 alkalinities (Finch *et al*., 2014, p. 37 - 62). The optimum pH for mineral soils where arable crops is grown is 6.5 and for continuous grass and clover swards the figure is 6.0 (FAO & ITPS, 2015; Finch *et al*., 2014). Toxic concentrations of H and Al occur when the pH drops below 5.5 on the other hand values of pH above 7.2

indicate an alkaline reaction and may be symptomatic for the immobilization of nutrients (FAO & ITPS, 2015). Very high pH values over 8.5 result in the dispersion of the soil particles and a collapse of structure. High rainfall results in more acid soils (Ferralsols/Oxisols, Alisols, Plinthisols, Acrisols/ Ultisols, Podzols/Spodosols), while drier conditions often lead to the accumulation of Gypsum (Gypsisols/ Gyspsids) or other less soluble salts (Silicon and Calcium Carbonate) in Durisols/Durids and Calcisols/Calcids (FAO & ITPS, 2015; Jaetdzold *et al.*, 2010). The soil pH is also important to the characterization of soil threats to ecosystem services such as acidification and sodification (FAO & ITPS, 2015).

Soil acidification management involves both neutralization of soil acidity and regulation of the acidification of limed soil (FAO & ITPS, 2015; Finch *et al.*, 2014; Karcauskiene *et al.*, 2019). The pH level in agricultural soils is strongly influenced by the fertilizers and pesticides applied, crops grown and their sequence in a crop rotation, as well as by tillage intensity (FAO, 2008). Most farm crops will not grow satisfactorily if the soil is very acidic. In acid conditions aluminium, iron and manganese become more readily available. Excessive uptake of aluminium in acid conditions can severally affect crop growth while some crops are more affected than others. This can be remedied by applying one of the commonly used liming materials (Finch *et al.*, 2014). Liming materials alter the mobility of some biogenic elements and their build up in the soil and the reaction of lime with soil to release calcium and/or magnesium ions into the soil solution leads to increase in soil pH and the reduction in exchangeable aluminium ions due to precipitation of H^+, Al^{3+}, Fe^{3+} and Mn^{4+} ions (Kisinyo *et al.*, 2013). Liming in combination with farmyard manure is more efficient for acidity indicators than its application alone and reduces the amount of mobile aluminium to a level that is not toxic to plants (Karcauskiene *et al.*, 2019). However, the long term field experiment to determine the stabilizing effect of farmyard manure on soil pH was not proved and after 14 years of farmyard manure application pH decreased at all the sites (Vašák *et al.*, 2016). The application of ash at the rates 3 to 5 tonnes per hectare decreased soil acidity, increased base saturation and the total amount of nutrients except N, in the surface layer of about 15 cm (Hale *et al.*, 2020; Huotari *et al.*, 2015).

2.1.2 Phosphorus in soils and plants

Phosphorus is found in rocks, soil, plant and animal tissues or as manufactures and is an essential macro nutrient, required for plant nutrition (Ghosh *et al.*, 2015; Robles, 2014). Phosphorus occurs in soil in several inorganic and organic forms; inorganic phosphorus includes apatitic minerals, secondary precipitates (formed with Ca, Fe and Al) and free phosphate ions ($H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-}) attached to sorption surfaces or dissolved in the soil water whereas organic phosphorus includes a group of organic molecules having P as a part of their structure (Shen *et al*., 2011; Yadav *et al*., 2012). The organic and inorganic (mineral) forms of P found in soils always have low solubility (Sims *et al*., 2005). Phosphorus plays very important roles in the synthesis of nucleic acid, membrane build up and stability; it participates in metabolic processes (photosynthesis, energy transfer and synthesis and breakdown of carbohydrates) and many other essential physiological and biological processes during plant growth and development (FAO & ITPS, 2015; Lambers *et al*., 2015; Lyu *et al*., 2016). Large amounts of P naturally exist in organic and mineral forms in many types of soils (Khan *et al*., 2014); on the contrary, the amount of readily available phosphorus is very low compared with the total amount of phosphorus in the soil; making P nutrition a major limiting factor for crop production in many soils due to relatively low P availability; as P can be readily adsorbed or fixed by free lime present in some calcareous soils and by aluminium (Al) and iron (Fe) in acid soils (Hinsinger, 2001; Shen *et al*, 2011). Therefore, in these cases phosphorus fertilizers specifically animal manure and plant residues that add organic matter and release available P upon decomposition should be applied in order to meet crop P nutrient requirements (Garg & Bahl, 2008; Maranguit *et al*., 2017).

The forms of phosphorus are determined by anthropogenic biotic and abiotic processes (Maranguit *et al*., 2017) since then, the type of P compounds that exist in the soil are mostly determined by soil pH (Zhu *et al.,* 2017) and by the type and amount of minerals in the soil. Mineral compounds of phosphorus usually contain aluminium, iron, manganese and calcium and in acidic soils phosphorus tends to react with aluminium, iron and manganese while in alkaline soils the dominant fixation is with calcium (Roberts & Johnson, 2015; Yadav & Verma, 2012). The optimal pH range for maximum phosphorus availability is 6.0 - 7.0.

In many soils decomposition of organic material and crop residue contributes to available phosphorus in the soil (FAO & ITPS, 2015; Garg & Bahl, 2008). Plants take up phosphorus from the soil solution as orthophosphate ion: either HPO_4^{-2} or H_2PO_4 (FAO, 2008). The proportion in which these two forms are absorbed is determined by the soil pH, when at higher soil pH more HPO_4^{-2} is taken up. The mobility of phosphorus in soil is very limited and therefore, plant roots can take up phosphorus only from their immediate surroundings. Since concentration of phosphorus in the soil solution is low (Lessl & Ma, 2013), plants use mostly active uptake against the concentration gradient (i.e. concentration of phosphorus is higher in the roots compared with the soil solution). Active uptake is an energy consuming process, so conditions that inhibit root activity, such as low temperatures, excess of water etc., inhibit phosphorus uptake as well (FAO, 2008).

Plants can only take up phosphorus dissolved in the soil solution (Sims *et al.*, 2005), and since most of the soil phosphorus exists in stable chemical compounds (Khan *et al.*, 2014), only a small amount of phosphorus is available to the plant at any given time. When plant roots remove phosphorus from the soil solution (Lugli *et al.*, 2019), some of the phosphorus adsorbed to the solid phase is released into the soil solution in order to maintain equilibrium. The most important factors controlling the availability of P to plant roots are its concentration in the soil solution and the P buffer capacity of the soil (controls the rate at which P in the soil solution is replenished); on the other hand the size of the root system and the extent to which roots grow into the soil and the efficiency with which roots take up P (FAO, 2008).

Symptoms of phosphorus deficiency include stunted growth and dark purple colour of older leaves, inhibition of flowering and root system development and reduced biomass (Carstensen *et al.*, 2018; Malhotra *et al.*, 2018). In most plants these symptoms will appear when phosphorus concentration in the leaves is below 0.2% (Malhotra *et al.*, 2018). Excess of phosphorus mostly interferes with uptake of other elements, such as iron, manganese and zinc (Malhotra *et al.*, 2018). Over-fertilization with phosphorus is common and many growers apply unnecessarily high amounts of phosphorus fertilizers, especially when compound NPK fertilizers are used or when irrigation water is acidified using phosphoric acid.

2.1.3 Soil cation exchange capacity

The cation exchange capacity of clay or clay minerals can be defined as the quantity of cations available for exchange at a given pH (Bergaya *et al.*, 2013). It is always determined at a neutral pH 7 and can be expressed in meq/100g or c mol kg^{-1} (Bergaya *et al.*, 2013; Christidis, 2013).

The cation exchange capacity of a soil with a declining content of basic cations can decrease, and this can happen over a longer period (Curtin *et al.*, 2015; Lu *et al.*, 2014). The decrease in soil cation exchange capacity is influenced by factors that include reduction in soil organic carbon content that results from practices such as overgrazing and cultivation (Babel *et al.*, 2014; Mu *et al.*, 2013; Yu *et al.*, 2012). Soil organic carbon has a great influence on soil cation exchange capacity and when it declines, may have negative impacts due to the following reasons: (1) the dissociation of some functional groups for instance carboxyl and phenolic hydroxyl that decreases with the decrease in soil organic carbon. As a result, the amount of negative charge possessed by humus is reduced and this weakens the complexation of the humus with exchangeable base cations (Brady & Weil, 2002; Chapin *et al*., 2011). (2) The cation bridging (for example Ca^{2+}, Fe^{3+}, and Al^{3+}) between clay minerals and humus can decline due to a reduction in soil organic carbon, making humus clay mineral complexes unstable (Brady & Weil, 2002; Mueller *et al*., 2012; von Lutzow *et al*., 2006). Consequently, the protection for soil organic matter against decomposition becomes weak and causes the decrease in cation exchange capacity of the soil. Similarly, reduction in soil cation exchange capacity can also be caused by soil acidity and this as a result of the reduction in soil base saturation in acid soils (Yang *et al*., 2012). An increase in the amount of soil organic carbon in the soil increases the soil cation exchange capacity suggesting that soils rich in organic matter have high cation exchange capacity (Gruba & Mulder, 2015; Lu *et al*., 2014; Tůma *et al*., 2011).

2.2 Maize production in Kenya

Maize is Kenya's most important food crop. Other major crops include common bean (*Phaseolus vulgaris* L), sorghum (*Sorghum bicolor*), cowpea (*Vigna unguiculata*), wheat (*Triticum aestivum*), pigeon pea (*Cajanus cajan*), potato (*Solanum tuberosum*), tea (*Camellia sinensis*), millet (*Panicum miliaceum*), coffee (*Coffea arabica*), other pulses and oilseeds, among others. Maize production has been fluctuating in Kenya over the past five years. The highest production was in 2016 on an area of 2.34 million ha and production of 3.339 billion kilogrammes while the lowest in 2017, an area of 2.09 million ha and a production of 3.186 billion kilogrammes (FAO, 2020 a). In spite of its huge importance for food security and economic wellbeing of the country, the productivity and production have not shown significant improvements over the years. The yield is estimated at 1622 kilogrammes per hectare, with average production of nearly 3.5 billion kilogrammes. The Increases in maize production in 2016 resulted from area expansion rather than from increases in productivity.

2.2.1 Maize production in Kakamega County

The main crops grown in Kakamega are: maize, bean, sweet potato, cassava, sorghum, finger millet, local vegetables, rice, tea and sugarcane. Maize meal forms the staple food for the county. The area under maize production in the county is 83,235 ha and the yield 261 million kilogrammes (Planning, 2018). Maize production in Kakamega decline due to factors that encompass low soil fertility, drought and weed infestation. The low soil fertility is related to the types of soils. The predominant types of soils are Acrisols, Ferralsols and Nitisols, but the first two are more infertile. Experimental trials conducted at Kakamega showed that, maize yield was highest in Nitisols 3.6 t ha^{-1} and lowest in Acrisols 2.1 t ha^{-1} when inorganic fertilizers were used as soil amendments (Ngome *et al.*, 2013). In addition, about 0.9 million hectares of land in western Kenya including the experimental site Kakamega are acidic with pH < 5.5 causing high phosphorus deficiencies. This has led to low levels of maize production with crop yield below 1 t ha^{-1} from small holder farms (Rao *et al.*, 2015). The current maize yields hardly reach 1 t ha^{-1} are significantly low compared to the potential yields of 6 t ha^{-1} from research stations where there are sufficient management practices (Munialo *et al.*, 2019).

2.3 Soils in Western Kenya and their characteristics

The predominant soil types in Western Kenya including the experimental site Kakamega include the Acrisols, Ferralsols, and Nitisols (Jaetzold *et al.*, 1982; NAAIAP, 2014). Acrisols are soils with an argic horizon starting ≤ 100 cm from the soil surface; a cation exchange capacity (by 1 M NH_4OAc, pH 7) of < 24 c mol kg^{-1} clay in some part of the argic horizon within ≤ 50 cm below its upper limit; and an effective base saturation [exchangeable (Ca + Mg + K + Na) / exchangeable (Ca + Mg + K + Na + Al)]; exchangeable bases by 1 M NH_4OAc (pH 7), exchangeable Al by 1 M KCl (unbuffered) of < 50%: in half or more of the part between 50 and 100 cm from the mineral soil surface; or at least in the lower half of the mineral soil above continuous rock, technic hard material or a cemented or indurated layer starting ≤ 100 cm from the mineral soil surface (IUSS Working Group WRB, 2015). Ferralsols are mineral soils with a ferralic horizon starting ≤ 150 cm from the soil surface; with no argic horizon starting at the upper limit of the ferralic horizon or above the ferralic hroizon, unless the argic horizon has, in its upper 30 cm, one or more of the following: a. < 10% water dispersible clay; or b. geric properties; or c. ≥ 1.4% soil organic carbon (Jaetzold *et al.*, 1982; IUSS Working Group WRB, 2015). Nitosols develop on tertiary and even older basic igneous rocks (like basalts, tuffs etc.) and contain emerging argillic horizons with prominent shiny clay skins. They are soils with normally high fertility due to high contents of montmorillonites (as dominating clay minerals), minerals and available soil water as well as a high cation exchange capacity (IUSS Working Group WRB, 2015; Jaetzold *et al.*, 1982; United Nations Environment Programme, 2019).

2.4 Soil conditioners definition and importance

Soil conditioning refers to any process which can increase the capacity of a soil to enhance the yield of crops, or which can improve the performance of a soil for any function. This implies that, any product that is used for soil conditioning is known as a soil conditioner.

Therefore, a soil conditioner can be defined as any material that contains limited amount of nutrients, but are managed primarily for their beneficial impacts on the biological, physical or chemical nature of the soil (Shinde *et al*., 2019). The definition of soil conditioners indicates that, they encompass many kinds of organic materials, gypsum, lime, natural deposits, various water-soluble polymers and cross-linked polymers that hold water in soil, living plants, microbes, many industrial waste products and others (Mukherjee, 2013; Shinde et al., 2019). Now days we can see an overabundance of fertilizers and more focus on the chemical inputs but we often ignore the soil conditioners and soil amendments (Shinde *et al*., 2019). Soil needs conditioning for a number of reasons. One vital need is to control soil degradation; another is to improve soil air - water relations, soil drainage and soil aggregation; to reduce soil crusting and compaction, to overcome water repellence and etc. (Mukherjee, 2013; Shinde *et al*., 2019). When considering the role and function of soil conditioners in crop production, it is important to realize that many soil properties may be affected, either favourably or adversely, by the addition of such materials to the soil. Some of the soil properties that can be influenced by the addition of materials to the soil include: (i) water holding capacity, (ii) aeration, (iii) temperature, (iv) nutrient holding capacity and availability, (v) cation exchange capacity (CEC) (vi) structure and aggregate stability, (vii) microorganism population and behaviour, (viii) organic matter chemistry, and (ix) animals, including insect and pest.

According to Shinde *et al*. (2019) the importance and function of soil conditioner include the followings: (i) Soil conditioners improve the physical, chemical and biological properties of the soil. (ii) In problematic soils such as acidic or alkaline soils it helps in maintaining the soil pH. (iii) In dry and sandy soils, soil conditioners improve the water retention capacity, infiltration, percolation and permeability of water. (iv) Soil conditioners create a healthy environment in soil which helps to attract useful microorganisms and earthworms in soil. (v) Soil conditioners improve the physical properties resulting in better soil aeration, water retention, root development and soil ecosystems. (vi) Soil conditioners can be used to improve poor soils, or to rebuild soils which have been damaged by improper soil management. (vii) They also add nutrients, enriching the soil and allowing plants to grow healthier, stronger and yield more. Soil becomes compressed over time and it has less air space. (viii) The use of soil conditioner helps in reducing the soil compaction and hard pan problem. (ix) It increases the soil fertility and helps to maintain soils in good condition.

This study integrates the use of sugarcane bagasse ash and lime as soil conditioners and decomposed cattle manure as fertilizer amendments in low pH and P deficient soil of Kakamega Western Kenya under maize field cultivation, and their effects on the selected soil properties, maize growth and yield determined. Manure is being used as fertilizer since it contains all the primary macronutrients N, P, and K whereas, the ash always have inadequate N and lime has nil primary macronutrients.

2.5 Sugarcane bagasse production and uses in Kenya and Western Kenya

The key solid wastes and by-products from the Kenya sugar factory processing plants include bagasse, and filter or press mud. Bagasse is cane milling waste fibre matter whose content is about 33 to 34 % of the cane. According to records, 12 sugarcane factories in Kenya produced approximately 1.7 to 2.8 billion of bagasse as recorded for 5 years 2013 to 2017 (United Nations Environment Programme, 2019) with an annual average of 23.9 billion kilogrammes. A three years data record for sugarcane bagasse production, utilization and disposal indicates that Mumias sugar factory produced an average of 8.9 hundred million kilogrammes, utilized 6.4 hundred million kilogrammes for power cogeneration and dumped 2.5 hundred million kilogrammes while Muhoroni sugar factory produced an average of 1.48 hundred million kilogrammes, used 1.1 hundred million kilogrammes power cogeneration and dumped 37 million kilogrammes of sugarcane bagasse over the period from 2003 to 2006 (Kabeyi *et al*., 2020). Sugarcane bagasse is generally used as a fuel to fire furnaces in the same sugar mill and it yields about 8 - 10% ash (Sultana *et al*., 2015) from the bagasse. Approximately an average of 24 million kilogrammes of bagasse is being produced by sugar mills in Kenya (United Nations Environment Programme, 2019), of which 25% (6 hundred million kilogrammes) is being used for cogeneration of heat and 10% (59 million kilogrammes) of ash produced and disposed.

2.6 The effects of sugarcane bagasse ash on soil properties, crop growth and yield

Sugarcane milling by products can influence soil chemical properties that encompass soil pH (Huotari *et al*., 2015; Pita *et al*., 2012), Soil cation exchange capacity (CEC) (Ferreira *et al*., 2012), and carbon content (Benbi *et al*., 2017). Sugarcane by products such as boiler ash increase soil pH thus increasing soil cation exchange capacity and the carbon content of the soil (Benbi *et al*., 2017; Ferreira *et al*., 2012; Pita *et al*., 2012). However, they do not improve Nitrogen and Phosphorous availability due to their lower contents of those nutrients (Huotari *et al*., 2015; Islami *et al*., 2017; Thind *et al*., 2012). On the other hand, the application of bagasse ash at the rate 250 t ha^{-1}in a calcareous soil resulted in a high increase in the amounts of phosphorous and potassium in the soil under wheat field cultivation (Khan & Qasim, 2008). The effect of ash on soil nutrients such as potassium and phosphorus vary with the material from which the ash is obtained (Hale *et al*., 2020). The application of ash at the rates 3 to 5 tonnes per hectare can decrease soil acidity whereas increase base saturation and the total amount of nutrients (Hale *et al*., 2020; Huotari *et al*., 2015).

Bagasse ash contains micronutrients, secondary macronutrients (magnesium and calcium) and primary macronutrients P and K (Benbi *et al*., 2017; Hale *et al*., 2020; Huotari *et al*., 2015; Khan & Qasim, 2008). The high amount of calcium or magnesium displaces aluminium from the exchange site and makes it form precipitates like Al $(OH)_3$. Furthermore, the major role of calcium in soils and plants in addition to being an essential nutrient is to exclude or detoxify other elements such as Al, Mn and heavy metals that might become toxic (Fageira & Moreira, 2011). This could be one of the reasons for increase in soil pH when sugarcane bagasse ash is applied. Hence with the precipitation of Al, crop root growth is promoted (Gonfa *et al*., 2018). The main Al toxicity symptom is inhibition of root elongation with simultaneous induction of β-1, 3-glucan (callose) synthesis with extensive root injury that leads to poor ion and water uptake and a sequence of toxicity at the root meristem causing injury at the root tip by decreasing mitotic activity in the plant hence shortening the region of cell division especially in maize (Fageira & Moreira, 2011).

In a study that included the use of ash from different sources (sugarcane bagasse ash, fly ash and rice husk ash) ash had the capacity to lower the soil bulk density and microbial biomass in the soil (Benbi *et al*., 2017). The increment in the microbial biomass and decrease in soil bulk density was dependent on the source of ash (sugarcane bagasse ash, fly ash and rice husk ash) and a significant improvement resulted from the application of sugarcane bagasse ash (Benbi *et al*., 2017; Ferreira *et al*., 2012). Sugarcane bagasse ash, due to its influence on soil properties and nutrient availability may lead to improved growth, development and increased yield of crops. The application of sugarcane bagasse ash resulted in a significant increase of maize shoot biomass and yield (Pita *et al*., 2012). This increase could be as a result of the liming effect of ash that raises soil pH in addition to cation exchange capacity and base saturation of the soil to satisfy crop growth and yield (Ingerslev *et al*., 2014). Additionally, ash contains biogenic elements necessary for the proper growth of plants and can supplement deficiencies of micro and macro nutrients in soils (Saletnik *et al*., 2018). Similarly wheat root length and grain yield (Gonfa *et al*., 2018), significantly increased due to the application of sugarcane bagasse ash.

2.7 Effects of integrated use of ash and farmyard manure on crop growth, yield and soil properties

The application of ash in combination with farm yard manure add nutrients directly to the soil and improve soil conditions, availing favourable environment for crop growth through better soil aeration, root activity and nutrient absorption (Reddy *et al*., 2017). Similarly liming in combination with farmyard manure is more efficient for acidity indicators than its application alone and reduces the amount of mobile aluminium to a level that is not toxic to plants (Karcauskiene *et al*., 2019). Furthermore, the combined application of farmyard manure and ash or farmyard manure combined with gypsum or lime can result into maximum maize grain yield (Kaur *et al*., 2019). On the other hand, integrating the use of ash and farmyard manure at the rates 10 t ha^{-1} ash in combination with 10 t ha^{-1} farmyard manure and 15 t ha^{-1} ash in combination with 10 t ha^{-1} farmyard manure can increase the available nutrient status (N, P, K, S, Fe, Mn, Cu, and Zn) in the soil and also grain and straw yields in crops such as rice (Reddy *et al*., 2017). Similar to the increases in nutrient contents, incorporation of manure and ash in acid soils can have liming effects through the increase of soil pH and the improvement of soil properties like the soil organic matter content and water holding capacities (Bougnom *et al*., 2011). The integration of ash with inorganic fertilizer and farm yard manure can lead to high crop growth and yield which is attributed to the potential of this combination to provide conducive physical environment (better aeration, moisture holding capacity) promoting root activity and nutrient absorption as a consequence of the complementary effect of ash and farmyard manure (Das *et al*., 2013; Lal, 2015).The incorporation of ash with farmyard manure or chemical fertilizers can increase soil micro and macro nutrients due to their effects on the physicochemical properties of soil (Singh *et al*., 2017). The integrated use of organic (farmyard manure) and inorganic (NPK) fertilizers can substantially increase crop growth (height, roots and shoot) and yield as the result of increased nutrient uptake (Masood *et al*., 2013; Otieno *et al*., 2018).

2.8 The effects of farmyard manure on soil properties

Manure incorporation is considered as a primary substrate for replenishment of soil organic matter and can be regarded as an alternative way of adding nutrients to increase soil fertility and crop productivity (FAO & ITPS, 2015). Manure helps in providing carbon and carbon compounds to the soil and it is an organic material that helps build and fortify the structure of soil as an important role that cannot be played by any other fertilizer (FAO, 2020 b). Farmyard manure increases soil water content, improves nutrient availability, and contributes to the protection of soil from erosion (Agyarko *et al*., 2006; Bayu *et al*., 2006; FAO, 2020b; Khan & Qasim, 2008). Soil organic matter supplied by manure on the other hand is an important component of soil quality as it determines many soil characteristics such as nutrient mineralization, aggregate stability, aeration, and favourable water uptake and retention properties (Ademba *et al*., 2015; Cellier *et al*., 2013; Opala *et al*., 2009; Otieno *et al*., 2018). Organic matters not only increase the water holding capacity of the soil but also the portion of water available for plant growth and improves physical properties of soil (FAO, 2015). Farm yard manure applications significantly increased total N, available P, and exchangeable K contents of the soil, organic carbon content while it served as source of nutrients and also as a substrate for decomposition and mineralization of nutrients thereby creating favourable conditions for proliferation of microbes in the soil (Thind *et al*., 2016). The amount of available organic manure is not enough to provide the actual nutrient requirements of crops in many African regions on the other hand the little produced are misused as a result of minimal technical skills (Abbas, 2016). In South Africa for instance, 3 million tonnes of animal manure are being produced every year which is enough to supply about 13.3% N, 27.6% P and 9.9% K of the soil nutrient need, but only 25% is used on the soil while the remaining is not used as a result of management constrictions (Harris, 2002; Okorogbona & Adebisi, 2012). Moreover, nutrient mining has continued to deplete African farmlands of about 8 million tonnes of soil nutrients per year, an annual loss valued at over USD 4 billion (Toenniessen *et al*., 2008). This implies that there is a dire need to find all reasonable means of using the available resources like the manure in an effective and efficient way through research.

2.9 Use of farmyard manures in field crop production

Cattle manure is one of the natural materials used as an organic amendment among other materials that include poultry manure, household wastes, crop residues, compost etc. (Ngetich *et al*., 2012). Organic fertilizers improve the physical structure and biochemical activity level of the soil as well as supplying plant essential nutrients through gradual decomposition of the organic matter; in this way regulating the rate at which organic matter is being added and built up hence causing a balance of organic matter content in the soil (Morris *et al*., 2007). However, the challenge of its availability, management and cost have decreased its use among sub-Saharan African smallholder farmers (Ndambi *et al.,* 2019).

Unfortunately, some African soils lack essential nutrients for example in Uganda, Kenya and Tanzania low yield of crops are attributed mainly to poor soil fertility (Keino *et al*., 2015). For instance, Zn is deficient in most West African soils, especially the lowland areas

(Abe *et al.*, 2010) while plant viable P is unavailable in the iron rich tropical soils of Africa due to low pH and high level of iron and aluminium oxides (de Valença & Bake, 2016). Similarly, 80% of smallholder farmlands for maize cultivation in Kenya are extremely deficient in P (Tittonell *et al.*, 2008).

Manure is a major source of plant nutrients in the soil including phosphorus as well as sulphur and is a primary source of nitrogen for most plants (Ademba *et al.*, 2015; Okorogbona & Adebisi, 2012; Thind *et al.*, 2016). In a study done by Bayu *et al.* (2006) in a semi-arid area of Ethiopia, it was reported that farmyard manure applied at the rates 10 and 15 t ha^{-1} has the potential to increase dry matter production during post anthesis and grain filling (by 74 and 90%) in sorghum crop. The increase in crop growth and yield when manure is applied is attributed to the slow release and constant supply of nitrogen and phosphorus by manure which might lead to increased leaf area duration and the increase in the rate of photosynthesis during grain filling (Ademba *et al.*, 2015; Bayu *et al.*, 2006; Opala *et al.*, 2009). The addition of farmyard manure to rice significantly increased the grain and straw yield of subsequent wheat crop. This also lead to an increase in uptake of total nitrogen from 29 to 32%, phosphorous from 29 to 33% and potassium from 27 to 49% of wheat in the following years due to the residual effect (Thind *et al.*, 2016). When farm yard manure was applied directly in wheat field, the results showed that, there were significant increases in the straw yield, grain yield and harvest index of wheat at high rates of application compared to the lower rates (Lemanowicz *et al.*, 2014).

Like other crops such as sorghum and wheat dry matter production by maize in response to fertilizers and manure is attributed to the fact that maize depends on P fertilizer at its early stages of growth; this might stimulate root proliferation and acquisition of nutrients for growth (Jacob *et al.*, 2014). In an experiment that was carried out by Mohanty *et al.* (2006) to examine phosphorus uptake in maize due to application of organic fertilizers: farmyard manure, poultry manure, vermicompost, sewage sludge, inorganic phosphorus (single superphosphate) fertilizers and no amendments, they concluded that organic fertilizer had significant direct and residual effect compared to the inorganic single superphosphate on biomass P content and uptake in corn. Farmyard manure residual effect on corn was more pronounced than any other organic fertilizer and the P use efficiency was highest 15.27% (Mohanty *et al.*, 2006). The application of farmyard manure and vermicomposting can increase stover and grain yields in crops like maize, wheat and sorghum and this is due to their ability to store several micro and macro nutrients that are released during the process of mineralization; the provision of favourable soil conditions and biochemical processes (Shilpashree *et al*., 2012; Thind *et al*., 2016).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of experimental site

The study was carried out in Kakamega County, Western Kenya (Figure 1) in a farmers' field for two seasons; the short rain season (September - December 2019) and long rain season (March - July 2020). The site is situated on longitude 34^{o} 36$^{'}$ E and latitude 0^{o} 15$^{'}$ N at 1,377 meters above sea level. The annual rainfall received ranges between 2,214 mm and 1,280 mm per year. This rainfall is evenly distributed all year round, with March and July receiving heavy rains while December and February receive light rains. The temperature range is between 18^{o}C and 29^{o}C. The hottest months are November, December, January and February. Other months have relatively higher and similar temperatures. The average humidity is 67%. The site falls within the Upper Medium (UM) Agro ecological zone where intensive farming of maize, bean and vegetables is carried out by small scale farmers with a section of the population practicing large scale farming (Government of Kenya, 2014). The predominant soils are Acrisols with few Nitisols and Ferralsols, with a pH range of 4.18 to 6.09 (Jaetdzold *et al*., 1982; NAAIAP, 2014).

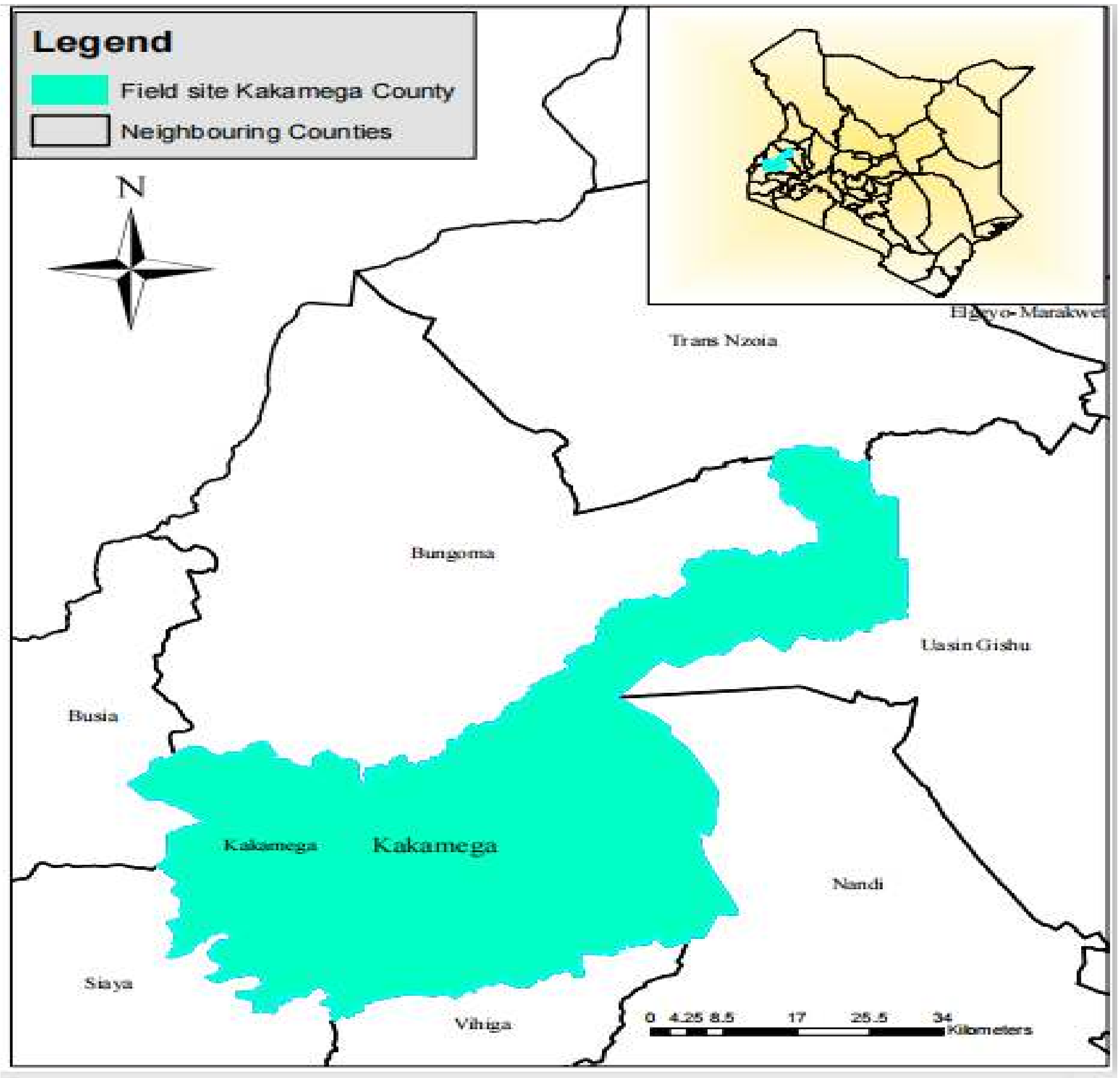

Figure 1. Shows map of the study area Kakamega derived from GIS ArcMap version 10.5

3.2 Experimental design and treatment layout

The specific objectives of this study were to determine the effects of application of sugarcane bagasse ash and manure on (i) soil pH, (ii) soil cation exchange capacity (CEC) and available phosphorous, and (iii) maize growth and yield. Treatments consisted of two factors; decomposed cattle manure (manure) at three levels (0, 5 and 10 t ha^{-1}) and soil conditioners at three levels i.e. 0 and 5 t ha^{-1} sugarcane bagasse ash, and 2 t ha^{-1} lime (positive control). There were 9 treatment combinations (Table 1). The experiment was laid down as a Randomized Complete Block Design with three replications. The experimental field was divided into blocks by ensuring that uniformity within the block was maximized and differences among blocks were increased. Factors that were considered for blocking included the slope, soil colour, organic matter cover and soil depth. The treatment combinations were allocated randomly within each block.

Table 1: The factorial treatment combinations of three levels of manure and soil conditioners in tonnes per hectare (t ha^{-1})

	Factorial treatment combination		
Manure level (t ha^{-1})	0 t ha^{-1}soil conditioner (C0)	5 t ha^{-1}soil conditioner (C1)	2 t ha^{-1} soil conditioner (C2)
0 (M0)	M0C0	M0C1	M0C2
5 (M1)	M1C0	M1C1	M1C2
10 (M2)	M2C0	M2C1	M2C2

Key;

M0C0 = No decomposed cattle manure, no soil conditioner (negative control)
M0C1 = No decomposed cattle manure, 5 t ha^{-1} bagasse ash
M0C2 = No decomposed cattle manure, 2 t ha^{-1} lime (positive control)
M1C0 = 5 t ha^{-1} decomposed cattle manure, no soil conditioner
M1C1 = 5 t ha^{-1} decomposed cattle manure, 5 t ha^{-1} bagasse ash
M1C2 = 5 t ha^{-1} decomposed cattle manure, 2 t ha^{-1}lime
M2C0 = 10 tha^{-1} decomposed cattle manure, no soil conditioner
M2C1 = 10 t ha^{-1} decomposed cattle manure, 5 t ha^{-1} bagasse ash
M1C2 = 10 t ha^{-1} decomposed cattle manure, 2 t ha^{-1}lime

The field was divided into three blocks which were sub divided into plots and experimental units. Each block measured 31.25 m × 4.83 m and a plot measured 4.83 m x 3.47 m. The total number of experimental units was 27 and there were 9 experimental units per each block. The blocks were separated by 1.6 m paths between the blocks whereas the plots within the block were separated by 1.1 m paths.

3.3 Basic soil characterisation of the experimental site Kakamega, Western Kenya

3.3.1 Sampling of soil and amendments

Soil samples (0-30 cm depth) were collected before sowing from different points in the experimental field using zig zag random sampling method, and composited. This was for the purpose of characterising the soil before sowing maize. The samples were air dried under shade for two weeks and were well protected from the rains. After drying, the samples were ground, then passed through a 2 mm mesh wire sieve. The well dried sieved samples were packaged in labelled khaki bags of size 2. They were stored in the laboratory until required for analysis.

The initial soil properties are presented in Table 2. The pH was not satisfactory for maize production. The soils were deficient in nitrogen, phosphorus and potassium and soil organic matter content required to be improved (Table 2). To correct this, application of well decomposed manure or compost (5 t ha^{-1}) during land preparation, 300 kg ha^{-1} of NPK 17:17:17 or 19:19:19 fertilizer at planting and top dressing with 125 kg ha^{-1} of calcium ammonium nitrate (CAN) was recommended according to KALRO (Kenya Agricultural, Livestock and Research Organisation) National Agriculture and Research Laboratories, Nairobi, where the soil analyses were done. The application of two tonnes lime per hectare and five tonnes sugarcane bagasse ash per hectare were recommended to improve the pH to an optimum level favourable for maize production. The two tonnes lime per hectare and five tonnes sugarcane bagasse ash rates were used as levels of soil conditioner among the nine treatment combinations and five tonnes decomposed cattle manure per hectare recommendation was used as the midpoint of the three levels (0, 5 and 10 t ha^{-1}) of manure amendments used in the field experiments as shown in the list of treatments (Table 2).

Table 2. Basic soil characteristics of the experimental field Kakamega, Western Kenya

Soil parameter	Value	Class	Soil parameter	Value	Class
Soil depth (m)	0.30	Top soil	Fe (mg kg^{-1})	32.4	adequate
Soil pH	5.39	medium acid	Zn (mg kg^{-1})	15.0	adequate
Exch. Acidity (C mol kg^{-1})	0.2	adequate	Na (C mol kg^{-1})	0.54	adequate
Available N (mg kg^{-1})	1800	low	Elect. Cond. (mS/cm)	0.08	*
Organic Carbon (mg kg^{-1})	19300	moderate	Sand (%)	42	*
Phosphorus (mg kg^{-1})	25	low	Silt (%)	20	*
Exch. Bases			Clay (%)	38	*
K (mg kg^{-1})	1600	low	Texture Class	Cay loam	*
Ca (mg kg^{-1})	58000	adequate	Bulk density (gcm^{-3})	1.4	*
Mg (C mol kg^{-1})	1.76	adequate	CEC (C mol kg^{-1})	20.0	*
Mn (C mol kg^{-1})	0.80	adequate	Bases (%)	56	*
Cu (mg kg^{-1})	5.22	adequate	ESP	4.5	*

*- meaning there was no classification of the parameter.

Decomposed cattle manure was collected from Bukura Agricultural College. The manure was decomposed using composting method. The manure was piled into a windrow 10 to 12 feet wide and 4 to 6 feet high. The pile comprised of 16.67% straw and 83.33% cattle dung to maintain the carbon to nitrogen ratio at 30:1. The compost pile was turned up every 10 days to ensure proper aeration and temperature was monitored. The moisture content of the compost was maintained within a range of 40 to 60%. This was monitored by simple hand test known as the wet rag test, where the compost is squeezed and felt for the moisture. If water drips out, then it is too wet but if the compost feels like a wrung out wet rug, the compost has sufficient amount of water (Rynk *et al* 1992). In situation where there was inadequate moisture, water was directly supplied. The process of composting was done for 90 days (3 months). The lime was sourced from Omya International AG Baslerstrasse, 42 4665 Oftringen Switzerland www.omya.com.

The soil amendments manure and soil conditioners (bagasse ash and lime) were sampled to characterize them in terms of physical and chemical properties before application to the field. All the samples were analysed at KALRO (Kenya Agricultural, Livestock and Research Organisation) National Agriculture and Research Laboratories, Nairobi and the results used to form the basis for the selection of treatment for this experiment. The same sampling procedure was used to collect soil samples at harvest, in both cropping seasons, according to each treatment.

The characteristics of the soil amendments manure and soil conditioners [bagasse ash and lime] are shown in table 3. In comparison with farm yard manure, the decomposed cattle manure sample had high content of iron. All other nutrient elements were within the adequate range. The sugarcane bagasse ash in comparison with other ashes had high content of nitrogen. All other nutrient elements were within the adequate range. The lime was highly soluble and was recommended to be applied at planting. The application rate was determined by buffer solution method (Kamprath & Smyth, 2005) and the recommended rate for the type of soil was 2 t ha^{-1}.

Table 3. Characteristics of soil amendments (manure, bagasse ash and lime)

Sample description	Manure	Bagasse ash	Lime
pH-water	7.40	7.96	_
Nitrogen (mg kg^{-1})	19800	23300	_
Phosphorus (mg kg^{-1})	3100	3700	_
Potassium (mg kg^{-1})	5200	5700	_
Calcium (mg kg^{-1})	3500	3800	3600
Magnesium (mg kg^{-1})	2300	2500	6000
Iron mg/kg	3583	3717	_
Copper mg/kg	6.67	21.7	_
Manganese mg/kg	597	827	_
Zinc mg/kg	163	88.3	_
Granulated calcium carbonate mm	_	_	2 – 6
Calcium carbonate %	_	_	91
Magnesium carbonate %	_	_	2
Neutralizing value	_	_	52
Calcium oxide %	_	_	51
Magnesium oxide %	_	_	0.9
H_2O %	_	_	< 2

_ meaning there was no analyses for the description

3.3.2 Analysis of soil samples and amendments

Determination of Soil Physical Properties:

Soil texture: Soil texture was determined by hydrometer method. A weight of 100 g of Calgon (Sodium hexametaphosphate) 10% was dissolved in 1 litre of distilled water to make a solution which was used as a dispersing agent. Other reagents and equipment used were amyl alcohol, Hydrometer with Bouyoucos scale in gram per litre, soil dispersing stirrer and reciprocating shaker. A weight of 50 g of air dry < 2 mm soil was weighed out into a 400 ml beaker then saturated with distilled water and 10 ml of 10% Calgon solution. These were allowed to stand for 10 minutes before transferring the suspensions into the dispersing cup where distilled water was added to the mark. The procedures followed were according to Okalebo *et al.* (2002). The percentages of sand, silt, and clay were quantified and the textural class determined from the texture triangle.

Soil bulk density: Core samples for soil bulk density determination were taken to the laboratory, weighed and oven dried at a temperature of 105°C to constant weight (Okalebo *et al.*, 2002). The oven dry samples were put in desiccator to cool down, then dry weight was measured using an electronic balance.

Soil bulk density (ρ_b) was calculated using the formula;

$$(\rho_b) = \frac{M_D}{V_T} \quad \text{.......} \quad (1)$$

Where;

M_D = the mass of oven dried soil;

V_T = total volume of the soil sample which was equivalent to the volume of the core ring that contained the dried soil.

Determination of Chemical Properties of soil and amendments:

Soil pH: Soil pH was determined by a pH meter (Make: Jenway, UK; model: 3510 pH meter) standardized by the use of pH buffers at pH 7 and pH 4. The ratio 1:1 of soil: distilled water was used (Mehlich *et al.*, 1962).

Available Nutrients: Available nutrient elements (P, K, Na, Ca, Mg and Mn): were analysed using Mehlich Double Acid Method (Mehlich *et al.*, 1962). The soil samples (< 2 mm) were oven - dried at 40° C. Soils were extracted in a 1:5 ratio (w/v) with a mixture of 0.1 N HCl and 0.025 N H2SO4. The extracting solution included a mixture of 0.1 N HCl and 0.025 N H_2SO_4 as the stock solution in a soil solution ratio of 1:5. Part of the stock solution, 25 ml was diluted to 1 litre that was used to extract all the nutrients mentioned above. Elements such as Na, Ca and K were determined with a flame photometer (Make: Corning 400, UK; model: M400) and P, Mg and Mn spectrophotometrically using UV/VIS spectrophotometer (Make: Analytik Jena, Germany; model: SPEKOL 1500). Available trace elements (Fe, Zn and Cu) were extracted with 0.1 M HCl in a 1:10 ratio (w/v). The elements were determined with AAS (Atomic Absorption Spectrophotometer) (Make: PerkinELMer, USA; model: AAnalyst 100).

Exchangeable acidity: Exchangeable acidity (for soils with pH < 5.5) was determined as follows: A soil sample oven dried at 40° C and sieved to < 2 mm was placed into a 50 ml container. A volume of 12.5 ml of 1 M KCl was added and the content was stirred using a clean glass rod. It was allowed to stand for 30 minutes, then filtered through a funnel and leached with 5 successive 12.5 ml aliquots of 1 M KCl. Three (3) drops of phenolphthalein indicator solution were added and the mixture was titrated with 0.1 M NaOH to the first permanent pink colour of end point. The burette was read and the volume (ml) of NaOH used was recorded.

The titration readings for a blank of titration of 75 ml KCl solution was then corrected (Okalebo *et al.*, 2002).

Cation exchange capacity: Cation exchange capacity (CEC) was determined using the following reagents: 1 M Ammonium acetate, pH 7.0, 95% Ethanol and 1 M potassium chloride. 77.1 g ammonium acetate was dissolved in 950 ml water. The pH was adjusted to 7.0 with acetic acid and volume added up to 1000 ml with water then mixed well. 74.55 g potassium chloride was dissolved in 1000 ml water. 2.5 ± 0.01 g soil was weighed into a 50 ml centrifuge tube and 33 ml 1 M potassium chloride was added. The tube was stoppered and shaken for 5 minutes. The procedures were followed according to Anderson and Ingram (1993).

Total nitrogen: Total nitrogen was determined according to Kjeldahl method. Soil samples (< 0.5 mm) oven dried at 40° C were digested with concentrated sulphuric acid containing potassium sulphate, selenium and copper sulphate hydrated at approximately 350° C. Total N was determined by distillation followed by titration with diluted standardized H_2SO_4 (Page *et al.*, 1982).

Total organic carbon: Total organic carbon was determined according to the procedure of Anderson and Ingram (1993). Colorimetric method which is suitable for all soils except with those where organic carbon < 0.2% was used. The reagents used were barium chloride 0.4% obtained by dissolving 4 g barium chloride in 1000 ml water and potassium dichromate 5% by dissolving 50 g in 1000 ml water and concentrated sulphuric acid (H_2S0_4, about 36 N). Standards were prepared by drying about 15 g sucrose at 105°C for 2 hours and allowing to cool in a desiccator. Dry sucrose of weight 11.886 g was dissolved in water to 100 ml volume in a volumetric flask to make 50 mg/ml concentration stock solution from which a series of working standards were prepared. The procedure with external heating was applied where 1 ± 0.001 g of ground soil < 0.15 mm was weighed into a labelled 100 ml digestion tube then 2 ml water and 10 ml 5% potassium dichromate solution added and allowed to completely wet the soil or dissolve the standards. A volume of 5 ml H_2S0_4 from a slow burette was gently added and the mixture was swirled, digested at 150°C for 30 minutes. It was allowed to cool down, then 50 ml of 0.4% barium chloride was added, swirled to mix thoroughly and allowed to stand overnight so as to leave a clear supernatant solution. An aliquot of the supernatant solution was transferred into a colorimeter cuvette, each standard and sample absorbance was measured and recorded at 600 nm. The % of total organic carbon was calculated using the formula:

$$\% \text{ organic carbon} = (K \times 0.1)/W$$

Where;

K = corrected concentration, and W = weight of soil.

Analysis of sugarcane bagasse ash and farmyard manure: Sugarcane bagasse ash and decomposed cattle manure were analysed for the chemical properties; pH, total elements content, thus; N, P, K, Ca, and Mg, using methods described in the soil analyses above.

3.4 Germplasm

Hybrid maize seed DH04 was selected for planting. It was purchased from Kenya Seed Company. The characteristics were identified prior to selection. They included characteristics such as: it takes 120 days from planting date to harvest and normally gives an average yield of 3.6 t ha^{-1} (40 bags of 90 kg weight per hectare). It possesses 'long stay green trait', is drought tolerant and has good level of tolerance to southern corn leaf blight (*Bipolaris maydis*), common rust (*Puccinia sorghi*) and ear rot (*Giberella zeae*).

3.5 Land preparation and application of treatments

Land preparation was carried out in the short rain season using a tractor driven plough and harrow. In the long rain season land was prepared manually. Sugarcane bagasse ash was collected from West Kenya Sugar Company Limited. The bagasse ash was passed through a 2 mm sieve prior to its application in the field to enable compatible mix with the soil particles. The bagasse ash chemical composition was determined before application. It was placed on top soil (15 cm depth) at planting according to treatments and mixed with soil thoroughly. The mixes were covered with light soil. Well decomposed cattle manure and lime were placed to depth of 15 cm and were thoroughly mixed with soil. The mixes were covered with light soil before placement of the seed to avoid seed burn. Maize was planted as a mono crop during the short rain and long rain seasons, at the spacing of 75 cm × 30 cm. Two seeds were planted per hill; later thinned to one seedling per hill two weeks after emergence, to give the recommended plant population of 44,444 plants per hectare. There were 4 rows of maize per treatment. Two internal rows were used for sampling. Two rows of maize plants were left as guard rows and two plants were left at the end of a row to act as guard.

3.6 Routine crop management

Weed control: Weeding was done by hand three times starting two weeks after emergence. Thinning of the plants to one seedling per hill was done during the first weeding. Insect pest control: Stalk borer (*Busseola fusca*) was controlled by the use of Beta-Cyfluthrin 0.5 g kg^{-1} (BULLDOCK GR) at the rate of 6 - 8 kg ha^{-1} in 1000 litre of water. Army worm

(*Spodoptera frugiperda*) was sprayed with Match ® 50 EC, whose active ingredient is 50 g/l Lufenuron. This insecticide works by interrupting the lifecycle of all caterpillars (Lepidoptera) and is very effective against the fall army worm. The plants were sprayed after first weeding to ensure early control of the pests. Crops were sprayed early in the morning when the pests were still active. These routine practices were done for both short rain season (first season) and the long rain season (second season).

3.7 Measurements of crop growth

The growth parameters that were measured included plant height, number of leaves, leaf area index (LAI), stem collar diameter, number of days to 50% tasselling and root length. Data on the number of leaves, plant height and stem collar diameter were collected after 50% emergence of the seedlings, then at two weeks' intervals until physiological maturity. Three plants were randomly selected from two internal rows of each treatment and were tagged for data collection.

Plant height: Plant height was measured from the soil surface to the bent point of the most recent matured leaf during the growth period. At maturity when the crop had stopped growing, the final height was measured from the ground surface to the tip of the plant. Measurements were done using a measuring tape while the number of leaves were counted.

Stem collar: Stem collar diameter was measured with an electronic digital Vernier calliper (Zhejiang China (Mainland) Brand Name: DLTC, model number: 0-150). The number of days to tasselling were counted from the date of 50% emergence to the date of 50% tasselling of the maize.

Leaf area: Leaf area per plant was calculated by multiplying leaf length (L) and width (W) corrected to 0.75. Leaf length was measured from the base to the tip. Width was measured laterally across the margins.

$LA = 0.75\ (L \times W)$ .... (8)

Where: L = leaf length, cm

W = width of widest portion of leaf, cm

LA = leaf area, cm^2

Leaf area index (LAI) was calculated using the following formulae (Addo-Quaye and Darkwa, 2011):

$LAI = LA/P$ Where: P is the ground area, cm^2.. (9)

Root length: Maize root length was measured at harvest. This was done by uprooting the plant and measuring the length from the top origin of the root to the root tip using a ruler.

3.8 Measurement of maize grain and dry matter yields

At physiological maturity of maize, the above ground portion was harvested from two internal rows of each plot targeting 5 plants. The samples were divided into stover (stalk and leaves) and the number of cobs were counted.

Dry matter content (kg ha^{-1}): Fresh weight of stalks and leaves were determined immediately in the field using a weighing balance. Sub samples were finely chopped and oven dried at 65°C for 72 hours. Dry weight was determined and used to calculate above ground dry matter yield.

Grain yield (kg ha^{-1}): cobs were shelled, threshed and grains weighed at 12% moisture content. Yield was based on seed yield per plot (kg m^{-2}), and was converted to t ha^{-1}.

Weight of hundred grains: three 100 random samples of 12% moisture content dried grains per plot were counted and weighed using an electronic balance. The grain moisture content was determined using a grain moisture meter (Digital moisture and temperature meter; grains and seeds moisture 8 – 35% Corn ISO 6540 sampling ISO 7700/1 and ISO 7700/2 Standards).

3.9 Statistical analysis of data

Data were subjected to analysis of variance (ANOVA) using SAS software for windows 9.2 (TS2M0) 1999 – 2001 by SAS Institute Inc., Cary, NC, USA. Where the Fisher's protected F-test was significant, mean treatments were separated using LSD (Least significant difference) test at $p \leq 0.05$ level of significance. The statistical analyses and presentations for the data on soil, plant growth and yield parameters were done on the basis of the data collected for the two seasons. The following equation shows the model that was used to analyse the data.

$Y_{ijklm} = \mu + S_i + R_{j(i)} + C_k + M_l + CM_{kl} + CS_{ik} + MS_{il} + CMS_{ikl} + \varepsilon_{ijklm}$. Where; Y_{ijklm} were the observations (response of soil parameters, maize growth and yield) due to soil conditioners and decomposed cattle manure on the j^{th} replication within season k^{th} and l^{th} treatments, μ was the overall mean, S_i the effect due to the i^{th} season, $R_{j(i)}$ the effect due to replications within season, C_k was the k^{th} effect due to application of soil conditioners, M_l was the l^{th} effect due to application of decomposed cattle manure, CM_{kl} were the k^{th} and l^{th} effect of interaction between soil conditioners and decomposed cattle manure, CS_{ik} was the interaction between soil conditioners k^{th} and season i^{th}, MS_{il} was the effect due to interaction between manure l^{th} and season i^{th}, CMS_{ikl} was the effect of interaction among soil conditioners k^{th}, decomposed cattle manure l^{th}, and season i^{th} and ε_{ijklm} was the random error component. The levels of each variable are defined as; $i = 1, 2$; $j = 1, 2, 3$; $k = 1, 2, 3$ and $l = 1, 2, 3$.

CHAPTER FOUR

RESULTS

4.1 Effect of manure, bagasse ash and lime amendments on soil pH

The results of the study reveal highly significant interactions among season, decomposed cattle manure and conditioners (lime and bagasse ash) on soil pH at $P < 0.05$. Significant differences in pH values between seasons were observed with combinations of 5 t ha^{-1} decomposed cattle manure and 2 t ha^{-1} lime, and application of 5 t ha^{-1} manure with no soil conditioner (Table 4). In these treatments, the soil pH values at the end of the second season were significantly higher than values obtained at the end of first season (Table 4). The interaction of 5 t ha^{-1} manure with 2 t ha^{-1} lime significantly yielded the highest pH values in both short and long rain seasons.

Table 4. Interaction effect of manure and soil conditioner on soil pH during the short rain (2019) and long rain (2020) seasons at Kakamega, Western Kenya

Treatment	pH values short rain season	pH values long rain season
0 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	5.38^{h}	5.38^{gh}
0 t ha^{-1} manure × 2 t ha^{-1} lime	5.41^{fg}	5.42^{f}
0 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	5.48^{e}	5.50^{de}
5 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	5.56^{c}	5.73^{b}
5 t ha^{-1} manure × 2 t ha^{-1} lime	5.73^{b}	5.85^{a}
5 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	5.54^{c}	5.56^{c}
10 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	5.41^{fgh}	5.42^{f}
10 t ha^{-1} manure × 2 t ha^{-1} lime	5.55^{c}	5.56^{c}
10 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	5.53^{cd}	5.55^{c}
Standard error	0.01	0.01

Means within a column or row followed by same letter are not significantly different $P > 0.05$ whereas means followed by different letters are significantly different $P < 0.05$ level of significance. The missing letter ‘’a’’ in short rain column shows that pH value (s) during the long rain season was significantly higher than the short rain season.

When 5 t ha^{-1} bagasse ash was incorporated with 5 t ha^{-1} manure, this resulted in pH values that were not significantly different in the two seasons but were significantly higher than treatments with no soil amendments in both seasons (Table 4). The results show that the interaction of manure at the rate 0 tonnes per hectare with bagasse ash caused a significant increase of pH compared to its interaction with lime at the end of the short and long rain seasons. However, high improvement of soil pH was observed mostly when lime interacted with either 5 or 10 tonnes per hectare manure unlike bagasse ash.

4.2 Effect of manure, bagasse ash and lime on soil available phosphorus and cation exchange capacity

The main effect of cattle manure on soil available P was significant ($p < 0.05$). Plots that received 5 t ha^{-1} manure gave the highest improvements followed by 10 t ha^{-1} while 0 t ha^{-1} remained significantly lower (Figure 2).

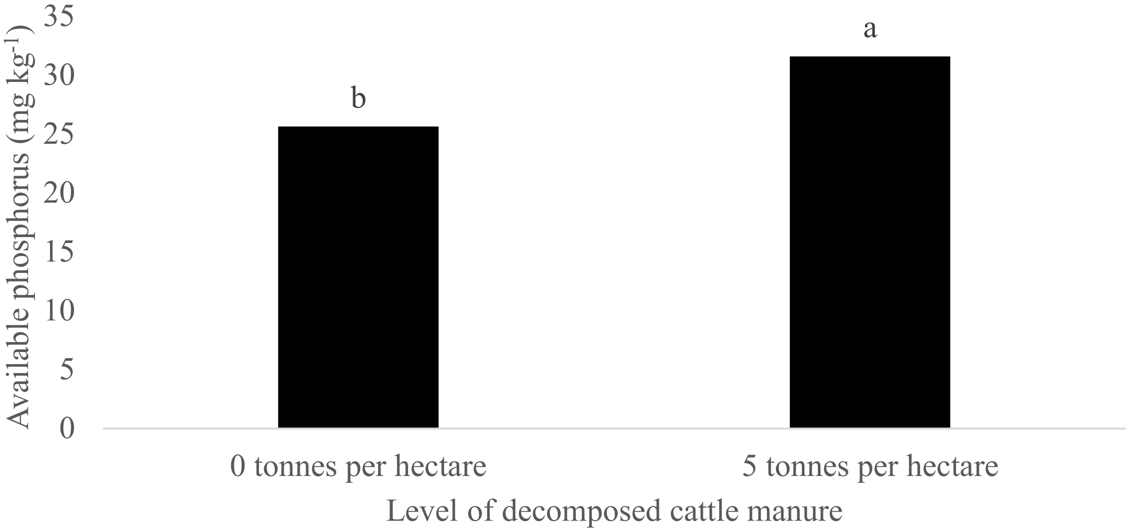

Figure 2. The main effects of decomposed cattle manure application level of 5 tonnes per hectare on soil available phosphorus at Kakamega, Western Kenya.

The different letters a and b show that the means were significantly different with letter a higher than b at least significance difference = 0.4114

Similarly, when decomposed cattle manure was applied at the rate of 10 tonnes per hectare, there was a significant difference in the values of soil available phosphorus from nil application (Figure 3).

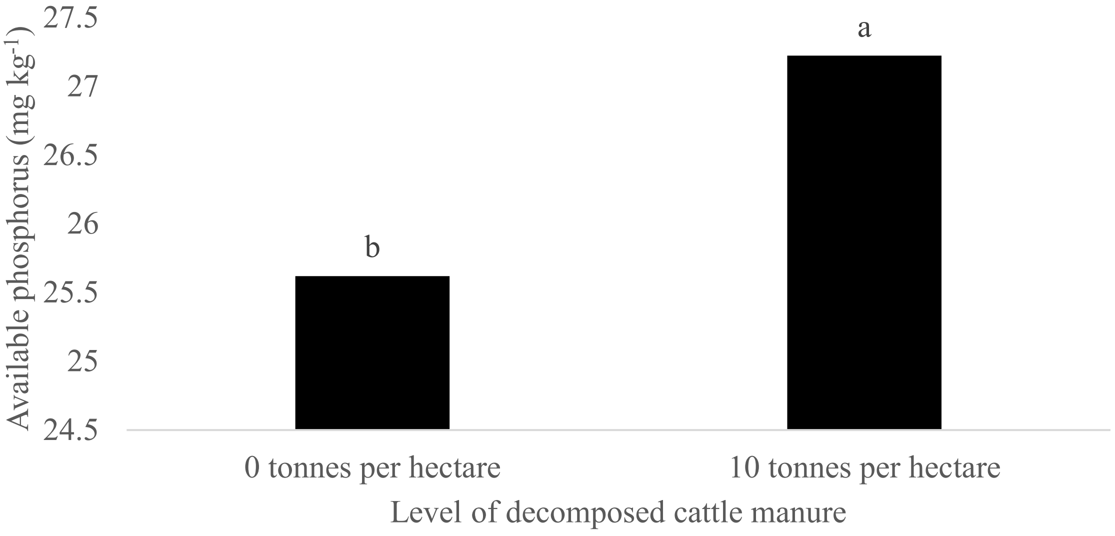

Figure 3. The main effects of decomposed cattle manure application level of 10 tonnes per hectare on soil available phosphorus at Kakamega, Western Kenya

The different letters a and b show that the means were significantly different with letter a higher than b at least significance difference = 0.4114

The main effect of soil conditioner on soil available P was significant ($P < 0.05$). The application of bagasse ash and lime under field conditions resulted in significant changes of soil available phosphorus at $P < 0.05$ level of significance. Treatments that received 5 tonnes of bagasse ash per hectare gave the highest values for soil available phosphorus (Figure 4).

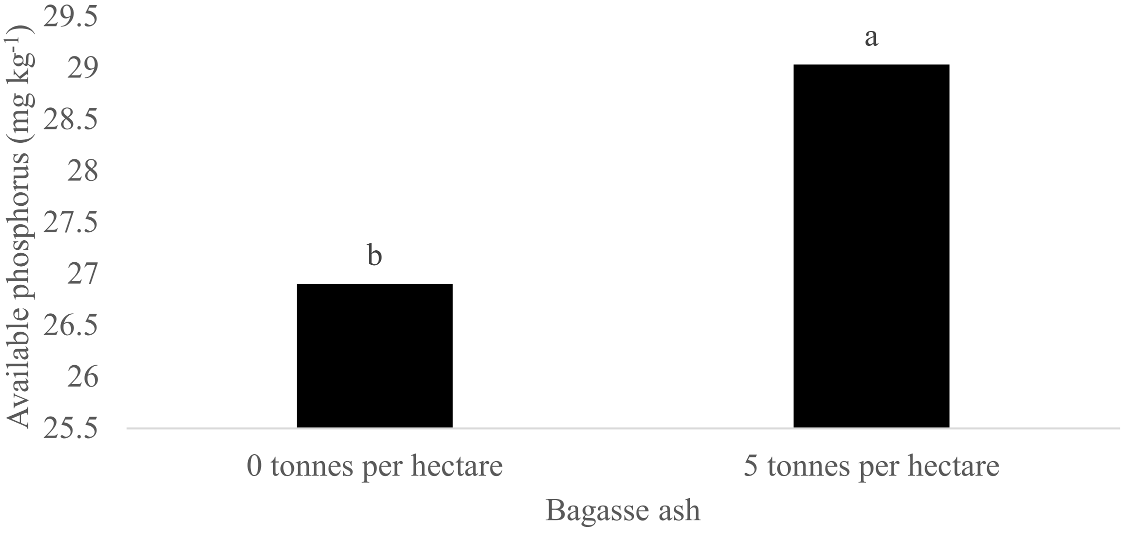

Figure 4. The main effects of type of soil conditioner bagasse ash application on soil available phosphorus at Kakamega, Western Kenya

The different letters a and b show that the means were significantly different with letter a higher than b at least significance difference = 0.4114

Single application of lime at the rate of 2 tonnes per hectare was significantly different from 0 tonnes per hectare treatment rate (Figure 5). The nil amendment treatments remained significantly the lowest for soil available p.

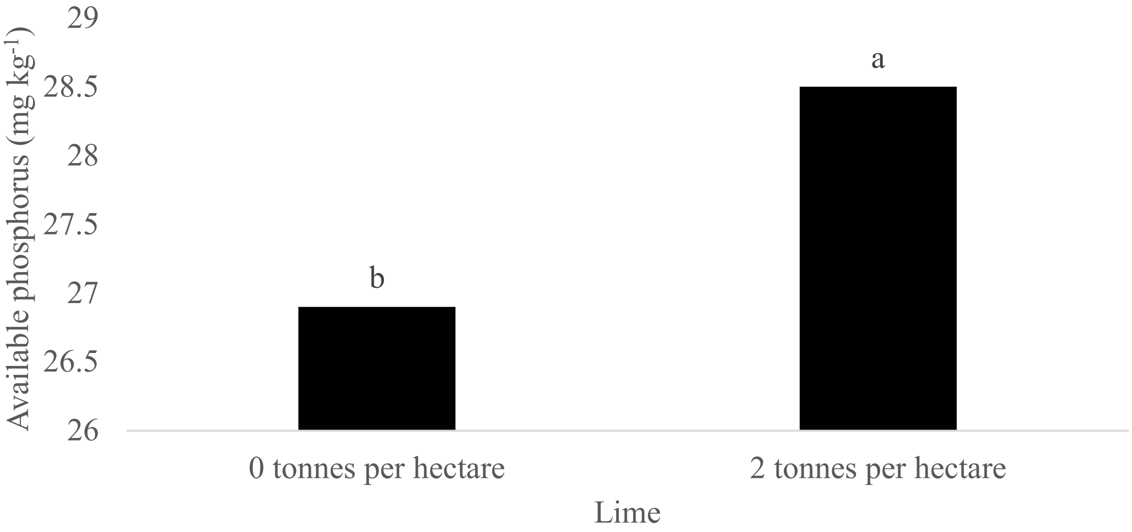

Figure 5. The main effects of type of soil conditioner lime application on soil available phosphorus at Kakamega, Western Kenya.

The different letters a and b show that the means were significantly different with letter a higher than b at least significance difference = 0.4114

Results show that the main effect of season was significant at $P < 0.05$. The cation exchange capacity was higher at the end of the second season as shown in figure 6 below.

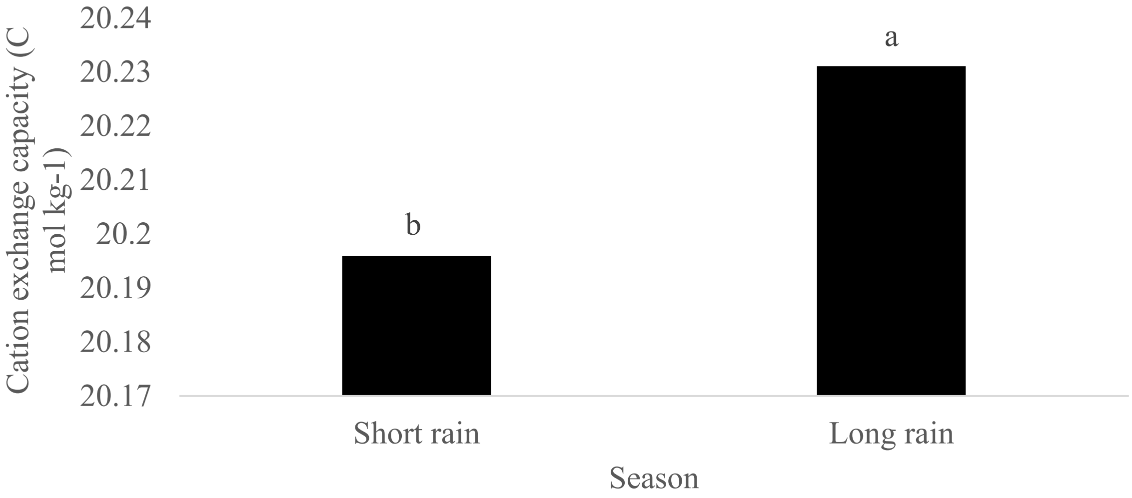

Figure 6. Main effect of season on soil cation exchange capacity at Kakamega, Western Kenya.

The letters a and b are different and show that there were significant differences between the short and long rain seasons when means were separated at least significant difference = 0.0223

The main effect of decomposed cattle manure on soil cation exchange capacity was significant ($P < 0.05$). The application of decomposed cattle manure at the rate of 5 tonnes per hectare was significantly higher that nil application as shown in figure 7 below.

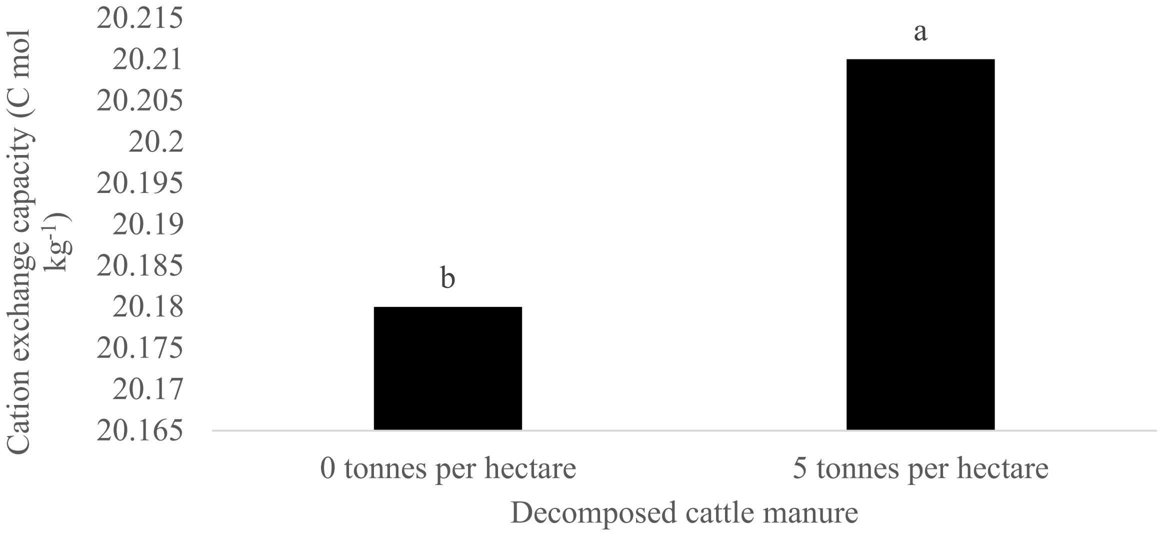

Figure 7. The main effects of decomposed cattle manure application level of 5 tonnes per hectare on soil cation exchange capacity at Kakamega, Western Kenya.

The different letters a and b show that the means were significantly different with letter a higher than b at least significant difference = 0.0274

The cation exchange capacity was higher at the 10 tonnes per hectare rate of decomposed cattle manure applied. Nil treatment remained significantly lower as shown in figure 8 below.

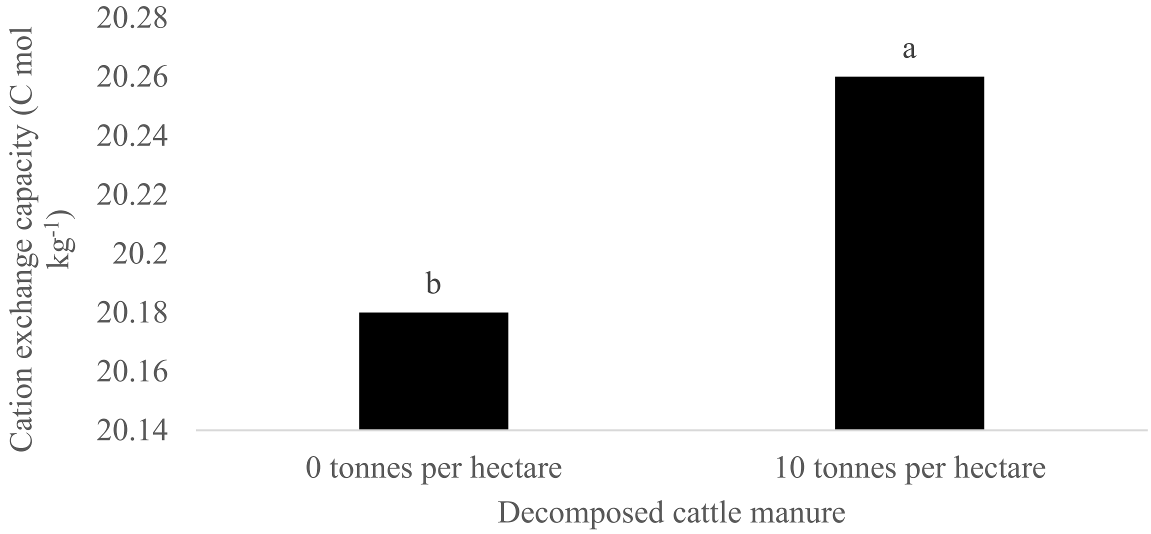

Figure 8. The main effects of decomposed cattle manure application level of 10 tonnes per hectare on soil cation exchange capacity at Kakamega, Western Kenya.

The different letters a and b show that the means were significantly different with letter a higher than b at least significance difference = 0.0274

The main effect of soil conditioner on soil cation exchange capacities was significant ($P < 0.05$). Significantly higher cation exchange capacity resulted from the application of bagasse ash (Figure 9). There was no significant difference in soil cation exchange capacity values between the application of lime and none application of any amendment (Figure 10).

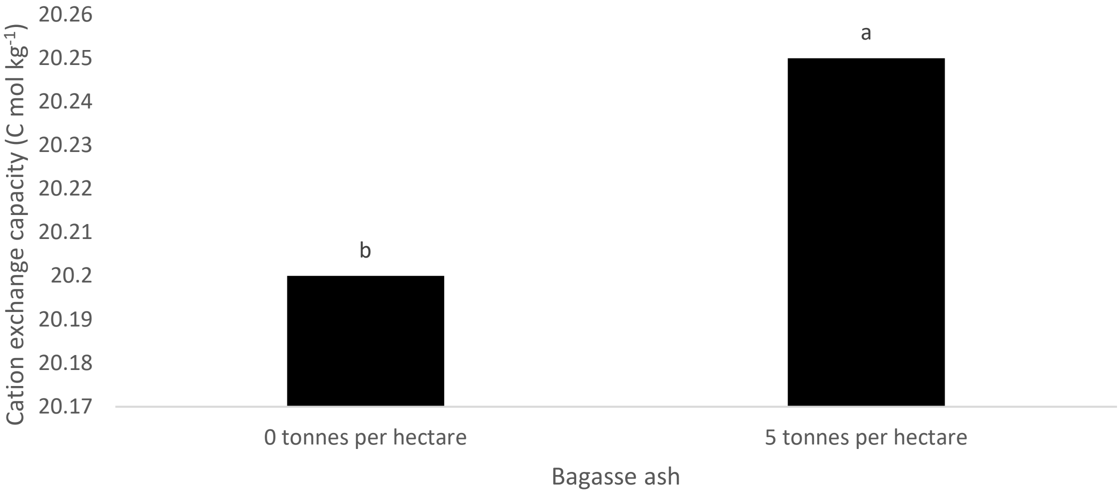

Figure 9. The main effects of type of soil conditioner bagasse ash application on soil cation exchange capacity at Kakamega, Western Kenya.

The different letters a and b show that the means were significantly different with letter a higher than b at least significance difference = 0.0274

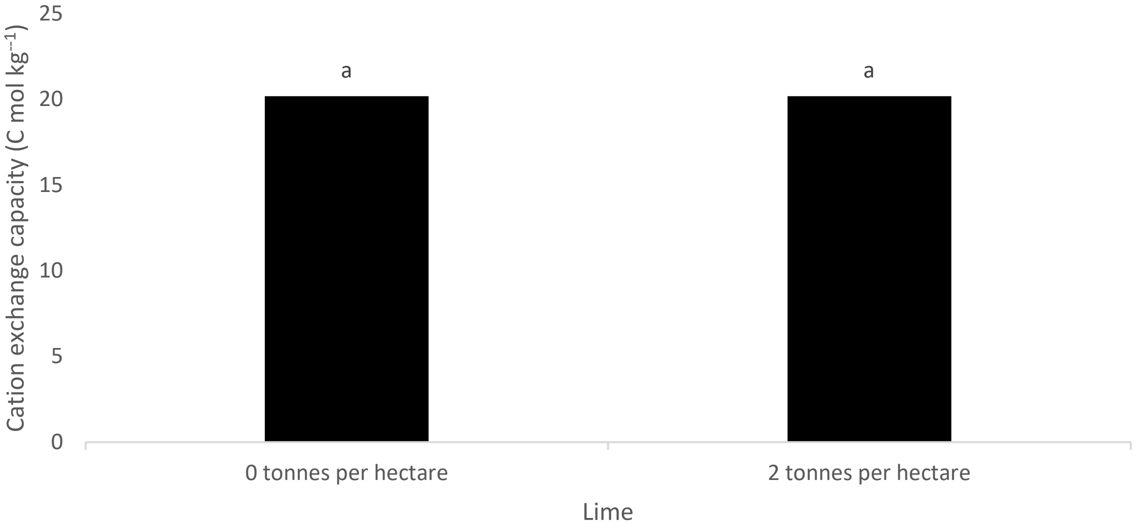

Figure 10. The main effects of type of soil conditioner lime application on soil cation exchange capacity at Kakamega, Western Kenya.

The same letter a show that the means were not significantly different from each other at least significance difference = 0.0274.

4.3 Effect of season manure, bagasse ash and lime on maize height

The results for the two seasons show that maize heights were significantly different due to the interaction of both experimental amendments (manure and soil conditioner) and the different growing seasons at $P < 0.05$. Maize heights in the second season were higher than in the first season in treatments; 5 t ha^{-1} manure combined with 2 t ha^{-1} lime, and 0 t ha^{-1} manure with 5 t ha^{-1} bagasse ash (Table 5). The incorporation of manure at the rates 5 t ha^{-1} combined with 2 t ha^{-1} lime gave the highest values for the maize height, in the second season. The interaction of manure at the rate 0 tonnes per hectare with lime or bagasse ash and 5 tonnes per hectare manure with bagasse ash were not significantly different during the second season and had the second highest values for maize height. Treatments with no amendments remained significantly lower than those that received manure, bagasse ash or lime in both seasons.

Table 5. Interaction effect of manure and soil conditioner on maize height in metres at physiological maturity during the short rain (2019) and long rain (2020) seasons at Kakamega, Western Kenya

Treatment	Maize height (m) short rain season	Maize height (m) long rain season
0 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	1.94^{j}	1.94^{j}
0 t ha^{-1} manure × 2 t ha^{-1} lime	2.42^{bc}	2.44^{b}
0 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	2.07^{i}	2.44^{b}
5 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	2.08^{hi}	2.09^{hi}
5 t ha^{-1} manure × 2 t ha^{-1} lime	2.40^{bc}	2.65^{a}
5 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	2.37^{cd}	2.40^{bc}
10 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	2.12^{ghi}	2.24^{e}
10 t ha^{-1} manure × 2 t ha^{-1} lime	2.23^{ef}	2.32^{d}
10 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	2.15^{gh}	2.17^{fg}
Standard error	0.02	0.02

Means within a column or row followed by different letters are significantly different at $P \leq 0.05$ level of significance while means followed by the same letter are not significantly different $P > 0.05$. The missing letter ''a'' in short rain season's column shows that maize height value (s) during the long rain season was significantly higher than the short rain season.

4.4 Effect of manure, bagasse ash and lime amendments on maize root length, stem collar diameter and leaf area index

Significant differences in the maize root length at $P < 0.05$ were observed due to interaction of manure and soil conditioner whereas different seasons made no significant change. The results show that root lengths where manure was incorporated at the rates 5 t ha^{-1} and 10 t ha^{-1} combined with 2 t ha^{-1} lime were not significantly different and gave the highest values. This was followed by interaction of 5 t ha^{-1} manure with 5 t ha^{-1} bagasse ash, where maize root length was higher in comparison with the other treatments (Table 6). Root length in treatments with no amendments remained significantly lower than those that received manure, bagasse ash or lime.

Table 6. Interaction effect of manure and soil conditioner on maize root length, stem collar diameter and leaf area index at Kakamega, Western Kenya

Treatment	Root length (cm)	Stem collar (cm)	Leaf area index (cm^2cm^{-2})
0 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	24.1500^{f}	2.4672^{g}	0.8301^{h}
0 t ha^{-1} manure × 2 t ha^{-1} lime	25.4988^{e}	2.9576^{b}	1.0342^{b}
0 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	27.1667^{c}	2.8332^{d}	0.9674^{de}
5 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	26.0483^{d}	2.8866^{c}	0.9573^{ef}
5 t ha^{-1} manure × 2 t ha^{-1} lime	29.4533^{a}	3.3016^{a}	1.3521^{a}
5 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	27.7267^{b}	2.8387^{d}	1.0165^{c}
10 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	25.6083^{de}	2.5260^{f}	0.9422^{g}
10 t ha^{-1} manure × 2 t ha^{-1} lime	29.3333^{a}	2.6898^{e}	0.9753^{d}
10 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	25.9950^{de}	2.7150^{e}	0.9553^{f}
Standard error	0.1589	0.0138	0.0033

Means within a column followed by same letter are not significantly different $P > 0.05$ whereas, means in a column followed by different letters are significantly different $P < 0.05$ level of significance.

Maize stem collar diameter was significantly higher at $P < 0.05$ when there was interaction of manure with soil conditioner. Nevertheless, seasons were not significant in the models, their interactions were not significant and are not presented. The results show that the incorporation of manure at the rates 5 t ha^{-1} with 2 t ha^{-1} lime were significantly different and gave the highest values for the maize stem collar diameter followed by interaction of 0 t ha^{-1} manure with 2 t ha^{-1} lime in comparison with the other treatments (Table 6). Treatments with no amendments remained significantly lower than those that received manure, bagasse ash or lime.

Maize leaf area index was significantly different at $p < 0.05$ and this was caused by the interaction of manure with soil conditioner. The results show that the incorporation of manure at the rates 5 t ha^{-1} with 2 t ha^{-1} lime were significantly different and gave the highest values for the maize leaf area index followed by interaction of 0 t ha^{-1} manure with 2 t ha^{-1} lime, then 5 t ha^{-1} manure with 5 t ha^{-1} bagasse ash in comparison with the other treatments (Table 6). Treatments with no amendments remained significantly lower than those that received manure, bagasse ash or lime. The main effect of season was significant. The maize leaf area index was significantly higher in the second season than the first season as shown in figure 7 below.

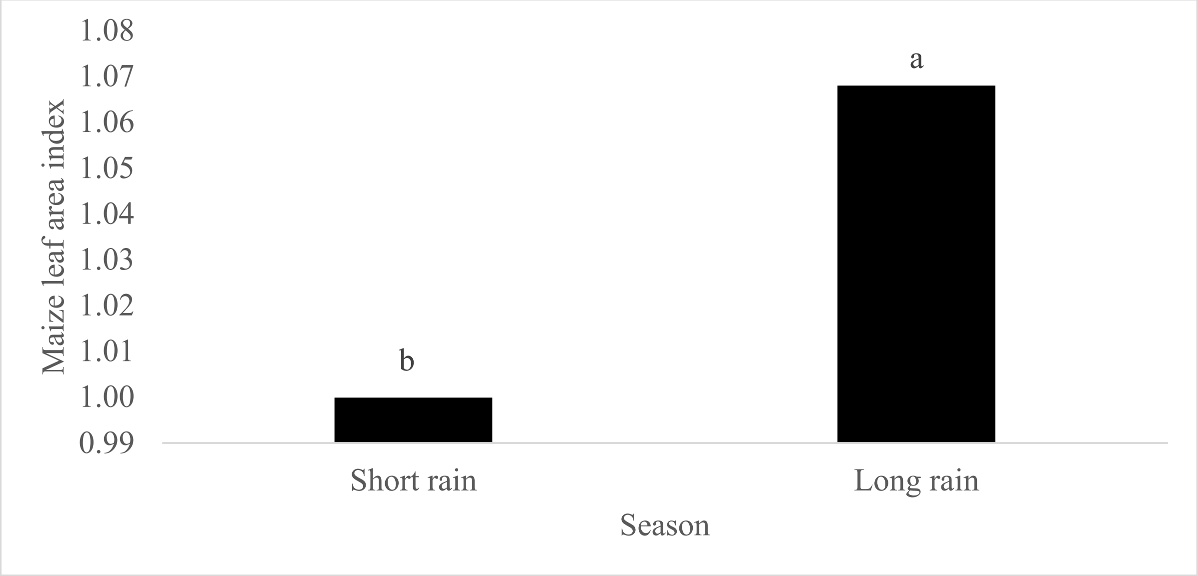

Figure 7. The main effect of season on maize leaf area index in m^2 m^{-2} during the short rain (2019) and long rain (2020) seasons at Kakamega, Western Kenya.

4.5 Effect of manure, bagasse ash and lime amendments on maize biomass weight

Maize biomass weights were significantly different at $p < 0.05$ level of significance as a result of the interactions between the levels of manure with the levels of soil conditioners. All treatment combinations were significantly different from each other except for the interaction of 0 t ha^{-1} and 10 t ha^{-1} manure with 5 t ha^{-1} bagasse ash were not significantly different (Table 4.2). The highest biomass weight was observed in treatments where 5 t ha^{-1} manure interacted with 2 t ha^{-1} lime while treatments that received neither decomposed cattle manure, bagasse ash nor lime had the lowest observation for maize biomass weight (Table 7).

Table 7. Interaction effects of manure and soil conditioner on maize biomass, grain weight and hundred grain weight at Kakamega, Western Kenya

Treatment	Biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	100 grain weight (g)
0 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	2121.76^{h}	2140.49^{e}	27.27^{e}
0 t ha^{-1} manure × 2 t ha^{-1} lime	5054.86^{d}	4351.70^{d}	28.27^{d}
0 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	4784.04^{f}	4925.63^{b}	30.19^{b}
5 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	5226.33^{b}	4599.11^{c}	32.93^{a}
5 t ha^{-1} manure × 2 t ha^{-1} lime	6255.15^{a}	5178.52^{a}	32.52^{a}
5 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	4373.02^{g}	4632.30^{c}	29.88^{b}
10 t ha^{-1} manure × 0 t ha^{-1} soil conditioner	4964.05^{e}	4533.63^{c}	28.30^{d}
10 t ha^{-1} manure × 2 t ha^{-1} lime	5137.20^{c}	4916.15^{b}	29.00^{c}
10 t ha^{-1} manure × 5 t ha^{-1} bagasse ash	4800.76^{f}	4214.22^{d}	29.31^{c}
Standard error	23.41	49.24	0.18

Means within a column followed by same letter are not significantly different at $P < 0.05$ level of significance.

4.6 Effect of manure, bagasse ash and lime amendments on hundred grain weight

The interaction of manure and conditioner was significant $P < 0.05$. The interactions between 5 t ha^{-1} manure with 2 t ha^{-1} lime and 5 t ha^{-1} manure with 0 t ha^{-1} soil conditioners were not significantly different at $P < 0.05$ and resulted in the highest values for 100 grains weight. Similarly, when 0 t ha^{-1} manure was interacted with 5 t ha^{-1} bagasse ash and 5 t ha^{-1} manure with 5 t ha^{-1} bagasse ash, there were no significant differences and they rated second best performed treatments. Treatments with no soil amendment significantly gave the lowest 100 grains weight (Table 7).

4.7 Effect of manure, bagasse ash and lime amendments on maize grain yield

All interactions were tested at $P < 0.05$ level of significance. The interaction of manure and conditioner was significant $P < 0.05$. The highest grain weight was observed in treatments where 5 t ha^{-1} manure interacted with 2 t ha^{-1} lime. Treatments with 0 t ha^{-1} manure combined with 5 t ha^{-1} bagasse ash, and 10 t ha^{-1} manure with 2 t ha^{-1} lime interactions were not significantly different from each other and had the 2nd best improvement in maize grain yield

(Table 7). Treatments with no soil amendment significantly gave the lowest grain weight when compared with treatments where soil amendments were applied.

CHAPTER FIVE

DISCUSSION

5.1 Effect of sugarcane bagasse ash and decomposed cattle manure application levels on soil pH in the field

The initial soil pH value was 5.39, which was not conducive for crop growth due to toxicity of H^+ and Al^{3+} ions (Jaiswal *et al.*, 2018). The application of manure combined with lime, manure only and manure combined with sugarcane bagasse ash significantly lowered soil acidity. The pH values of sugarcane bagasse ash and cattle manure were 7.96 and 7.4, respectively confirming their effects in lowering soil pH. Liming in combination with farmyard manure is more efficient for acidity indicators than its application alone and reduces the amount of mobile aluminium to a level that is not toxic to plants (Karcauskiene *et al.*, 2019). Lime (positive control) and manure contained 3600 mg kg^{-1} and 3800 mg kg^{-1} Ca and 6000 mg kg^{-1} and 2500 mg kg^{-1} Mg, respectively (Table 3). The reaction of lime with soil to release calcium and/or magnesium ions into the soil solution leads to increase in soil pH and the reduction in exchangeable aluminium ions due to precipitation of H^+, Al^{3+}, Fe^{3+} and Mn^{4+} ions (Kisinyo *et al.*, 2013). These amendments were reapplied in the second season, hence released bases over time. The results of this study concur with research findings in the Nordic Countries where the application of ash at the rates 3 to 5 tonnes per hectare decreased soil acidity, increased base saturation and the total amount of nutrients (Hale *et al.*, 2020; Huotari *et al.*, 2015). Research findings by Ingerslev *et al.* (2014) showed that ash had a liming effect as it increased pH of the soil's O horizon. Mineralisation of manure over time also released basic elements into the soil. Manure used in the study contained 3500 mg kg^{-1} calcium and 2300 mg kg^{-1} Mg, respectively. The increase of soil pH in plots that received decomposed cattle manure after two seasons contrasts findings of a long-term field experiment where the stabilizing effect of farmyard manure on soil pH was not proven. After 14 years of farmyard manure application pH decreased at all the sites in the study (Vašák *et al.*, 2015).

5.2 Effect of bagasse ash and decomposed cattle manure application levels on soil available phosphorus and soil cation exchange capacity in the field

Sole application of decomposed cattle manure and sugarcane bagasse ash resulted in significant increases in soil available phosphorus. This can be attributed partly to dissolution of the precipitated soil phosphorus with rise in soil pH. Huotari *et al.* (2015) reported that as the soil pH approaches 5.5 to near neutral, the precipitated phosphorus in soils occurring in pH below 5.5 is released and hence becomes available. Additionally, both manure and sugarcane bagasse ash had adequate phosphorus; 3100 mg kg^{-1} and 3700 mg kg^{-1}, respectively which improved the soil available phosphorus pool.

This study found that application of manure at the rate 5 tonnes per hectare caused highest soil available phosphorus improvements followed by 10 tonnes per hectare and lastly no amendment. This could be possible because higher quantities of manure would require more time for mineralisation to take place and nutrients to be released. This is in contrast to findings by Lemanowicz *et al.* (2014) who found that the amount of available phosphorus in soil increased with increase in the amount of organic fertilizers (manure and slurry) applied. Bagasse ash significantly increased available P compared to liming and no amendment application. This agrees with findings by Hale *et al.* (2020) who reported that ash increased soil available phosphorus more than biochar, inorganic fertilizers and treatments with no amendment. Although the average available phosphorus was increased from 25 mg kg^{-1} to 29 mg kg^{-1}, it is slightly above the adequate range.

The CEC of soil increased due to application of decomposed cattle manure at high rate (10 t ha^{-1}). Manure adds organic matter to soil and releases basic cations into the soil solution over time. Changes in CEC were not visible during the first season but increases were observed during the second season. The decomposed cattle manure and ash had been reapplied at the planting of second season. Despite CEC being an inherent soil property, it is highly influenced by the content of organic matter of a soil (FAO & ITPS, 2015). This implies that soils with low organic matter content are likely to have low cation exchange capacity as seen in the highly weathered soils like the Acrisols and Feralsols and can be improved by increasing the organic matter content. Ingerslev *et al.* (2014) similarly reported that soil cation exchange capacity and base saturation significantly increased in plots treated with ash, as a result of increase of magnesium and calcium ions at 10 – 75 cm soil depth.

5.3 Effect of bagasse ash and lime as soil conditioners and decomposed cattle manure application levels on maize growth and yields

Soil acidity limits crop growth and yield as hydrogen and aluminium ions become toxic, inhibiting root growth thereby reducing water and nutrients uptake (Peret *et al.*, 2014; Singh *et al.*, 2014). The increase in maize height observed in the amended plots were due to the increase in root length, soil available phosphorus and pH. This can be explained by the positive role of phosphorus in influencing maize root growth and development (Peret *et al.*, 2014). Periodical liming of acid soils and farm yard manure fertilization is an important amelioration means of acid soils (Karcauskiene, 2019). Since the manure had adequate phosphorus and relatively high pH, its interaction with lime or ash had high influence on soil pH and could add more phosphorus that initiated root growth. Whereas plots with no amendments had low pH and shallow roots which could be attributed to aluminium toxicity. This is related to the study which found that negative effects of aluminium on plant growth prevail in soils with low pH and a reduction in root growth being the most serious consequence (Krstic *et al*., 2012). Roots are responsible for absorption of water and nutrients which are important resources affecting crop yields, hence crop yield is significantly related to total root length (Fageria & Moreira, 2011). This study shows that the interaction of manure with lime or with ash led to the achievement of high increases of maize height over the negative control in the two seasons. The differences in seasons are ascribed to the release of nutrients from manure and sugarcane bagasse ash over time and the addition of these amendments at planting during the first and second seasons. Maize stem collar diameter was larger in plots that received the amendments compared to those without amendments. This is attributed to low soil pH and available phosphorus in plots without amendment. The significant increase in leaf area index due to sugarcane bagasse ash, lime and manure application are related to adequate nutrient and water absorption. Similarly, significant difference in maize leaf area index was reported as result of liming (Muindi *et al*., 2015).

Maize yield parameters (biomass weight, grain yield and hundred grain weight) were significantly different such that interaction of 5 t ha^{-1} manure with 2 t ha^{-1} lime, or with 5 t ha^{-1} ash or the amendments applied alone were always superior to the plots without amendment. Similarly, Kaur *et al*. (2019) reported that greater weight (1000 grain weight), was observed in fly ash and farmyard manure in combination while plots without amendments had lower weights. In addition, average grain weight was greater in the combination of ash and farmyard manure followed by farmyard manure and gypsum, farmyard manure and lime and lowest in the negative control (Kaur *et al*., 2019). The significant differences observed in maize yield parameters are attributed to the better nutrient and water absorption and crop growth which were influenced by soil pH.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This research determines the effect of integrated application of decomposed cattle manure, lime and sugarcane bagasse ash on soil pH, available phosphorus, soil cation exchange capacity, maize growth and yield for two seasons in Kakamega, Western Kenya. There are significant differences due to different treatment combinations.

The following conclusions are drawn from the study:

(i) The application of decomposed cattle manure at the rate five tonnes manure per hectare in combination with two tonnes lime per hectare, secondly manure alone at the rate five tonnes manure per hectare, and finally the incorporation of ten tonnes decomposed cattle manure per hectare with two tonnes lime per hectare significantly lowers soil acidity.

(ii) Significant increases in soil available phosphorus result from the sole applications of decomposed cattle manure at the rates of 10 t ha^{-1} and 5 t ha^{-1}, sugarcane bagasse ash at 5 t ha^{-1} and lime at 2 t ha^{-1}. Highest increases result from more than one season's application of the amendments. Plots with no amendments yield the lowest values. Soil cation exchange capacity significantly increases with application of 10 t ha^{-1} decomposed cattle manure and 5 t ha^{-1} bagasse ash, singly. Significantly lower values result where there are applications of manure at 5 t ha^{-1}, lime at 2 t ha^{-1} and nil amendment.

(iii) Maize growth and yield are higher in plots that receive decomposed cattle manure, lime, and sugarcane bagasse ash than in plots without amendments. High significant differences occur due to the interaction of decomposed cattle manure with lime or sugarcane bagasse ash. Maximum maize grain yield result from the interaction of five tonnes decomposed cattle manure per hectare with two tonnes lime per hectare and five tonnes sugarcane bagasse ash per hectare follows. Nil application of the treatments gives the lowest maize yield and growth performance.

6.2 Recommendations

(i) To raise soil pH to the optimum for crop production, a combined application of decomposed cattle manure and lime at the rates 5 t ha^{-1} manure and 2 t ha^{-1} should be the first choice. The second alternative should be the application of 5 t ha^{-1} decomposed cattle manure alone or in combination with 5 t ha^{-1} sugarcane bagasse ash.

(ii) To improve soil available phosphorus, 5 t ha^{-1} sugarcane bagasse ash or 5 t ha^{-1} well decomposed cattle manure and lime at 2 t ha^{-1} should be the best choice. On the other hand manure should be applied at high rates such as 10 t ha^{-1} or 5 t ha^{-1} sugarcane bagasse ash if improvement of soil cation exchange capacity is the main objective.

(iii) To improve maize growth and yield, incorporation of 5 t ha^{-1} decomposed cattle manure with lime at 2 t ha^{-1} should be the first choice. Low pH soils should be amended to increase root growth for better absorption of nutrients and water.

The study recommends the following area of further research

(i) There is a need for further research on the long term effects of combined application of decomposed cattle manure and lime at the rates five tonnes decomposed cattle manure per hectare and two tonnes lime per hectare and decomposed cattle manure in combination with five tonnes sugarcane bagasse ash per hectare on soil pH.

(ii) There is a need to research on the mineralization rate of 5 t ha^{-1} sugarcane bagasse ash or 5 and 10 t ha^{-1} decomposed cattle manure and its effect on soil available phosphorus and cation exchange capacity.

(iii) The amendments during this study are added at the planting time of each season. This implies that, there is need for further research on the residual effect of the interaction of 5 t ha^{-1} decomposed cattle manure with 2 t ha^{-1} lime or with 5 t ha^{-1} sugarcane bagasse ash on maize growth and yield.

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APPENDICES

Appendix A. Analyses of Variance (ANOVA) for soil pH during the Short Rain (2019) and Long Rain (2020) Seasons at Kakamega, Western Kenya

Source of variation	df	Mean squares for soil pH
Season	1	0.0241***
Manure	2	0.2500***
Soil conditioner	2	0.0510***
Manure × soil conditioner	4	0.0464***
Season × manure	2	0.0117***
Season × soil conditioner	2	0.0018**
Season × manure × soil conditioner	4	0.0034***
Error	36	0.0003
Total	53	
CV%		0.3337
R^2		0.9858

Means followed by **, *** in each column are significantly different at $P < 0.01$ and $P < 0.001$ levels of significance. Where df is the degree of freedom and CV% is the coefficient of variation in percentage.

Appendix B. Analyses of Variance (ANOVA) for Soil Available Phosphorus during the Short Rain (2019) and Long Rain (2020) Seasons at Kakamega, Western Kenya

Source of variation	df	Mean squares for soil available phosphorus
Season	1	0.6512^{NS}
Manure	2	171.5029***
Soil conditioner	2	22.0518***
Manure × soil conditioner	4	0.6687^{NS}
Season × manure	2	1.6478^{NS}
Season × soil conditioner	2	0.0995^{NS}
Season × manure × soil conditioner	4	0.2208^{NS}
Error	36	0.3703
Total	53	
CV%		2.1624
R^2		0.9673

Means followed by *** in column are significantly different at $P < 0.001$ level of significance while means followed by ^{NS} are not significantly different. Where df is the degree of freedom, CV% is the coefficient of variation in percentage

Appendix C. Analyses of Variance (ANOVA) for Soil cation exchange capacity during the Short Rain (2019) and Long Rain (2020) Seasons at Kakamega, Western Kenya

Source of variation	df	Mean squares for cation exchange capacity
Season	1	0.0167**
Manure	2	0.0259***
Soil conditioner	2	0.0158***
Manure × soil conditioner	4	0.0038^{NS}
Season × manure	2	0.0013^{NS}
Season × soil conditioner	2	0.0008^{NS}
Season × manure × soil conditioner	4	0.0005^{NS}
Error	36	0.0016
Total	53	
CV%		0.2003
R^2		0.6730

Means followed by **, *** in each column are significantly different at $P < 0.01$ and $P < 0.001$levels of significance while means followed by ^{NS} are not significantly different. Where df is the degree of freedom and CV% is the coefficient of variation in percentage

Appendix D. Analyses of Variance (ANOVA) for Root length during the Short Rain (2019) and Long Rain (2020) Seasons at Kakamega, Western Kenya

Source of variation	df	Mean squares for maize root length
Season	1	0.5013^{NS}
Manure	2	21.1201***
Soil conditioner	2	36.4182***
Manure × soil conditioner	4	9.9224***
Season × manure	2	0.3475^{NS}
Season × soil conditioner	2	0.3227^{NS}
Season × manure × soil conditioner	4	0.2777^{NS}
Error	36	0.1515
Total	53	
CV%		1.4539
R^2		0.9666

Means followed by *** in column are significantly different at $P < 0.001$ levels of significance while means followed by ^{NS} are not significantly different. Where df is the degree of freedom and CV% is the coefficient of variation in percentage

Appendix E. Analyses of Variance (ANOVA) for Maize height during the Short Rain (2019) and Long Rain (2020) Seasons at Kakamega, Western Kenya

Source of variation	df	Mean square for height
Season	1	0.1392***
Manure	2	0.0994***
Soil conditioner	2	0.5300***
Manure × soil conditioner	4	0.0831***
Season × manure	2	0.0030^{NS}
Season × soil conditioner	2	0.0113***
Season × manure × soil conditioner	4	0.0437***
Error	36	0.0015
Total	53	
CV%		1.7427
R^2		0.9722

Means followed by *** in column are significantly different at P < 0.001 levels of significance while means followed by ^{NS} are not significantly different. Where df is the degree of freedom and CV% is the coefficient of variation in percentage.

Appendix F. Analyses of Variance (ANOVA) for Maize Leaf Area Index during the Short Rain (2019) and Long Rain (2020) Seasons at Kakamega, Western Kenya

Source of variation	df	Mean squares for Leaf Area Index
Season	1	0.00063**
Manure	2	0.15043***
Soil conditioner	2	0.20737***
Manure × soil conditioner	4	0.06569***
Season × manure	2	0.00002^{NS}
Season × soil conditioner	2	0.00013^{NS}
Season × manure × soil conditioner	4	0.00024
Error	36	0.00002
Total	53	
CV%		0.57437
R^2		0.99928

Means followed by **, *** in column are significantly different at $P < 0.01$ and $P < 0.001$ level of significance while means followed by ^{NS} are not significantly different. Where df is the degree of freedom and CV% is the coefficient of variation in percentage

Appendix G. Analyses of Variance (ANOVA) for Maize Stem Collar Diameter during the Short Rain (2019) and Long Rain (2020) Seasons at Kakamega, Western Kenya

Source of variation	df	Mean squares for stem collar diameter
Season	1	0.0032^{NS}
Manure	2	0.6334***
Soil conditioner	2	0.5720***
Manure × soil conditioner	4	0.1349***
Season × manure	2	0.0008^{NS}
Season × soil conditioner	2	0.0008^{NS}
Season × manure × soil conditioner	4	0.0012^{NS}
Error	36	0.0011
Total	53	
CV%		1.2045
R^2		0.9863

Means followed by *** in column are significantly different at $P < 0.001$ levels of significance while means followed by ^{NS} are not significantly different. Where df is the degree of freedom and CV% is the coefficient of variation in percentage

Appendix H. Analyses of Variance (ANOVA) for Maize Biomass weight during the Short Rain (2019) and Long Rain (2020) Seasons at Kakamega, Western Kenya

Source of variation	df	Mean squares for biomass
Season	1	33.19^{NS}
Manure	2	8240163.87***
Soil conditioner	2	8668022.51***
Manure × soil conditioner	4	6297485.82***
Season × manure	2	136.43^{NS}
Season × soil conditioner	2	225.01^{NS}
Season × manure × soil conditioner	4	717.84^{NS}
Error	36	3287.01
Total	53	
CV%		1.21
R^2		0.99

Means followed by *** in column are significantly different at $P < 0.001$ levels of significance while means followed by ^{NS} are not significantly different. Where df is the degree of freedom and CV% is the coefficient of variation in percentage.

Appendix I. Analyses of Variance (ANOVA) for Maize Grain Yield during the Short Rain (2019) and Long Rain (2020) Seasons at Kakamega, Western Kenya

Source of variation	df	Mean squares for grain yield
Season	1	13130.90^{NS}
Manure	2	4851457.72***
Soil conditioner	2	5589319.48***
Manure × soil conditioner	4	4381368.20***
Season × manure	2	10920.00^{NS}
Season × soil conditioner	2	22708.45^{NS}
Season × manure × soil conditioner	4	7496.82^{NS}
Error	36	14547.29
Total	53	
CV%		2.75
R^2		0.99

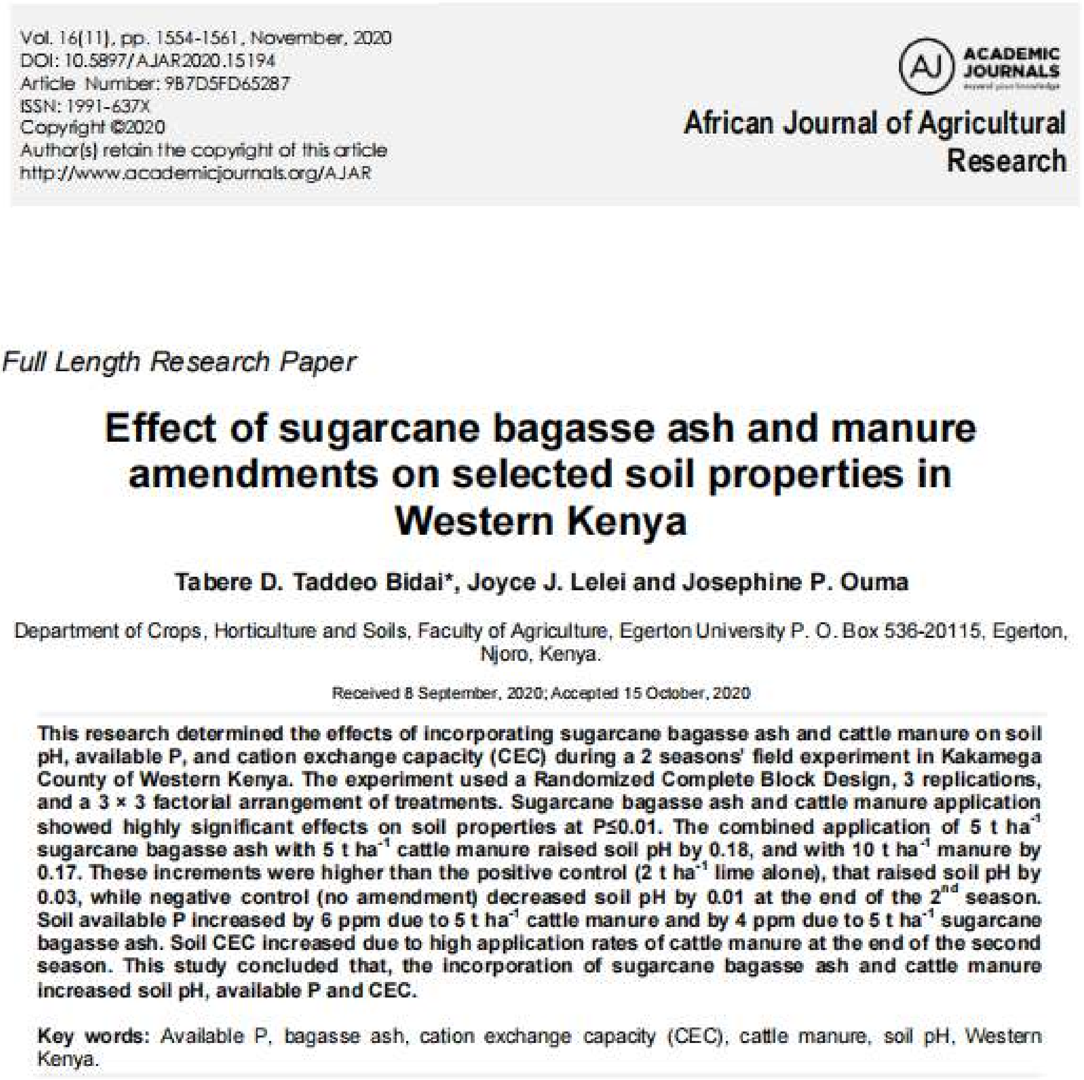
Means followed by *** in column are significantly different at $P < 0.001$ levels of significance while means followed by ^{NS} are not significantly different. Where df is the degree of freedom and CV% is the coefficient of variation in percentage.

Appendix J. Analyses of Variance (ANOVA) for Hundred Maize Grain Weight during the Short Rain (2019) and Long Rain (2020) Seasons at Kakamega, Western Kenya

Source of variation	df	Mean squares for 100 grains
Season	1	0.13^{NS}
Manure	2	57.08***
Soil conditioner	2	1.02*
Manure × soil conditioner	4	15.55***
Season × manure	2	0.06^{NS}
Season × soil conditioner	2	0.04^{NS}
Season × manure × soil conditioner	4	0.02^{NS}
Error	36	0.13
Total	53	
CV%		1.48
R^2		0.96

Means followed by *, *** in column are significantly different at $P < 0.05$ and $P < 0.001$ levels of significance while means followed by ^{NS} are not significantly different. Where df is the degree of freedom and CV% is the coefficient of variation in percentage.

Appendix K. Abstract of publication



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Full Length Research Paper

Effect of sugarcane bagasse ash and manure amendments on selected soil properties in Western Kenya

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This research determined the effects of incorporating sugarcane bagasse ash and cattle manure on soil pH, available P, and cation exchange capacity (CEC) during a 2 seasons' field experiment in Kakamega County of Western Kenya. The experiment used a Randomized Complete Block Design, 3 replications, and a 3 × 3 factorial arrangement of treatments. Sugarcane bagasse ash and cattle manure application showed highly significant effects on soil properties at $P \leq 0.01$. The combined application of 5 t ha^{-1} sugarcane bagasse ash with 5 t ha^{-1} cattle manure raised soil pH by 0.18, and with 10 t ha^{-1} manure by 0.17. These increments were higher than the positive control (2 t ha^{-1} lime alone), that raised soil pH by 0.03, while negative control (no amendment) decreased soil pH by 0.01 at the end of the 2^{nd} season. Soil available P increased by 6 ppm due to 5 t ha^{-1} cattle manure and by 4 ppm due to 5 t ha^{-1} sugarcane bagasse ash. Soil CEC increased due to high application rates of cattle manure at the end of the second season. This study concluded that, the incorporation of sugarcane bagasse ash and cattle manure increased soil pH, available P and CEC.

Key words: Available P, bagasse ash, cation exchange capacity (CEC), cattle manure, soil pH, Western Kenya.

Appendix L. Research Authorization

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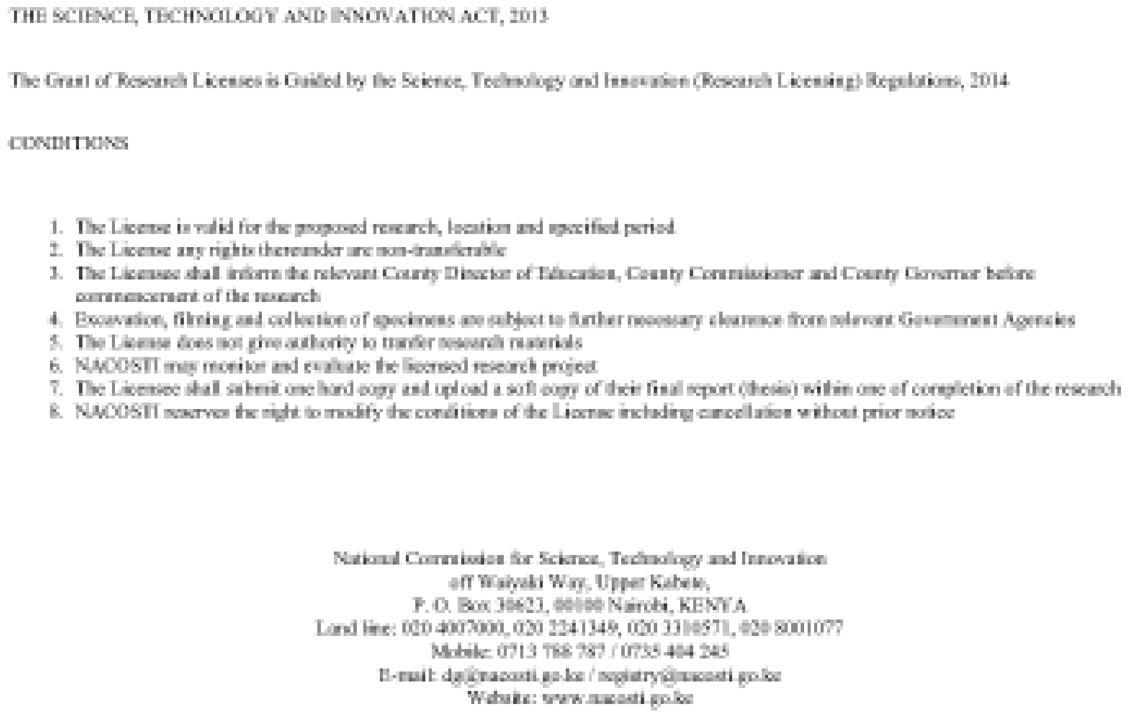

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