BIOMASS-BASED FERTILIZER FORMULATION USING CHEMICALLY DECOMPOSED AGRICULTURAL WASTES AND EVALUATION OF ITS EFFICACY IN GROWING MAIZE

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DECLARATION

I confirm that this thesis is my original work and has not been presented for award of any degree or any other award in any other University.

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DEDICATION

I dedicate this work to my beloved family.

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ABREVIATIONS, ACRONYMS AND SYNONYMS

AW	Agricultural wastes
ANOVA	Analysis of variance
APHA	American Public Health Association
BBF_1	Biomass-based Fertilizer formulation 1
CAN	Calcium Ammonium Nitrate
CASD	Cobs Ash Sisal Digest
CDMPDD	Clean Development Mechanism Project Design Document
CFA	Calcium Fluorapatite
CFAs	Compost Fungus Activators
CNMPs	Comprehensive Nutrient Management Plans
DAP	Diammonium Phosphate
DM	Dry Mass
DOC	Degradable organic Carbon
EAC	East African Community
EFMA	European Fertilizer Manufacturers Association
EPA	Economic Partnership Agreements
EMO	Effective Microorganisms
FAO	Food and Agriculture Organization of the United Nations
FTWG	Fertilizer Technical Working Group–Kenya
GDP	Gross Domestic Product
GoK	Government of Kenya
HD	Horns or Hooves digest
HA	Hydroxyapatite
IARI	Indian Agricultural Research Institute
IFDC	International Fertilizers Development Centre
IPNI	International plant nutrient institute
LFE	Low fertilizer efficiency
KEBS	Kenya Bureau of Standards
KEPHIS	Kenya Plant Health Inspectorate Services

KESREF	Kenya Sugar Research Foundation
KNBS	Kenya National Bureau of Statistics
KMDP	Kenya maize development programme
KSI	Kenya sugar industry
MAP	Monoammonium Phosphate
MoP	Muriate of Potash
NAAIAP	National Accelerated Agric. Inputs Access
NaSD	Sodium Sisal digest
NDVI	Normalized Difference Vegetation Index
NPK	Nitrogen, Phosphorous and Potassium
NRAES	Natural Resource, Agriculture, and Engineering Service
NRCS	National Resource Conservation Services
NUE	Nutrient use efficiency
PCU	Polymer coated Urea
SBW	Sisal bole waste
SoP	Sulphate of Potash
SRF	Slow Release fertilizers
SSP	Single Superphosphate
SW	Sisal wastes
TSP	Tripple Superphosphate
UNESP	Universidade Estadual Paulista
USDA	United states of America department of Agriculture
KSS	Kenya Soil Survey
ACD	Augmentative Communication Device
VOCA	Voice Output Communication Aids

ABSTRACT

Utilization of the conventional fertilizers such as NPK, DAP, CAN and Urea by smallholder farmers in developing countries like Kenya has remained dismal due to high retail prices as well as environmental and soil related concerns such as P-fixation, leaching and volatilization. Organic fertilizers generated using traditional composting methods come in handy despite own challenges of long composting periods, imbalanced nutrients and environmental impacts of pathogens. The long composting period can be shortened through chemical decomposition of selected farm wastes that can provide balanced nutrients. The objective of this study was to utilize chemically decomposed agricultural wastes to formulate a biomass-based fertilizer and evaluate its efficacy in growing maize. Selected agricultural waste (maize cobs, maize stalks, sugar cane bagasse, sisal leaf pulp and cattle horns/hoofs) were analyzed for nutrients N, P, K and Ca to determine their suitability for formulating a Biomass-Based Fertilizer (BBF). Results indicated that the agricultural wastes had varied levels of macronutrients sufficient to support use in fertilizer formulation. The acidic sisal leaf pulp required basic conditions to decompose. The lye from burned maize cobs was used to digest sisal leaf pulp to give a basic cobs ash sisal digest (CASD) product while cattle horns and hoofs soaked in peracetic acid gave an acidic horns and hooves digest (HD) product. HD (acidic) was mixed with CASD (basic), (HD: CASB) in varying ratios to give different fertilizer formulations namely, BBF_0 (0:1), BBF_1 (1:1), BBF_2 (2: 1), BBF_3 (3:1), BBF_4 (1:2) and BBF_5 (1:0). The formulations had pH varying from 6.82±0.15 to 8.41±0.27 and would provide macronutrients in the ranges of 1.0-3.9 g (N), 0.002-0.17 g (P), 0.001-6.30 g (K) and 0.08-9.20 g (Ca) per plant environment. Fertilizer formulation BBF_1, with pH above 7.5 and macronutrients 2.31% N, 0.08% P, 2.5% K and 3.46% Ca, was used in efficacy study carried out in Lugari, Kakamega county because of the acidic nature (pH<7.0) of the field soils. Plant height and yield of maize under the BBF_1/BBF_1 and that under the DAP/CAN schedules were comparable, but differed significantly from those of maize in the plots without fertilizer schedule. Side dressing maize whose leaves developed purple coloration (phosphorus deficiency) with freshly prepared BBF_1 cleared P-deficiency symptoms in $\leq$ 7 days. Chemical decomposition of agricultural wastes produces digests that blend into a BBF formulation that is effective in promoting growth and yield of maize crops.

CHAPTER ONE

1 INTRODUCTION

1.1 Background Information

Macronutrients are nutrients that are consumed in large quantities and are present in plant tissues in quantities ranging from 0.15 % to 6.0 % on dry mass basis. These nutrients are recycled back to the soil when the organic matter is broken down by soil microorganisms during decaying (Solano *et al*., 2001). This is particularly important for phosphorus which has no significant gaseous phase and cannot circulate freely in the atmosphere. This means that plant wastes should deliberately be returned to the soils upon harvesting to replenish the soil nutrients. However, decomposition of the materials takes long periods and the nutrients may not be readily available in the next planting season for small scale farm holdings who must use the same farmlands year after year. One practical way of achieving this is intentional composting of the agricultural wastes before returning them to the farms.

Composting is a natural method that uses bacteria and other organisms to breakdown organic matter (animal matter, animal excreta (manure), human excreta and vegetable matter) to release the macronutrients into the humus that can be used as organic fertilizers (Dittmar *et al*., 2009). It takes 3-7 months for a compost to become ready for use as a fertilizer. The compost is considered mature once it has lost 20-60 % of its mass.

The composting methods currently in use can broadly be divided into traditional, evolved traditional and rapid composting methods. The traditional methods involve stalking the material in piles or pits to decompose over a long period with little agitation and management (Misra, Roy and Hiraoka, 2003). The traditional methods are based mainly

on anaerobic decomposition or decomposition aided by passive aeration through measures like little and frequent turning or static aeration provisions like pipes or perforated poles for several months. Evolved traditional methods have been developed with intention of reducing the period of decomposition. They include the Indian Bangalore method with decomposition period of 4 months (FAO, 1980), Chinese rural composting (2-3 months) and windrow composting method that takes 8 weeks (NRAES, 1992).

Rapid composting methods are those that make use of the above innovations that enhance aerobic process bringing down composting period from month to weeks. The Berkley rapid composting and North Dakota University hot composting improves on the previous approaches by having accelerated decomposition through measures like sizing of the raw material, use of chicken manure, urine, turning of the material daily. Degradation period in these cases reduce to 2-3 weeks and 4-6 weeks, respectively (Raabe, 2001; Smith, R.C., 1995). Special methods have further been developed targeting definite biomass. Decomposition of rice husks, bran and cow dung using microorganism takes four weeks just as cellulolytic culture based method that uses a fungus *Trichoderma harzianum* as decomposer (Virginia, 1997). Vermicomposting utilizing worms takes 6-12 weeks (NRAES, 1992).

Though the rapid decomposition methods now exist, the high costs and time investment expected of farmers account for the slow or no adoption of the slow release fertilizer technology, evolved traditional and rapid composting methods. The smallholder farmers resort to the use traditional composting methods, where they face challenges including long periods of composting (months-years), imbalanced nutrients, odour and environmental

impacts of pathogens. Use of organic fertilizers generated in either way risks over or under supplying macronutrients. These have remained unresolved despite the importance of composting. There remains, therefore, a need for a method of rapidly decomposing organic matter that is cost-effective, with predictable levels of macronutrients and minimal environmental effects of pathogens.

Blending the chemically treated biomass from different sources would constitute a biomass- based fertilizer (BBF) formulation. Blending chemically treated biomass in given ratios further ensures uniformity of nutrients. The blends would not only address challenges of conventional inorganic fertilizers but also those of the composting methods (traditional, evolved traditional or rapid). Efficacy is defined as the performance of an intervention derived under ideal and controlled circumstances. As such a fertilizer formulation can be tested alongside an inorganic fertilizer as control in promoting growth of select trial plants. The blends would therefore need to be evaluated for effectiveness.

1.2 Problem Statement and Justification

Farming households in rural communities in Kenya generate enormous solid farm wastes such as manure, tree trimmings, grass clippings, and animal and crop residues, accounting for up to 80 % the total waste generated on a farm (Brown and Root, 1997). The agricultural wastes such as sisal leaf pulp, maize stovers, animal hooves and horns are rich in plant macronutrients (N, P, K and Ca) necessary for crop production. Although farmers are often encouraged to utilize the wastes as a fertilizer resource after composting, some keratinous waste materials such as feathers from poultry, horns, hooves and fur from farm animals take long (some years) to decompose. Thus though rich in nitrogen, when not used for other

industrial applications keratinous waste materials end up in municipal solid waste landfills where they remain for very long periods. Other wastes such as sisal leaf wastes, sugarcane (bagasse), coffee (husks), corn stover (maize cobs and stalks) and rice husks not only pose a disposal challenge but produce a bad odour during decomposition. Sisal leaf wastes being acidic and with no documented uses in Kenya, are mainly disposed into landfills or burnt to ashes at the sisal processing sites. Mechanisms including pre-treatment of the biomass that would help reduce composting periods, microorganisms involved and odour but increase nutrient / material volume ratio should be encouraged.

Rapid chemical decomposition of farm wastes overcomes the decomposition challenges by not only reducing long composting periods but also the characteristic bad odour that emanates during decomposition. In this approach what would take months (sisal leaf pulp and maize cobs) is ready in hours while those that would take years to decompose like horns and hoofs are ready in weeks. Chemical decomposition also encourages blending to minimize imbalances in nutrients that would be experienced if individual wastes were used on their own.

The objective of this study was to investigate the chemical decomposition of selected agricultural wastes into forms suitable for the formulation of biomass-based fertilizer (BBF). The efficacy of the formulated biomass-based fertilizer was evaluated in the growing of maize, a staple food crop in Kenya, against conventional commercial fertilizers. Utilization of these agricultural wastes through formulating an effective BBF is not only a value addition venture but a pathway of waste disposal.

1.3 Research Hypothesis

Rapid chemical decomposition of agricultural wastes does not give materials that can be used to formulate an efficacious fertilizer for growing of maize.

1.4 General Objective

To investigate the rapid chemical decomposition of selected agricultural waste for use in formulation of biomass-based fertilizer and to evaluate the efficacy of the formulated fertilizer in the growing of maize.

1.5 Specific Objectives

i) To determine levels of N, P, K and Ca in selected agricultural waste (cobs and stalks of different maize varieties, livestock horns/hooves, sisal leaf wastes and sugarcane bagasse).

ii) To determine the optimum conditions for the chemical decomposition of sisal leaf pulp, animal hooves and horns.

iii) To formulate and characterize biomass-based fertilizer (BBF) from chemically decomposed agricultural waste.

iv) To evaluate the efficacy of the formulated biomass-based fertilizer (BBF) on growth and yield of maize.

1.6 Significance of the Study

A method for the rapid chemical decomposition of agricultural biomass has been developed. Rapid chemical decomposition of sisal leaf pulp, maize cobs and stalks, horns and hoofs enables use of these rich but underutilized agricultural wastes for biomass-based

fertilizer formulation. The study creates a value addition pathway for the agricultural waste disposal.

1.7 Scope and Limitations

The study only considered agricultural biomass sisal (*Agave sisalana*) leaf pulp, cattle hooves and horns, corn stover (cobs and stalks) and sugarcane bagasse. The effectiveness of BBF in promoting growth and yield of crops was based on performance of one of the formulations (BBF_1). The formulation (BBF_1) evaluated was considered as ideal on the basis of its high pH to counter the acidic (pH < 7.0) soils at the study site. other possibilities ideal for neutral or basic soils were only subjected to pH and macronutrient analysis. The efficacy of BBF on the growth and yield of maize were considered in comparison with DAP and CAN. Maize as test crop was chosen because of its widespread consumption by many households.

Only horns and hooves of adult cattle slaughtered in local (Lugari) slaughter houses were considered. The corn stover (maize stalks and cobs) were of eight maize varieties H500, H505, H513, H614, H6213, oduma, pioneer and DK commonly grown in the study area (Lugari of kakamega county). Lugari was chosen as a test site given that it is one of the regions growing maize on large scale. The stalks and cobs used in the study were not necessarily of the same plant but from same farms. The sugarcane bagasse was collected disregarding the varieties. The soil environments of the sisal, sugarcane and maize plants whose leaf wastes, bagasse and the stover used were not considered. The study had no control over the heavy rains during field work.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Agricultural Production

Agricultural production is the main source of livelihood in the rural areas in Kenya and is driven by small to medium farmers who on average own land sizes ranging from 0.2 to 3 ha (Kenya Economic Report, 2017). They grow a range of subsistence crops and one or two cash crops relying on family labour (Nagayets, 2005). They produce 63 % of the food in Kenya. These include growing of maize (*Zea mays*), beans, sorghum, millet, vegetables, potatoes, cassava, sugarcane and livestock keeping to supplement their farm incomes. Maize accounts for 40 % of cultivated area and > 51 % of staple food produced in Kenya. Smallholder farmers produce more than 75 % of the maize in Kenya (Abate *et al.*, 2015). Because of the small sizes of the farms, and the multiplying demands on agriculture, farmers use high-yielding crop varieties that progressively deplete the soils' natural nutrients pool. Coupled with repeated cultivation of cereals on the same land without addition of organic or inorganic fertilizers leads to low yield, especially, where farmers are unable to afford farm inputs (FAO, 2011). Recycling the biomass would be ideal but for the long composting periods that hinder rapid release of the retained nutrients.

One objective of modern agriculture is to maximize and sustain crop yields. Agriculture production and productivity are directly linked with nutrient availability in the soils (Fageria and Baligar, 2005). Soil infertility (natural element deficiencies or unavailability) is probably the single most important factor limiting crop yields worldwide (Fageria and Baligar, 2005). For sustained high crop yields, the application of nutrients is required. It is pertinent that innovations related to fertilizers consider macronutrient levels in the output.

Compost that arises from decomposition of the biomass through traditional composting methods is handy but for imbalance in the nutrients. This certainly is a factor affecting agricultural production since most small scale farmers rely on it.

Factors affecting agricultural production are constantly evolving and not just limited to fertilizers. A number can cause productivity to increase or decrease (Folnovic, 2015). Productivity is not an absolute measure, but rather a reflection of the ratio between inputs and outputs. Some factors that affect agricultural production are not within the farmers' control. They may run as farmer interactions with natural resources, government policies, international trade agreements, traditional practices, public opinion and concerns. Access to fertilizer is constrained by market liberalization and trade policies that increase fertilizer prices relative to commodity prices. Limited access to market and infrastructure limits abilities to purchase fertilizers and other inputs (Kherellah, Delgado, Gabre-Madhin, Minot, and Johnson 2002). This therefore calls for efforts to monitor and strategize on available farm inputs including fertilizers.

Production of biomass-based fertilizer from rapidly decomposed agricultural wastes as in this study targets recycling the underutilized agricultural wastes. A biomass-based fertilizer with sufficient and balanced macronutrients will be an optional avenue of disposing the wastes while enhancing agricultural production.

2.2 Fertilizer Supply and Consumption

Many agricultural soils in Sub-Saharan Africa (SSA) are deficient in N, P, K, S and micronutrients. Africa is therefore a key driver of the future fertilizer growth, with consumption expected to increase from 5 million tons annually to reach 5.9 million tons of

nutrients by 2022. This represents a change from 16 kg/ha to 22 kg/ha rate that is well below the continent-wide recommendation of about 100 kg/ha (Antonella, 2019). This consumption however would represent 3% of the world global fertilizer consumption (Antonella, 2019). The small share of the global market is a reflection of decreasing soil fertility, low application rates, unfavorable input output ratio and constraints to input and output market development (Gregory and Bumb, 2006; Ariga and Jayne, 2009). The current growth is mainly driven by higher application rates rather than increased cropland.

More than half (62 %) fertilizers consumed in Africa are imported so as to meet requirements. The consumption within the continent is equally uneven both between countries and within individual countries (Bumbe, Makonese, Nijhoff, Mathende, and Phiri, 2008). The fertilizer application rates vary widely between commercial and traditional communal farm lands. The countries with more commercialized agriculture consume the bulk of fertilizers in Africa. A high local consumption provides a bigger market for producers and so the biggest consumers are also the producers with exception of Ethiopia, Sudan and Kenya which do not produce but import significant tonnages (Makonese, 2003).

The changes in the annual amounts of conventional fertilizers consumed in Kenya (2012-2015) exhibit consumer preferences (Table 2.1).

Table 2. 1: Fertilizers consumption in Kenya 2012-2015

Fertilizer Name	2012	2013	2014	2015
NPK	139,578	129,540	136,880	166,342
DAP	126,470	273,939	144,450	127,672
CAN	53,616	101,201	87,900	99,120
UREA	66,804	114,515	25,117	43,584
OTHERS	46,684	49,983	64,779	54,419

Source: FTWG- KEN. Others include Phosphate Rock, SOP, MOP, KNO_3.

NPK's, DAP and CAN accounted for most (71%) of the total fertilizers officially imported to Kenya in the period 2012 to 2015. Nduati *et al*., (2015) compared imports for the past four years and noted that the top 5 imports have been consistent throughout. Urea imports increased (8%) in 2015 compared to previous year' change (5 %). Steady rise in demands for NPK helps direct efforts in the supply and research in the fertilizer industry. This is also supported in part by records with the ministry of agriculture (Kenya), farm division (GoK, 2011) that showed utilization of fertilizers DAP, MAP, TSP, SSP and NPK for plants rose by 48.56% in the period 2002-2009. The same report noted that there was a 25.36% increase in demand over the same period for CAN, ASN, Urea and SA for side dressing. The rise in consumption is not because the number or land size is increasing but those who afford use more. The high prices are still a barrier to smallholder farmers.

Additives to the soil can either counter or aggravate the soil condition. Farm soils can be acidic, neutral or basic. Continued use of conventional fertilizers urea, DAP and CAN have a predictable effect of turning soils acidic. The manure generated through composting are basic in nature. Both conventional fertilizers and manure are applied by most households regardless of soil pH. With both continental fertilizer supply and consumption low appropriate initiatives to improve on already in use composting methods will help improve the fertilizer situation. In this regard studies should seek a flexible fertilizer formulation that minimizes limitations like fertilizer cost, soil pH and inequity in plant macronutrients.

2.3 Plant Macronutrients

A fertilizer is any material of natural or synthetic origin (other than living material) that is applied to the soil or to plant tissues to supply one or more plant macronutrients essential

for plant growth or yield (Scherer, 2000). They enhance plant growth by either providing nutrients or modify water retention and aeration thereby enhancing effectiveness of the soil. Fertilizers provide in varying proportions N, P and K as the main macronutrients; Ca, Mg and S as secondary macronutrients and micronutrients Cu, Fe, Mn, Mo, Zn, B, Si, Co and V. Macronutrients play an important role in the entire plant life. They perform various beneficial roles in plant metabolism as well as protection from biotic and abiotic stresses that include stresses of heavy metals, drought, heat, UV, radiations and from diseases and insect attack (Shanker and Venkateswarlu, 2011). The macronutrients also help increase growth, quality and yield of crops (Morgan and Connolly, 2013). This is as each has specific roles they play during the growth of a plant.

Nitrogen has a conspicuous place in plant metabolism system being an essential component of the protein. Thus, to get more crop production, nitrogen application is indispensable. Nitrogen increases yields (Massignam *et al*., 2009) and quality (Ulla, Annuar and Rana, 2010). A sufficient supply of nitrogen increases photosynthetic processes, leaf area production, leaf area duration as well as net assimilation rate (Ahmad *et al*., 2009). Plant nitrogen use efficiency is greatly affected by soil and climatic factors including soil pH, crop removal, leaching, organic matter and presence of other nutrients. Nitrogen use is efficient in soils pH 6.5-7.0.

The plants require phosphorous for the development of ATP (energy), sugars and nucleic acids. Phosphorous deficient plants turn dark green and appear stunted. Older leaves are usually affected first because phosphorous is a mobile nutrient. The older leaves acquire

purple discoloration due to the accumulation of sugars. The plants appear weak and leaf expansion is inhibited.

Potassium levels in plants are quoted to range 3-4 % (SQM, 2006) with young leaves having 3-5 % range (Plank and Kissel, 2008). Potassium has no structural purpose but it is the most common cation in the plant biochemical process that is useful in the protein synthesis, photosynthesis and transport of sugar from leaves to the fruits. The role of potassium in protein synthesis enhances conversion of nitrate into the protein which contributes to enhanced efficiency of supplied nitrogen fertilizers (SQM, 2006).

Calcium is required for structural roles in the cell wall and membranes as a counter cation for inorganic and organic anions in the vacuole and as an intracellular messenger in the cystol (Maschmer, 1995). In a soil growing medium, calcium travels right along with water and its uptake by plant roots is directly affected by a plant's transpiration rate and the level of moisture present. Old leaves contain more calcium and less potassium and magnesium than young ones (Kirkby and Pilebeam, 1984). Calcium cannot be mobilized from old tissues and be redistributed via the phloem (White and Broadley, 2003). This forces the developing tissues to rely on the immediate supply of calcium in the xylem. Its uptake is passive and does not require energy input and therefore calcium uptake is directly related to the plant transpiration rate. Transpiration is low in young leaves, enclosed tissues and in fruit (White and Broadley, 2003). The range of calcium and magnesium in plant tissues varies considerably within a given crop and among crops (Plank and Kissel, 2008). The calcium content of leaves changes downward in the shoot and crown and from the crown

peripheries to its center. Younger leaves show deficiency earlier because they have low transpiration rate (Gilliham *et al*., 2011).

Plants growing in adequate calcium in their natural habitat usually have shoot calcium concentrations of 0.1 and 5.0 % dry weight (Maschmer, 1995). These values reflect both calcium available in the environment and contrasting calcium requirements of different plant species.

The small scale farmers may not necessarily be aware of the roles of the different macronutrients in plant life but are able to judge the need for fertilizer addition from deficiency symptoms. Many however may not tell the particular nutrient needed and those with conventional fertilizers may give up when they are only applying a wrong fertilizer. It is at this point organic fertilizers have an advantage for the blind (without knowing macronutrient levels) application of manure increases chances of supplying the right nutrient. Organic fertilizers however don't have proportionate levels of macronutrients. Being a key alternative to the use of conventional fertilizers, production of organic fertilizers through composting requires more approaches so as to be applicable to all biomass. Some biomass though plenty and rich in macronutrients are ignored for on the basis of the current composting methods would still take long to be in a state that delivers the nutrients.

2.4 Biomass Composting and the Future of Fertilizers

2.4.1 Policy Measures for Composting in Kenya

A policy on composting has been inexistent in Kenya till recently when strategies were put in place. According to the draft policy in the ministry of environment and forestry, 2019 a

major waste stream of biodegradable material consisting of organic and kitchen waste, waste generated in agriculture through poor post-harvest management, market places unsold produce, fresh and rotten vegetable waste, expired grain produce and farm level agricultural waste which is biodegradable under controlled aerobic conditions. Once segregated at source, composting is an effective method for recycling organic waste.

Embracing use of compost from organic (agriculture and food based) and other suitable wastes will contribute to the reduction in greenhouse gases. This will recycle the nutrients outside of landfills. The Policy Statement in part says,

"National Government shall:

i) Provide technical support to county governments and private sector to manage food and organic wastes collection with appropriate treatment options depending on the local conditions.
ii) Develop guidelines, standards and review relevant legislation to mainstream and recognize compost and organic fertilizer.
iii) Support market development of compost as an alternative or complimentary for synthetic fertilizer by mainstreaming 40% quota system for organic fertilizer in the national and county fertilizer subsidy program.
iv) Develop a public information and awareness campaign to disseminate the benefits of composting as technology in waste management."

Concurrently the national and county government shall carry out feasibility study to identify potential sites for setting up composting plants and financial requirements of setting up composting technology in the country.

"The County Government shall:

i). Identify and prioritize potential sites for setting up composting plants and financial requirements of setting up composting technology in the county.

ii). Establish composting sites.

iii). Establish clear procedures for providing incentives to encourage private sector participation in composting ventures."

Utilization of chemically decomposed agricultural wastes or biomass in formulating a biomass based fertilizer is in step with this proposed policy.

2.4.2 Composting Methods

Composting is the sum of complex metabolic processes performed by different microorganisms that in the presence of oxygen use nitrogen and carbon available to produce own biomass (Roman, Martinez and Pantoja, 2015). Threats to ecosystems from inappropriate and over use of inorganic fertilizers, soil biodiversity, land degradation, atmospheric pollution have rekindled the global interest in composting. The potential of composting offers several benefits such as enhanced soil fertility and soil health thereby increased agricultural productivity, improved soil biodiversity and reduced ecological risks and a better environment.

The process of composting takes place in phases determined by temperature that results from reactions (Roman *et al*., 2015). At 45 ^{o}C metaphilic phase that takes 2-8 days starts off before thermophilic and hygienization at 60 ^{o}C involving bacteria degradation of cellulose and lignin transforming nitrogen to ammonia sets in for a period ranging weeks to months. Once the carbon and nitrogen are exhausted temperature drops to 40-45 ^{o}C leading to the cooling phase in which there is continued polymer degradation of cellulose

before fungi appearing. This is followed by maturation phase that takes place at an ambient temperature and involves condensation and polymerization occurring to form humic and fulvic acids (Roman *et al*., 2015). The pH then drops slightly though remains alkaline. All the phases involve reduction in levels of carbon as well as nitrogen. An input that reduces carbon but sustains nitrogen would be adding value to the composting practices.

Composting methods can broadly be divided into traditional and rapid composting practices. In either way aerobic and anaerobic processes have been developed and reported.

2.4.2.1 Indian Bangalore method

This is one of the traditional anaerobic methods also called direct composting. Highly recommended where night soil (human waste) and refuse are used for preparing the compost (FAO, 1980). Trenches or pits stashed with organic residues and night soil in alternate layers are set up (FAO, 1980). After filling, the pits are covered with layers of refuse of 15-20 cm. The materials are allowed to remain in the pit without turning and watering for three months. During this period, the material settles owing to reduction in biomass volume. Additional night soil and refuse are placed on top in alternate layers and plastered or covered with mud or earth to prevent loss of moisture and breeding of flies. After the initial aerobic composting (about eight to ten days), the material undergoes anaerobic decomposition at a very slow rate. It takes about six to eight months to obtain the finished product.

The shortcomings of this method of composting include length of time (6-8 months) before the compost can be used. The method is only suitable for areas with scanty rainfall, cannot be refilled once used, digging holes or trenches every now and then and the compost cannot

be collected and used elsewhere. Use of night stools can be a strong deterrent due to believes in some developing countries.

2.4.2.2 Passive composting of manure piles

Passive composting or open air composting or bay composting is also a traditional method that involves stacking the materials in piles to decompose over a long time with little agitation and management (NRAES, 1992). The process has been used for composting animal wastes. The anaerobic micro-organisms dominate the degradation. All of the undesirable effects associated with anaerobic degradation occur.

It is commonly used for composting leaves. It demands minimal labour and equipment. Passive composting is slow because of its low aeration rate, and the potential for odour problems is greater. Turning to aerate is essential part of the process though quite involving. The heaps require covering in case of raining. The set up can smell and attract flies if filled with wrong material.

2.4.2.3 Indian Coimbatore method

An aerobic composting method through passive aeration (Manickam, 1967). It involves digging a pit in which farm wastes such as straw, vegetable refuse, weeds and leaves are spread to a thickness of 15-20 cm (IARI, 1989). Wet animal dung is spread over this layer to a thickness of 5 cm. Water is sprinkled to moisten the material (50-60 percent of mass). This procedure is repeated until the whole mass reaches a height of 60 cm above ground. It is then plastered with mud, and anaerobic decomposition commences. In four weeks, the mass becomes reduced and the heap flattens. The mud plaster is removed and the entire mass is turned. Aerobic decomposition commences in at this stage. Water is sprinkled to

keep the material moist before the compost is ready for use after four months. This method has been modified in many ways.

The Indian Indorepit method, is a modification of the Coimbatore method. It is also a traditional procedure in which raw materials used are mixed plant residues, animal dung and urine, earth, wood ash and water. All organic material wastes available on a farm, such as weeds, stalks, stems, fallen leaves, pruning's, chaff and fodder leftovers, are collected and stacked in a pile (IARI, 1989). The mixture of different kinds of organic material residues ensures a more efficient decomposition. The material is turned three times while in the pit during the whole period of composting. At each turning, the material is mixed thoroughly and moistened with water. As a modification it is faster but labour intensive.

The Indian Indore heap method is another modification that is useful during rainy seasons or in regions with heavy rainfall (Misra *et al.*, 2003). The compost may be prepared in heaps above ground and protected by a shed. The heap is usually started with a layer of carbonaceous material like leaves, hay, straw, sawdust, wood chips and chopped corn stalks. This is covered with nitrogenous material such as fresh grass, weeds or garden plant residues, fresh or dry manure or digested sewage sludge. The pile is sometimes covered with soil or hay to retain heat and it is turned at intervals of 6 and 12 weeks. In some instances the heaps are covered with thin plastic sheets to retain heat and prevent insect breeding. The process takes about four months to complete.

2.4.2.4 Chinese rural composting - pit method

A method in which composting is in a circular or rectangular pit (FAO, 1980). Animal dung, rice straw, aquatic weeds and green manure crops are used. Silt pumped from river

beds is often mixed with the crop residues. The pits are filled layer by layer, each layer being 15 cm thick. Usually, the first layer is a green manure crop or water hyacinth, the second layer is a straw mixture and the third layer is animal dung. These layers are alternated until the pit is full, when a top layer of mud is added. A water layer of about 4 cm deep is maintained on the surface to create anaerobic conditions, which helps to reduce nitrogen losses. In total, there are three turnings. A little superphosphate is added and mixed thoroughly after the first turning. Water is added as necessary. The second turning is done after another month and the third two weeks later. The material is allowed to decompose for three months.

Chinese rural composting, a high temperature method is a form of rapid method (Misra *et al*., 2003). The compost is prepared mainly from night soil, urine, sewage, animal dung, and chopped plant residues at a ratio of 1:4. The materials are heaped in alternate layers starting with chopped plant stalks and followed by human and animal wastes; water is added to an optimal amount. At the time of making the heap, a number of bamboo poles are inserted for aeration purposes. Once the heap formation is complete, it is sealed with 3 cm of mud plaster. The bamboo poles are withdrawn, leaving the holes to provide aeration. Temperature rises to 60-70 °C and the holes are then sealed. The first turning is usually done after two weeks and the moisture is made up with water or animal or human excreta; the turned heap is again sealed with mud. The compost is ready for use within two months (FAO, 1980).

2.4.2.5 Ecuador on-farm composting

In this method, animal manure: from pigs, cows, poultry, horses, donkeys, ducks, crop residues and weeds: maize, bean, broad bean, groundnut, coffee and weeds; agro-industrial wastes, ash and phosphate rock; wood cuttings; topsoil from the forest or from an uncultivated or sparingly cultivated area; freshwater (Misra *et al*., 2003) are used. The raw materials are put in layers of crop residues (20 cm); a layer of topsoil (2 cm); a layer of manure (5-10 cm). Ash or phosphate rock (50 g/m^2) is then spread on the surface, and freshwater is sprinkled on the material. These steps are repeated until a height of about 1-1.2 m is reached. Water is sprinkled weekly. After three weeks, the heap must be mixed to ensure that all materials reach the center. During the process, the temperature rises to 60-70 °C, and most weed seeds and pathogens are killed. While it may take about two to three months to prepare the compost in a warm climate, in cold regions it could take five to six months.

2.4.2.6 Berkley rapid composting method

This is a shredding and frequent turning method (Raabe, 2001). It corrects some of the problems associated with the earlier methods of composting. The process can produce compost in two to three weeks. Several factors are essential for the rapid composting method: materials compost best when they are 1.25-3.75 cm in size. For the composting process to work most effectively, the material should have a C: N ratio of 30:1 (Raabe, 2001). Mixing equal volumes of green plant material with equal volumes of naturally dry plant material yields such a ratio. Manures from herbivorous animals such as rabbits, goats, cattle, horses, elephants and fowl are also used. The micro-organisms active in the

decomposition process are ubiquitous where plant materials are found and develop rapidly in any compost pile. Moisture content of materials in the pile should be about 50 percent.

Heat is supplied by the respiration of the micro-organisms as they break down the organic materials. To prevent heat loss and to build up the amount of heat necessary, a minimum volume of material is essential. Heat retention is better in bins than in open piles, so rapid composting is more effective where bins are used. In addition, the use of bins is much neater. High temperatures favour the micro-organisms that are the most rapid decomposers; these micro-organisms function at about 71°C and a good pile maintains itself at about that temperature. The compost pile turned to prevent overheating. If the temperature in the pile raises much above 71° C, the micro-organisms will be killed, the pile will cool, and the whole process will have to start again from the beginning. Turning the pile prevents overheating and aerates it, both necessary conditions for keeping the most active decomposers functioning. If the material in the pile is turned every day, it will take two weeks or a little longer to compost. If turned every other day, it will take about three weeks. The longer the interval between turnings, the longer it will take for the composting to finish. It is an intensive labour venture.

2.4.2.7 North Dakota State University hot composting

This involves use of mineral nitrogen activator. Compost piles with a height of 1.8 m are raised (Smith, R.C., 1995). The maximum size of the organic matter pieces should be 15-23 cm long. To keep the aerobic bacteria population high and active, proportionate amounts of nitrogenous fertilizer should be added (0.12 kg of fertilizer per 0.0283 m^3 of dry matter) and four or five holes punched into the center of the pile. It is a high temperature, bacterially

active system, best to turn the composting material every three or four days. Once activated, the temperature range should be 49-71°C. When bins are constructed the compost is ready in four to six weeks.

By adding lignin-rich organic wastes such as sawdust, wood shavings, coir pith, pine needles, and dry fallen leaves, the compost does not ripen rapidly. To make a good compost from hard plant materials involves mixing lime in a ratio of 5 kg per 1,000 Kg of waste material.

2.4.2.8 Effective Micro-Organisms (EMO) Method

This is a high temperature composting method. It entails use of common and food-grade aerobic and anaerobic micro-organisms mainly photosynthetic bacteria (Misra *et al*, 2003). The strains of the micro-organisms are commonly available from microbe banks or from the environment. These means use is limited to a few. There are no genetically engineered strains that are in use. In its operation an accelerator, Effective Micro-Organisms (EMO) solution or *Trichoderma* solution is required per pit. The EMO solution functioning as accelerator reduces the composting period from three months to one month.

2.4.2.9 IBS Composting Technology

The IBS rapid composting technology involves inoculating the plant substrates used for composting with cultures of *Trichoderma harzianum*, a cellulose decomposer fungus (Virginia, 1997). The fungus, grown in a medium of sawdust mixed with the leaves of a leguminous tree called ipil ipil (*Leucaena leucocephala)*, is termed compost fungus activator (CFA). The technology is a development of the wind-row type of composting.

Using this procedure, the composting time ranges from 21 to 45 days depending on the plant substrates used.

2.4.2.10 Wind-row Composting

Wind-row, a large-scale composting procedure that consists of placing the mixture of raw materials in long narrow piles called wind-rows that are agitated or turned on a regular basis (NRAES, 1992). The turning operation mixes the composting materials and enhances passive aeration. Typically, the wind-rows are from 90 cm high for dense materials such as manures to 360 cm high for light, voluminous materials such as leaves. Wind-rows aerate primarily by natural or passive air movement (convection and gaseous diffusion). The rate of air exchange depends on the porosity of the wind-row. These release odours when the wind-row is turned. On the other hand, small wind-rows lose heat quickly and may not achieve temperatures high enough to evaporate moisture and kill pathogens and weed seeds. For small- to moderate-scale operations, turning can be accomplished with a front-end loader or a bucket loader on a tractor. The challenge of this method would additionally be the cost of machinery. It is however a versatile system that can be adjusted to different conditions caused by seasonal changes.

Passively aerated wind-row method, an improvement of the above, air is supplied to the composting materials through perforated pipes embedded in each wind-row, thereby eliminating the need for turning. The pipe ends are open. Air flows into the pipes and through the wind-row because of the chimney effect created as the hot gases rise upward out of the wind-row. The covering layer of peat or compost also insulates the wind-row,

discourages flies, and helps to retain moisture, odour and ammonia. The windrows composting method takes sixteen weeks to mature.

2.4.2.11 Aerated static pile

The aerated static pile method takes the piped aeration system a step further, using a blower to supply air to the composting materials. The blower provides direct control of the process and allows larger piles. No turning or agitation of the materials occurs once the pile is formed. When the pile has been formed properly and where the air supply is sufficient and the distribution uniform, the active composting period is completed in about three to five weeks. The layer of finished compost protects the surface of the pile from drying, insulates it from heat loss, discourages flies, and filters ammonia and potential odours generated within the pile.

2.4.2.12 In-vessel composting

An in-vessel composting refers to a group of methods that confine the composting materials within a building, container or vessel (NRAES, 1992). In-vessel methods rely on a variety of forced aeration and mechanical turning techniques to accelerate the composting process. Many methods combine techniques from the wind-row and aerated pile methods in an attempt to overcome the deficiencies and exploit the attributes of each method. There are a variety of in-vessel methods. They vary with vessels, aeration devices, and turning mechanisms. The methods include: bin composting.

Bin composting is perhaps the simplest in-vessel method. The materials are contained by walls and usually a roof. The bin may simply be wooden slatted walls (with or without a roof), a grain bin, or a bulk storage building. The buildings or bins allow higher stacking

of materials and better use of floor space than free-standing piles. Bins can also eliminate weather problems, container odours, and provide better temperature control. Bin composting methods operate in a similar way to the aerated static pile method. They include some means of forced aeration in the floor of the bin and little or no turning of the materials. Occasional remixing of material in the bins can invigorate the process. The compost bin takes three month to two years to be ready.

2.4.2.13 Vermicomposting

The term vermicomposting means the use of earthworms for composting organic residues. Earthworms can consume practically all kinds of organic matter and they can eat their own body weight per day, e.g. 1 kg of worms can consume 1 kg of residues every day. The excreta (castings) of the worms are rich in nitrate, available forms of P, K, Ca and Mg. The passage of soil through earthworms promotes the growth of bacteria and actinomycetes which thrive in the presence of worms and their content in worm casts is more than six times that in the original soil (Misra *et al*., 2003).

Turning the heaps is not necessary where earthworms are present. The ideal environment for the worms is a shallow pit and the right sort of worm is necessary. *Lumbricus rubellus* (red worm) and *Eisenia foetida* are thermo-tolerant and so particularly useful. Field worms (*Allolobophora caliginosa*) and night crawlers (*Lumbricus terrestris*) attack organic matter from below but the latter do not thrive during active composting, being killed more easily than the others at high temperature. Others are the European night crawlers *(Dendrabaena veneta* or *Eisenia hortensis)* and the African night crawler (*Eudrilus eugeniae*).

Vermicomposting is in use in many countries. In the Philippines, use of *Lumbricus rubellus* and or *Perionyx excavator* has been reported (FAO, 1980). Cuba too has reported vermicomposting (Cracas, 2000). The Vermiculture approach has been reported in India (Jambhhekar, 2002).

Vermicompost production that uses epigeic compost worms such as *Eisenia foetida*, *Lumbricus rubellus* and *Eudrilus eugeniae* can be enhanced effectively by supplementing the organic wastes used for vermicomposting with cow's urine (Misra *et al*., 2003). Undiluted urine can be used for moistening organic wastes during the preliminary composting period (before the addition of worms).

The theoretical value of compost application includes increasing organic matter, improving aggregate stability, reduction of bulk density, increase in water holding as well as cation exchange capacities, enhancement of the soil microbial community, suppression of soil pests and provision of nutrients.

Studies have been done to establish the levels of macronutrients in the compost. Table 2.2 shows the general nutrient properties of composts.

Table 2. 2: Nutrient content of composts (DM)

	% Nutrient content		
Biomass type	N	P	K
Poultry manure	2-4	1-3	1-3
Feedlot manure	2-3	1-1.5	1-2
Dairy manure	1-2	0.5-1.5	1-2
Urban yard waste	1-1.5	0.25-0.5	1-2
Crop residue	1.5-2.5	0.25-0.5	1-2
World bank Std (1997)	1.7	1.6	2.1
Plant requirement (Epstein,1965)	1.5	0.2	1.0

UCDavies, 2008. Including World Bank standards and plant requirements

In general compost manure should provide sufficient amounts of macronutrients required for plant growth as can be seen when say compost from crop residue (N, 1.5-2.5; P-0.25-0.5 and K-1-2) are compared with plant requirements (Epstein, 1965). This however is not true. Compost alone is not sufficient as a plant growth medium. Most of the nutrients in compost are in unavailable organically bound form. A typical compost maybe 1-3 % total N by weight but NH_4^+ and NO_3^- (available forms) are typically less than 0.05 % (Harrison, 2008). Doublet *et al.*, (2011) affirms the same as compost is > 90 % organic nitrogen and < 10 % mineral nitrogen (NH_4^+ and NO_3^-).

The availability of P, K and other nutrients is generally higher for most composts than is the availability of nitrate (Harrison, 2008). This means other approaches of breaking down agricultural biomass must be sought. Rapid chemical decomposition of the wastes as in this study ventures to leave more available nitrogen than the composting methods in use. It is equally known that P is highly variable in the different feedstock used in composting. It is quite important to establish by analysis and carry out field trials for the potential of nutrient availability due to high variability (Harrison, 2008).

2.4.2.14 Integrating traditional composting and vermicomposting

A critical look at all the composting methods whether traditional or rapid, characteristic challenges that call for attention emerge. Problems associated with traditional thermophilic composting relate to long duration of the process, frequent turning of the material, material size reduction to enhance the surface area, loss of nutrients during the prolonged process, and the heterogeneous resultant product. However, the main advantage of thermophilic

composting is that the temperatures reached during the process are high enough for an adequate pathogen kill.

In vermicomposting, the earthworms take over both the roles of turning and maintaining the material in an aerobic condition, thereby reducing the need for mechanical operations. In addition, the product (vermicompost) is homogenous. However, the major drawback of the vermicomposting process is that the temperature is not high enough for an acceptable pathogen kill. Whereas in traditional thermophilic composting the temperatures exceed 70 °C, the vermicomposting processes must be maintained at less than 35 °C.

Integrating traditional thermophilic composting and vermicomposting has been reported (Ndegwa and Thompson, 2001). The work involved combining pertinent attributes from each of the two processes to enhance the overall process and improve the product qualities. The two approaches investigated in the study related to: (i) pre-composting followed by vermicomposting; and (ii) pre-vermicomposting followed by composting. The duration of each of the combined operations i.e. composting and vermicomposting was four weeks. A comparison was made with vermicomposting alone (duration: 56 days). The results indicated that the combination of the two processes shortened the stabilization time and improved product quality. Furthermore, the resultant product was more stable and consistent, had less potential impact on the environment, and met pathogen reduction requirements.

In an effort to still shorten time other innovations such as mechanical composting have been reported. Mechanical composting is an efficient method of composting that uses electricity to create the heat required and rotation of the contents required to produce semi

composted waste literally within a 24 hour system. This is manageable on household level but for costs involved as well as need for further composting. Can the period of composting, pathogens, labour intensity and costs be reduced through chemically decomposing agricultural wastes and consequentially blending the pre-treated material to facilitate plant macronutrient requirements?

Composting is well known to farmers in many parts of the world though those in developing countries do not benefit from the opportunity due to various constraints which among others include absence of efficient technology, long composting time, intense labour involved, land and investment requirements and economic aspects (Misra *et al*., 2003).

2.4.3 Agricultural Biomass in Kenya

The use of biomass for energy, chemicals, and materials is considered an important alternative to fossil resources (Chum *et al*., 2011; Harvey and Pilgrim 2011). For biomass to deliver a sizeable contribution, the availability of sufficient sustainable and affordable biomass feed stock is crucial. The various biomass produced from agricultural activities include sugarcane bagasse, livestock horns/hooves, sisal leaf and maize stover.

2.4.3.1 Sugarcane Bagasse

Sugarcane (*Saccharum officinarum* L.) used in the sugar industry plays a significant role in Kenya's economy, contributing about 15 percent to the country's agricultural GDP (KSI, 2009). The country's mills have a capacity of milling 5 million tonnes of cane producing 475,000 tonnes of sugar annually (Jamoza, 2005). The sugarcane bagasse is usually 25-30% of the cane harvested. 1.8 million tonnes of bagasse generated annually is a fibrous

by-product basically made of cellulose (45-50%) hemi cellulose (20-25%), lignin (18-24%) and ash (1-4%) (Karekezi and Kithyoma, 2005).

Bagasse poses a glaring disposal problem though some attempts to make charcoal (Chardust Kenya Ltd, 2002) and power generation (CDM-PDD, 2006) have been reported. Unlike in other countries, fibre boards and paper making have not been actualized in Kenya. Recent studies involving bagasse have been limited to its tensile strength (Arsene, Bilba and Soboyejoa, 2005), as a substrate for cellulose production (Anuar, 2006) and composite material for cement (Agrawal, 1995).

The use of sugarcane bagasse as a resource has not had an impact on the volume churned out of factories. The waste disposal is a challenge and even when used for power generation disposal of the bagasse ash is still a problem in Kenya. It is dumped by roadsides. The choice of sugarcane bagasse for this study was not only guided by availability but also the mineral composition. The mineral composition of sugar cane bagasse ash has been established as consisting of inorganic oxides SiO_2 (75.27%), soluble K_2O (2.76 %), CaO (3.74 %) and P_2O_5 (1.07 %) (Sirirat and Supaporn, 2010). Their utilization in formulating a fertilizer would offer a pathway of disposal for these wastes.

2.4.3.2 Sisal (*Agave sisalana*) leaf waste (pulp)

Global production of sisal fibres reported in 2013 amounted to 281,000 tonnes of which Tanzania and Kenya produced 34,875 tonnes and 28,000 tonnes, respectively (Sawe, 2017). Sisal occupies 6th place among fibre plants representing 2% of the world's production of the plant fibres (Rehm and Espig, 1991). It grows best in a hot climate and may be grown throughout humid and sub-humid low land tropics (Yayock, 1988). As a

cactus, Agave plants survive and produce marketable products in fertile and arid regions which in many cases would otherwise be unproductive. It is a high waste generating industry with a current ratio of useful fibre to waste at 2.98% (Mshandate, Bjornsson, Kivaisi, Rubindamayugi and Mattiasson, 2008). Studies on the anaerobic digestions of the waste to produce biogas have been reported (Mshandate *et al.*, 2006). Possible utilization in production of electricity has been reported (Scoh, 2006; Mohammed, 2007).

The general chemical composition of the leaves has been determined. The protein (0.31g/100g) and mineral material (1.03 g/100g) content of sisal leaf wastes reported by UNESP (2010), provided the basis for the potential of their use in formulating a biomass based fertilizer. Though sisal leaf pulp takes long to decompose, a study in the direct utilization of this wastes in the cultivation and yield performance of *Coprinus cinereus* (schaeff) Gray established that the mixture of the wastes and cow dung gave the highest yield of mushrooms (Raymond, Mshandate and Kivaisi, 2012). This is suggestive that a rapid chemical decomposition would open up the wastes potential for use in the study.

2.4.3.3 Maize Cobs and Stalks

Maize production in Kenya within years 2017, 2018 and 2019 varied as 3186, 4000 and 3491 (1000 tonnes) respectively (FAO, 2019). Corn stover, the above ground plant excluding corn kernels has much potential as a biomass feed stalk (Graham, Nelson Shechan, Perlack and Write, 2007). Over 204 million dry metric tonnes of corn residue are returned to the ground as waste products from grain production annually (Perlack *et al.*, 2005). There are concerns associated with crop residues removal from the ground for this contributes to soil organic matter and nutrient depletion (Wilhelm, Johnson, Hatfield,

Voorhees, and Linden, 2004). While maize cobs have been used on small scale as a fuel for direct combustion in cooking and heating (Roth and Gustafson, 2019), their use as feedstock for large scale energy production is a more modern concept. Earlier studies established that corn cobs contain 32.3-45.6 % cellulose and 39.8 % hemi cellulose mostly composed of pentosan and 6.7-13.9 % lignin (Clark and Lathrop, 1953; Foley, 1978).

The elemental composition of maize cobs, leaves and stalks have been established and documented (Hanway, 2007). Table 2.3 shows the data.

Table 2. 3: Percentage of plant nutrients in maize plant remains

Maize parts	Dry matter kg/Acre	Nitrogen % of plant	P_2O_5 % of plant	K_2O % of plant
Cobs	548.75	0.33	0.11	0.62
Stalks	1609.97	0.43	0.14	0.90
Leaves	775.51	1.80	0.69	2.05

The different parts of the maize have significant amounts of the plant nutrients. The outcome of studies like viability of corn cobs as a bio energy feedstock (Daron, 2008) as well as effectiveness of maize cobs powder in controlling weevils in stored maize (Gadzirayi, Mutandwa and Chikuvire, 2006) have not made a significant impact on these wastes. On the basis of the high annual production and levels of macronutrients from earlier studies, maize cobs and maize stalks were considered in the study.

2.4.3.4 Keratinous Wastes

These are solid tenacious fibrous materials largely made of keratin and whose density varies (Bragulla & Homberger, 2009). Keratin is a major component in the skin, hair, nails, bird feathers, hooves, horns and teeth. Millions of tonnes of keratinous wastes are

generated annually globally, especially in wool textile industry and in slaughter houses (Aluigi, 2007).

The amino acids which constitute it have several unique properties and depending on the levels of various amino acids can be inflexible and hard as in horns or soft as with skin. It is difficult to dissolve keratin because it contains cysteine disulphide bonds which means it is able to form disulphide bridges. The bridges create a helix shape that is extremely strong as sulphur atoms bond to each other, creating a fibrous matrix not readily soluble.

Bird feathers consist of approximately 90 % keratin. The annual worldwide feather amounts to 8,910 tonnes (Grazziotin, 2006). It is usually deposited in landfills. Due to a large variety of microflora present on the feathers, including pathogens, they should be treated quickly. Although, the main method for disposal of feather waste is incineration high energy consumption and emission of foul gases have remained deterring factors (Suzuki, 2006). Another way is composting them with manure, but the composting process is long lasting and is subject to special requirements of the veterinary inspection concerning a closed composting area with a sewage carry systems, and periodic microbiological tests (Commission Regulation (EU) No 142, 2011). A serious problem regarding composting is also odorous emission of hydrogen sulfide that persists long in the air. Tronina and Bubel, (2008) stated that composting may not fully inactivate pathogenic microorganisms. Properly conducted composting must involve thermal phase of specific parameters that allows for sufficient sanitation of the composted biomass. This calls for chemical pre-treatment as proposed in this study.

The chemical composition of hooves and horns has been established. The high presence of calcium (8 g/kg), phosphorous (7.3 g/kg) and crude proteins (88.6-96.3%) (Qureshi, Khan and Schneider, 2012) makes these farm wastes a potential source of fertilizer production. Horns or hooves are dried, crushed and used as a first rate quality manure as is an excellent source on slow release of nitrogen (Chandy, 1994). The challenge of horns and hoofs taking long to decompose limits their use in composting. However the fact that ammonia can be obtained from these animal wastes using sodium hydroxide or slaked lime indicates that chemicals can rapidly decompose them facilitating formulation.

2.4.4 Challenges in the utilization of organic manure

Apart from high costs, nutrients in conventional fertilizers such as DAP, urea and NPK are poorly utilized due to environmental and soil related factors such as P-fixation, leaching and volatilization. This leads to low fertilizer efficiency (LFE) and hence high losses are challenges that not only influence crop production, but also the safety of the agricultural environment and groundwater (Puntel *et al*., 2016). Most smallholder farmers have tended to use organic fertilizers as an alternative.

Organic fertilizers are those derived from animal matter, animal excreta (manure), human excreta and vegetable matter (Dittmar *et al.*, 2009). One of the main challenges with the traditional approaches to organic fertilizer (manure) management is the fact that, while they provide most of the nutrients needed by crops, the relative proportions of plant nutrients present in manures are not in a balance with the amounts needed by many crops. This can result in under- or over application of some nutrients. Manures are viewed as N sources and applied to meet crop N requirements (Sims and Maguire, 2005). However, because the

N:P ratio in manures is not in balance with the N:P ratio in most crops, applying manures to meet crop N needs, results in the over application of P and buildup of P in soils to values well above those needed for optimum crop yields (Sims and Maguire, 2005).

Manure contains minimum nutrients in a large volume making it uneconomical to be transported to distant places from production sites (St-Pierre and Wright, 2013; Odhiambo and Magandini, 2008). Transporting organic manure to the point of use remains a major barrier to utilization of organic fertilizers. Alimi, Ajewole and Olubode-Awosola and Idowu, (2006) noted the major challenges facing farmers that use organic fertilizers were the uncertainty of its efficiency. Application of manure does not guarantee immediate availability of the nutrients. They may be released sometimes when plants are not actively growing so as to use them.

Manure can serve as a good source of plant nutrient though it is a pathway for heavy metals and pesticides (Pindozzi, Fauguo, Okello and Boccia, 2013). Other emerging concerns for manure use as soil amendments include environmental impacts of other constituents such as pathogens, non-essential trace metals on human health and environmental quality due to the offensive odour. These make storage difficult. Grazing or free-ranging animal systems pose different challenges because manure deposition is dispersed across grazing grounds. The challenges enumerated calls for a structured approach to the management of manure. Manure management is a farmer's affair in Kenya.

2.5 Fertilizer Formulation

The fertilizer formulation is guided by specific information needs which vary with regions. In fertilizer analysis (called fertilizer rating) the concentration of individual main nutrients

in the order N: P: K: S: Mg: Ca are expressed as percentages and mg/kg or parts per million for micronutrients (FAO, 1991). NPK rating is a system describing the amount of nitrogen, phosphorus, and potassium in a fertilizer. NPK ratings consist of three numbers separated by dashes as in formulations labeled 10-10-10, 16-4-8, 20-20-0 or 15-15-15 (Allgood, 1990). These describe the chemical content of each fertilizer. The first number represents the percentage of nitrogen in the product; the second number, P_2O_5; the third, K_2O.

Fertilizers do not actually contain P_2O_5 or K_2O, but the system is a conventional shorthand for the amount of the phosphorus (P) or potassium (K) in a fertilizer. Most fertilizers are labeled according to this N-P-K convention, although Australian convention, follows an N-P-K-S system- adds a fourth number for sulfur, and uses elemental values for all values including P and K.

To address and improve low fertilizer efficiency (LFE) of fertilizers, “smart” fertilizers have been developed, among them are slow release fertilizers (SRF) (Zeroual and Kossir, 2012). Use of SRF in crop production is considered beneficial due to reduced risk of environmental nutrient loss (Li *et al*., 2017). Nevertheless, the adoption of SRFs for agronomic use is currently hindered by higher production costs as compared to conventional fertilizers (Liu *et al*., 2014). Intensive research is directed towards formulating low cost eco-friendly SRFs and evaluating their efficacy on growth and yield of crops.

Li *et al.,* (2017) evaluated combined effects of polymer-coated urea (PCU) and carbon-based urea (CU), on the performance of tomato. The yield in CU treatment was better than those of PCU and urea treatments. Lui and Lal, (2014) assessed carboxymethyl cellulose

stabilized nano-HA (nano-hydroxyapatite) fertilizer suspension and observed improved growth and yield of soybeans, higher than those of $CaHPO_4$ treatment. Montalvo, McLaughin and Degryse, (2015) investigated P uptake by wheat (*Triticum aestivum*) derived from nano-HA (20 nm), bulk HA (600 nm) and triple superphosphate (TSP) in a strong P-sorbing andosols and oxisols group of soils. The % P in the plant derived from the fertilizers followed the order; TSP > nano-HA > bulk HA. These SRFs fertilizer formulations demonstrate enhanced LFE; hence, they can minimize economic losses and potential negative effects such as water pollution associated with conventional fertilizer use. High production costs remain the major hindrance of access to fertilizers (both LFEs and SRFs) as are expensive and not affordable by smallholder farmers. It is expected that a biomass-based fertilizer (BBF) formulated from chemically decomposed agricultural wastes would not only be cheap but also minimize some of challenges enumerated.

From the foregoing discussion it is imperative that efforts towards fertilizer formulation or acts to bring forth a fertilizer material that relates the roles of the constituent elements be reinforced. This is so since different macronutrients play different roles at different stages in the life of a plant. Since different biomass may vary in the levels macronutrients, it is imperative the study adds value to the existing works by blending chemically decomposed biomass in order to achieve formulations that will be comparable with NPK and yet keep advantages of organic fertilizer.

2.6 Rapid Chemical Decomposition of Agricultural biomass

Although both traditional and rapid composting are both biological and chemical processes, they are slow making the processes take long. It is necessary that faster

approaches that reduce composting period as well as minimizing accompanying disadvantages like loss of nitrogen be considered.

Agricultural activities generate enormous amounts of biomass like rice husks, maize cobs and stalks, sugarcane bagasse, hooves and horns, fish scales, sisal leaf and feathers. They can broadly be grouped as either cellulose or keratin dominated. Treatment of a given material depends on the role of the product. When maize cobs are burnt in sufficient air (300-500^{o}C), 99.5% cellulose combustible materials get oxidized to carbon (IV) oxide and water as in the equation:

$(C_6H_{10}O_5)_n + 6n\,O_2 \rightarrow 6n\,CO_2 + 5n\,H_2O + \text{Energy}.$

The remaining 0.5 % consists of minerals that do not burn and are instead converted to their oxides and remain in the ash. The ashes that remain consist mainly of potash (K_2CO_3) (Babayemi, Adewuyi, Dauda, & Kayode, 2011) though soda ash (Na_2CO_3) and arcanite (K_2SO_4) are also present as soluble components. The temperature range is far below 1200 ^{o}C necessary for decomposition of potash. When potassium carbonate dissolves in water, the carbonate ion (CO_3^{2-}) reacts to form bicarbonate and hydroxide that raises the pH:

$CO_3^{2-} + H_2O \rightarrow HCO_3^- + OH^-$

Carbonates too react with hydrogen ions in solutions, $CO_3^{2-} + H^+ \rightarrow HCO_3^-$ decreasing the amount of hydrogen ions and raising pH. The resulting solution (lye) with pH > 7.0 can be used in breaking down plant cellulose material.

Plant cell walls are resistant to deconstruction (recalcitrance) due to the highly crystalline structure of the cellulose which is embedded in a matrix of polymers-lignin and hemicellulose (Himmel *et al.*, 2007). Alkaline treatment that involves use of sodium,

potassium, calcium and ammonium hydroxides cause the degradation of ester and glycoside side chains resulting in structural alteration of lignin, cellulose swelling, partial de-crystallization of cellulose (Cheng, Selling and Biswas, 2010) and partial solvation of hemicellulose (Sills and Gosset, 2011). This has been established to increase surface area for bacterial action (Zhu, Elguindi, Rensing, and Ravishanker, 2012). Sisal leaves are acidic. This in addition to cellulose recalcitrance limits their use as composting feed. Boiling with an alkaline solution not only opens up the cellular material but also helps neutralize the acid increasing their potential utilization in biomass fertilizer formulation.

Sodium and potassium hydroxides strongly attack cellular constituents of animals like horns and hooves by dissolving keratins (Andre and Philippe, 1994). This is achieved through hydrolysis of the peptide chain that involves nucleophilic substitution in which the –NH-group is replaced by OH^- (Asquith and Leon, 1977). This involves an attack by the strongly nucleophilic hydroxide ions on the amide. Other ways of bringing keratin into solution include either refluxing with strong mineral acids for many hours followed by caustic alkali treatment or treatment with alkaline reducing agents that break the disulphide bonds so as to yield sulphydryl groups, sodium sulphide and compounds containing the thiol groups such as the salts of thioglycolic acid (Chojnacka, Górecka, Michalak and Górecki, 2011; Hill, Brantley and Van Dyke, 2010; Wawrzkiewicz, Łobarzewski and Wolski, 1987). The approach using alkaline reducing agents, however, suffers several disadvantages including objectionable odour, degradation of the proteins and non-confinement to disulphide bonds. These shortcomings are overcome by use of peracids.

The peracids are prepared by reacting alkanoic acids with hydrogen peroxide (Greespan, 1946). The peracids have high oxidative power, selective reaction by non-radical pathway, safe and break the cysteine $(-CH_2-S-S-CH_2-)$ bonds to give cysteic acid$(-CH_2SO_3H)$. This being acidic would still resist decomposition but can be neutralized by dissolving in NH_4OH or mixing with alkaline materials similarly generated from plant biomass like sisal leaves. Prior biomass treatment is a necessary condition for the composting process period to reduce from months (cellulose based biomass) or years (keratin based materials) to hours if not weeks. Studies on blending of chemically treated livestock biomass (except dung) with treated plant wastes to produce a biomass-based fertilizer (BBF) have not been reported.

2.7 Evaluation of Fertilizer Efficacy

2.7.1 Macronutrient Deficiency symptoms in growing maize

Deficiency symptoms can occur either as a general yellowing or whitening of the plant tissue i.e. a lack of chlorophyll called chlorosis or as death of plant tissue usually beginning with the yellowing of plant tissue, eventually browning before death (Necrosis) (Hochmuth, Maynard, Vavrina, Hanlon and Simonne, 2018). Some other times only plant tissue between the veins of the leaves exhibit chlorotic symptoms (Interveinal Chlorosis) or severe localized yellowing or browning, exhibiting a scorched appearance (Burning or scorching) or as spotted, irregular, or inconsistent pattern (Mottling). Each appearance signifies a deficient nutrient (Hochmuth *et al.*, 2018).

Deficiency symptoms on leaves of growing maize due to luck of both macronutrients and micronutrients as other crops are well documented. A healthy maize leaf should look green

while if nitrogen deficient, necrosis appears in a v-shaped pattern from the leaf tip, phosphorus deficient plants depict purpling along leaf edges while potassium deficiency is seen as necrosis and scorching along leaf edges. The magnesium deficiency occurs as interveinal chlorosis (Hochmuth *et al.*, 2018).

More often than not, complex factors are at play when crops exhibit deficiencies. Some can be easily corrected, but others might take years to rectify. The pH of soil plays an integral role in determining which nutrients are available for uptake by a plant (Hochmuth *et al.*, 2018). If soil is too acidic, the nutrients N, P, K, S, Ca, and Mg will be less available. In alkaline soils, Fe, Mn, B, Cu, and Zn will be less available (Mathayo, Majule, Marchant, and Sinclair, 2016; Trail, 2015). If one is identified deficient, a pH problem is also a possible cause. Nitrogen deficiency symptoms often occur in low-lying areas of a field, or areas with poor drainage. When soils are inundated with water, plant-available nitrate (NO_3^-) is leached (drained away) and/or denitrified (Sawyer, 2007). De-nitrification occurs when soil bacteria utilize nitrogen compounds in place of oxygen (which is limited by flooding); the compounds are subsequently broken down and the nitrogen is released back into the atmosphere in the form of nitrogen gas (Sawyer, 2007). De-nitrification can leave large areas deficient of nitrogen during and after flooding.

Drought stress symptoms can also be confused with nutrient deficiency symptoms (Trail, 2015). In both cases, plants exhibit a similar overall stunting. However, drought stress symptoms can be distinguished initially by the wilting and then curling of leaves, followed by the scorching of leaf tips. Many plant nutrients become unavailable to a plant when

there is little water to solubilize them into a form that can be taken up by plants (Trail, 2015).

Nutrient deficiency symptoms are more often than not mistaken for fungal, viral or bacterial diseases, because each of them results in yellowing and necrosis of leaves (Trail, 2015). Nutrient deficiency can typically be distinguished from pest damage and disease by its symmetry. Disease symptoms are mottled, blotchy, or unevenly positioned on the plant or leaf, while nutrient deficiencies tend to be symmetrical and evenly dispersed in the plant or leaf. Plants affected by nematodes show stress symptoms easily confused with a variety of nutrient deficiency symptoms. Nematode damage is especially easy to confuse with nitrogen deficiency from flooding and de-nitrification. The former can typically be distinguished by the presence of symptoms outside of low-lying areas (not a drainage issue) and wilting on only the tops of plants. Herbicide drifts can occur when herbicides are applied in close proximity with other crops. If the herbicide doesn't kill the unintended target crop, it can cause damage, leaving symptoms that can be easily confused with nutrient deficiency symptoms (Trail, 2015).

Mobile nutrients (N, S, P, K and Mg) generally exhibit deficiencies in the lower parts of the plants while immobile ones (Ca, N, Mn, Mo, Fe, Zn, S and Cu) exhibits in the upper parts (IPNI, 2016). Both N and P deficiencies will always be seen in the entire plant in contrast to K and Mg that are seen in only old leaves (Bolques, 2012). In the evaluating the efficiency of a formulation it apparently is necessary to diagnose plants for deficiencies. This will inform of correction measures to be taken. The review considered maize due to its importance as a stable food and importance to this study.

2.7.2 Measurement of Plant Growth

Efficacy of any fertilizer formulation derived can be compared with inorganic fertilizers in promoting select trial plants. Many basic methods of measuring plant growth have been documented (Wood and Roper, 2000). They are based on the many features plants have that can be measured through observation to determine the extent of plant growth or health. The methods include obtaining plant height that involves getting the height either by direct measurement from a common bottom boarder to the top of the main plant stem or putting the plant against a graphical matrix (Wood and Roper, 2000). Plant leaves are also used.

Counting leaves including the tips of those emerging or tracing a leaf on a graph paper and estimating its area by counting squares covered by the leave is one of the techniques. The trace can also be cut and weighed. Using digital image analysis cameras that capture an image of the plant and using special software analyze the surface area of the leaves is but another (Wood and Roper, 2000). Plant colour observation records and or counting number of flowers over a period are other approaches available for plant growth. Though all are indicative of plant health, measuring height would be ideal for maize apart from colour observation.

In evaluating rate of growth, select plants were used in the comparative assessment of efficacy of various nitrogen fertilizers (Wiesler, 1998). Nitrogenous fertilizers may differ markedly in their susceptibility to losses. In this study plant height was measured from a common ground base to the longest leave of that plant.

2.7.3 Measuring the crop yield

Various methods have been developed for quantifying production and productivity of agricultural systems at research plot level and also for agricultural statistics at regional and national levels (Dumanski and Onofrei, 1989). However, as agricultural production systems are changing to address new challenges, the yield estimation methods developed and tested for a particular production system may not adequately reflect the yield for new production systems.

In the crop cuts method, yield in one or more subplots is measured and total yield per unit area is calculated as total production divided by total harvested area in the crop cut plot or subplot (Murphy, Casley and Curry, 1991). In practice, 1–5 subplots of 0.25–50 m^2 are used for yield estimation. In on-farm research conducted by CIMMYT, use of a 0.5 m by 0.5 m sampling frame overestimated the wheat yield by more than two times as compared to 1 m^2 or larger sampling frame. This finding suggests that when estimating crop yield by using crop cut method, the size of sampling plot should be at least 1 m^2.

Crop production can also be estimated through farmers' interviews. It involves asking farmers to estimate or recall the yield for an individual plot, field, or farm (Fermont and Benson, 2011). It can be done before harvesting (estimate) or after harvesting (recall). Before harvesting, farmers are asked to predict what quantity they expect to harvest. Farmers will base their predictions of expected yield on previous experiences, by comparing the current crop performance to previous crop performances. Singh, R., (2013) argues that yield estimation surveys following this method should be made at maximum crop growth stage.

Using a sampling frame, count the number of ear heads/pods in 1 m^2 area at least five to seven times within a plot whose yield is to be determined and calculate the average number of heads/pods per meter square area. Count the number of grains in 20–25 heads/pods and take the average. Maize has weight range 237–268 g (Sampathkumar, Pandian, Rangaswamy, Manickasundaram, and Jeyakumar, 2013). The 1000-grain weight of crops however is influenced by many factors such as genotype, management, and environment.

The sampling for harvest unit is similar to yield estimation through whole plot harvest method except that only a few samples out of the total harvest are weighed. In this method, the number of units, such as sacks, baskets, bundles, is counted after the farmer harvests (Casley and Kumar, 1988). An alternative method which requires the physical threshing of only a small sample to estimate yield, biomass, and other yield-related parameters has been developed (Castellanos-Navarrete *et al.*, 2013). The procedure dramatically reduces the labor and large-scale threshing required to obtain reliable yield and associated yield-related parameters. The methodology can also be used for any situation.

Sometimes crop yield is estimated by summarizing the opinions of field agronomists, extension agents, and researchers (Dumanski and Onofrei, 1989). These experts are often able to estimate crop production or yield by visually assessing the crop condition, such as color, plant vigor, plant density, in the field. This is known as eye assessment. Eye assessment can be combined with field measurement and empirical formulas, collectively known as the expert assessment method.

The crop card method is a refined version of the farmer recall procedure to obtain more reliable harvest estimates for crops with an extended harvest period or multiple harvests,

such as cassava, banana, cowpea, sweet potato. As farmers may have problems in accurately remembering the amounts they harvested over time from one or several plots, this method helps them by keeping the written record of all plots. In this method, each farmer in a survey is given a set of crop cards where he/she records the quantity of crop in each harvest, which can then be added up to calculate the total harvested yield. However, this may be challenging to use in smallholder production contexts of developing countries due to high illiteracy rates and lack of adequate manpower for regular monitoring (Ssekiboobo, 2007).

Crop modeling is widely used to estimate average biological yields in the conditions of smallholder farmers. Empirical–statistical crop models establish a relationship between yield and environmental factors from long-term data sets and use the established relationship to predict crop yield at regional or national levels based on environmental data (Park, Hwang, and Vlek, 2005).

The allometric models are mathematical relationships between plant morphological characteristics and crop yield. The allometric models are based on variables that can be quantified easily using rapid, inexpensive, and non-destructive methods of data collection (Fermont and Benson, 2011). Data collection is one of the prerequisites of this method although data collection may be less labor intensive than with the crop cut method.

Biological crop yield can be estimated by remote sensing (Zhao, Peng, Fu, Ma and Yao, 2007). The Crop yield estimation using remote sensing is based on the principle of spectral reflectance of green plants, which can be captured in satellite images as spectral data, and depends on the state, structure, and composition of the plant. The spectral data can be used

to construct several vegetation indices such as normalized difference vegetation index (NDVI) which indicates the green biomass that can be used as a proxy indicator of the yield (Prasad, Chai, Singh, and Kafatos, 2006). The limitation in the use of satellite images to estimate crop yields of smallholder farmers is that the resolution of available satellite imagery is not sufficiently detailed to capture the variability of crops and crop performance in smallholder fields, which often are less than 0.1 ha in size and sometimes intercropped.

Another method is harvesting the entire field to determine crop yield. It is normally done in trial plots, excluding one or more boundary lines that may not reflect the tested treatment due to boundary effects. This method can be employed in experimental or demonstration plots. It can also be used to estimate yield from small-scale farmers' fields if farmers are willing to cooperate but is too costly for larger samples of farmers. Crops that have a defined maturity date, such as cereals or legumes with a determinate growth habit, can be harvested in a single operation.

In evaluating the efficacy of fertilizers derived from human excreta in agriculture, Moya *et al*., (2017) used yields by the two sets. Yield and uptake of macronutrients on the other hand were used in efficacy evaluation of fertilizers and weed control practices to mitigate wheat nutrient and yield losses (Nadeem *et al*., 2018). In this study harvesting the entire field to determine crop yield method was used.

2.8 Summary

In view of the foregoing literature review, agricultural production in developing countries including Kenya requires continuous research on inputs. This is to not only avert challenges generated but also minimize those the subsector faces as an entity.

Agriculture production generates enormous amounts of biomass (wastes) whose disposal remains a challenge. Though some like sisal leaf pulp, horns and hoofs are rich in plant macronutrients they remain underutilized for subjecting them to the current composting methods is a venture in futility. They take long to decompose (months and years respectively) and their potential remains untapped.

Smallholder households are key stakeholders in agriculture production. The cost function attached on the popular conventional fertilizers (DAP, Urea, CAN and NPK) or improved composting methods have remained a deterrent factor leading to a declining trend in agricultural productivity. Availability of macronutrient rich agricultural biomass as well as a subsector that is in dare need for other sources of macronutrient to promote growth and yield of crops gives the basis of continuous research to redirect the agricultural production. The need for alternative approaches to the current methods of composting with a view to offer an economical disposal pathway of the biomass, minimizing on the composting time as well as counter limitations of conventional fertilizers remains open.

This study centered on utilization of chemically decomposed select agricultural biomass to formulate a biomass-based fertilizer. The efficiency of the formulation was evaluated on growth and yield of maize compared to those under conventional fertilizers.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Research Design

The study involved laboratory and field works. In the laboratory work agricultural biomass (maize cobs and stalks, sisal (*Agave sisalana*) leaf, sugarcane bagasse and livestock hooves and horns) were analyzed for nitrogen, phosphorous, potassium and calcium using standard methods. The formulation processes involved blending acid treated horns and hooves with maize cobs ash-water extract treated sisal leaf pulp. Nutrient levels and pH of the formulations and field soils' pH were determined. Field work involved assessing the efficacy of BBF with DAP/CAN as the control on growth and yield of maize in Lugari sub-county, Kenya.

3.2 Study Area

The field work was done in Lugari sub-county, one of the administrative units that constitute Kakamega County in western Kenya. It borders Nandi County to the south, Bungoma County to the west, Uasin Gishu County to the east, and Trans-Nzoia County to the north. It lays between longitude 34°28′ and 35° East and latitude 0°25′ north of the equator (Republic of Kenya, 2002) as in Figure 3.1.

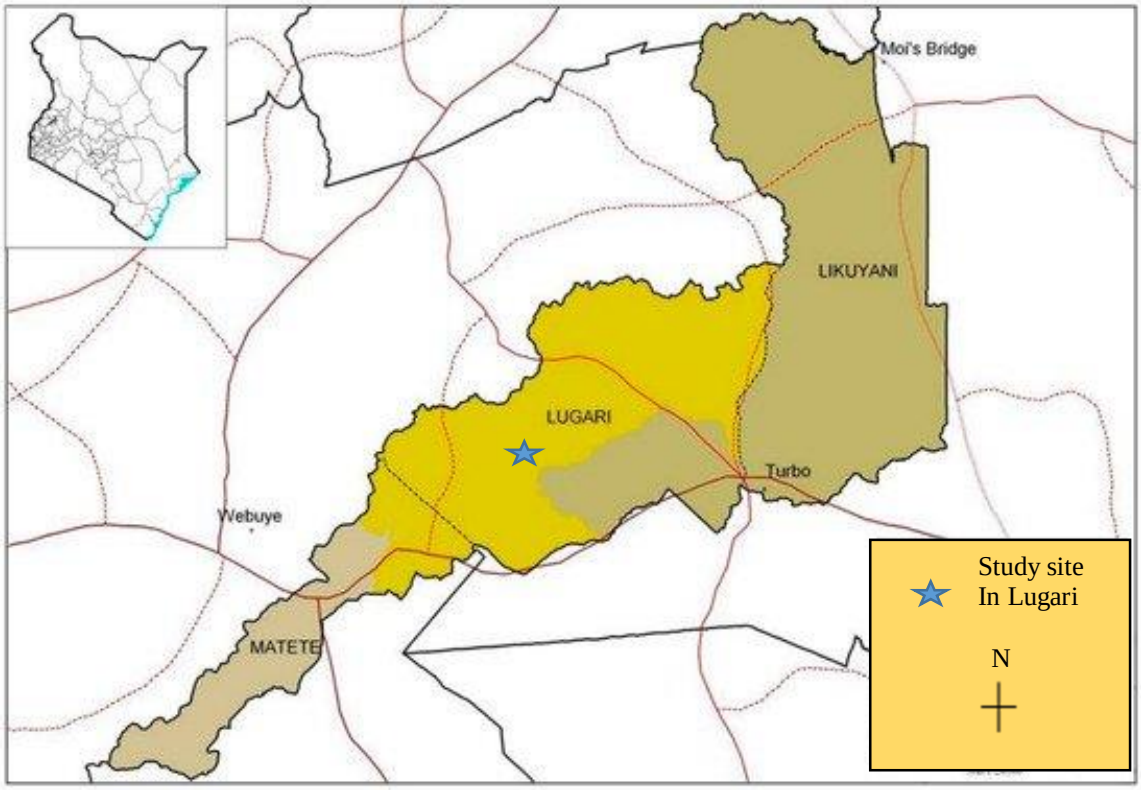

Figure 3. 1: Map of Lugari sub-county (source: Wanyonyi, 2012)

The sub-county lies between altitudes 1300 m and 1800 m above sea level. It is hilly and rocky towards the east and gradually falls into a plain as it progresses to the south (Republic of Kenya, 2009).

The climate and rainfall patterns are of an equatorial type. Temperatures vary between 6 °C and 23 °C in the high altitude areas and between 18 °C and 24 °C in low altitude areas. The rainfall pattern is bimodal with long rains occurring from March to August, while short rains are from October to November. The average annual rainfall is between 1000 mm and 1600 mm (Republic of Kenya, 2002). The soils are fertile and well drained, ranging from dark brown sandy loam to red oxisols (Sikuku, Apudo, and Ototo, 2014). Most people practice livestock, bee keeping as well as growing crops for food and commercial purposes

(Wandere & Egesah, 2015). Principal food crops include maize, beans, sweet potatoes, cassava, and sorghum. Cash crops include coffee, sunflower, sugarcane, sisal, bananas, and passion fruits. The principal livestock kept are dairy cows for milk production. Milk plays an essential part as food supplements and for household income (Republic of Kenya, 2002).

3.3 Sampling and Pre-treatment Procedures

3.3.1 Sisal leaves

Sisal leaves from center (young), middle (mid old) and outer (old) layers of sisal plants (Plate 3.1) were cut and collected from farms in different wards in Lugari Sub-County. Leaves collected were either with smooth or thorned edges. Sisal leaves were then stripped and sun dried for two days before decortication to obtain the biomass. The sisal leaf biomass was then spread in the sun daily to dry for one week until constant weight. The dry sisal waste samples were stored in stoppered containers

Plate 3. 1: Sisal plant exhibiting considered layers

3.3.2 Horns and Hoofs

Horns and hooves were collected weekly for three alternating months from different slaughter houses in Lugari, Kakamega County. Those collected from the same slaughter

houses were given similar labels and grouped as H_n with n as the slaughter house identity. They were washed with distilled water and dried at 140 ^oC in an oven to drive off any moisture as well as traces of humus. Plate 3.2 shows samples collected from one of the slaughter houses (H_1).

Plate 3. 2: Horn and Hooves (H1) collected from first slaughter house

3.3.3 Maize Stover and Sugarcane Bagasse

Maize cobs and stalks were collected from farmers within 2 km radius from Lugari market. Sample cobs and stalks collected were of varieties H6213, H614 DKF_1, Oduma, Pioneer, H513, H505, and H500. Ten samples each of cobs and stalks per farm were collected from heaps of biomass and labelled using variety and farm numbers. For example $H6213F_1$ meant variety H6213 was collected from farm-1). The samples $H6213F_1$, $H6213F_2$, $H6213F_3$, $H614F_1$, $H614F_2$, $H614F_3$, $H614F_4$, DKF_1, DKF_2, DKF_2, Oduma-F_1, $H513F_1$, $H513F_2$, $H513F_3$, $H505F_1$, $H505F_2$, $H500F_1$,$H500F_2$ and pioneer collected were spread out in the sun to dry, ground in a mill and further spread out to dry in the sun to a constant weight before storing in a stoppered container. The sugarcane bagasse was obtained from

Butali Sugar Company, Kakamega County. The fresh samples were sun dried for six hours daily for five days until constant weight and stored in the laboratory.

3.4 Chemicals and Reagents

All the chemical reagents used were of analytical grade purchased from Kobian-Kenya Ltd. They included sodium sulphate, copper fillings, sulphuric acid (98 %), perchloric acid, HNO_3 (68 %), boric acid, hydrogen peroxide (30%, 70% and 90%), hydrochloric acid (36 %), ammonium oxalate, oxalic acid and potassium permanganate

3.5 Instruments and Apparatus

Instruments used in the study included the UV-Vis spectrophotometer (Cecil-CE 2041-2000 series) for levels of phosphorous (EPA Method 365.3, 1978), a flame photometer (Sherwood classic model 410) in the determination potassium (Hald and Burkett, 1958) and pH meter (Benchtop pH / mv meter model 210) for determination of pH of decomposing sisal pulp, soil and BBF formulation.

3.6 Experimental Procedures

3.6.1 Preparation of Reagents and Solutions

3.6.1.1 Peracetic Acid

The Zhao, Peng, Fu, Ma and Yao, (2008) experimental and modeling procedures were adopted with amendments. Glacial acetic acid (95.00 ml equivalent to 100 g) was measured and added to cleaned and dry 250 ml volumetric flasks containing 10 ml of concentrated sulphuric acid (9 % of the contents). The flasks constituting a set (in triplicates) were labelled (ratios 1:1, 2: 1 and 3:2) and immersed in water baths stirred with a magnetic stirrer and maintained at 25 ^{o}C. Hydrogen peroxide (95 ml) of concentrations 30 %, 70 % and 90

% by volume were separately then added. The mole ratio of peroxide to acetic acid was kept at 1:1, 2: 1 and 3: 2 in designate flasks.

3.6.1.2 Biomass Digestion Solutions and Reagents

These included 18 M sulphuric acid (98 %), perchloric acid and 15 M HNO_3 (68 %) used as manufactured without dilution, a salt-metal mixture made by grinding sodium sulphate (20 g) with copper (2 g) in a motor with a pestle. Sodium hydroxide (10 M) was made by dissolving NaOH (40 g) in 100 ml distilled water. Boric acid (8 %) was made by dissolving H_3BO_3 (40 g) in 1000 cm^3 of distilled water and warmed with stirring. Standard hydrochloric acid (0.01 M HCl) was made by adding 2.20 ml of the concentrated acid (35 % purity) to a litre of distilled water and diluting 10 ml of this solution to 250 ml. The lanthanum solution was prepared by dissolving the lanthanum oxide (1.727 g) in 8 ml of concentrated HCl and made up to one liter with distilled water.

3.6.1.3 Phosphorous Colour Developing Reagents

The colour development reagents included molybdate and ascorbic acid solutions. Ammonium molybdate stock solution made by dissolving 6.2 g in 80 ml deionized water and heated and maintained at 60 ^oC for five minutes before cooling to room temperature. Antimonyl potassium tartrate (0.7 g) was added to the mixture and stirred. The flask with its contents was placed in an ice bath before slowly adding concentrated sulphuric acid (70 ml). Upon cooling, the mixture was diluted to 250 ml and stored in brown bottles at 4 ^oC. The ascorbic acid stock solution was made by dissolving ascorbic acid (10.56 g) in 75 ml distilled water and diluted to 100 ml. The mixture was equally stored at 4 ^oC. Phosphorous colour developing working solution was made by mixing acid molybdate stock solution

(20 ml), the ascorbic acid stock solution (10 ml) and 800 ml of de-ionized water. The resulting solution was thoroughly mixed before dilution with de-ionized water to 1 litre.

3.6.1.4 Calcium Precipitation and Dissolution Reagents

Since there was a possibility of interfering ions present in the digest, the calcium ions were to be precipitated as calcium oxalate. The ammonium oxalate/oxalic acid mixture was made by mixing 5 ml of 0.1M oxalic acid with 95 ml of 0.1M ammonium oxalate.

3.6.1.5 Stock solutions of K, Ca and P

Potassium chloride (0.1 g) was dissolved in 50 ml of de-ionized water in the preparation of 1000 ppm stock solution. A 2.5 ml of this solution, 100 ml de-ionized water and 10 ml of concentrated hydrochloric acid were thoroughly mixed before topping up to 250 ml with de-ionized water raising a 20 ppm working solution. Calcium carbonate (4.00 g) was reacted with 1 M HCl (10 ml) and topped up to 50 ml with deionized water to obtain the stock solution. The phosphorous stock solution was prepared by dissolving KH_2PO_4 (0.23 g) in 50 ml deionized water.

3.6.1.6 The pH Meter buffer Solutions

Fresh standard buffer solutions of pH 4.0, 7.0 or 9.2 were prepared by dissolving standard buffer tablets in 100 ml distilled water.

3.7 Methods Validation procedures

3.7.1 Calibration curves

Aliquots of 5, 10, 15, 20 and 25 ml of the stock solutions (3.6.1.5) were separately diluted to 50 ml with deionized water to obtain the working solutions with concentration range

1.30 mg to 10 mg ion per 50 ml of the solution. Absorbance of the solutions alongside blanks in triplicate was recorded at 766.5 nm (potassium) and 660 nm (phosphorous). Volumes of potassium permanganate (titers) were also recorded. The data obtained was used in drawing calibration curves. Absorbance, titer with the calibration equations raised was used to obtain ion concentration in samples. Limit of detection of each element was also calculated from calibration curves.

3.7.2 Recovery

Three sets of sisal biomass (0.5 g) determined to have 0.510±0.117 mg / g nitrogen was spiked separately with 0.5, 1.0 and 1.5 ml of a standard solution (0.1M NH_4NO_3) respectively to determine the recovery. Six determinations were performed for each addition level. The procedure was repeated with 0.1M KH_2PO_4 (phosphorous), 0.01M KCl (potassium) and 0.1 M $CaCl_2$ (calcium).

3.7.3 Precision

Six determinations on 0.5 g each of maize stalk (variety H6213), hoof/horn, and sisal samples were performed using the same reagents and apparatus to evaluate the methods precision.

3.8 Determination of Levels of Macronutrients

3.8.1 Determination of Total Nitrogen

The procedure by Upadhyay and Sahu, (2012) was used in the determination of total nitrogen by micro-kjeldahl method. Samples in triplicate were weighed (0.5 g) into digestion flasks before 0.2 g of Cu/Na_2SO_4 (catalyst/salt mixture) was added, followed by

10 ml of 18 M H_2SO_4. The mixture was heated on a hot plate at 200 ^oC until frothing subsided before temperature was raised to 350-375 ^oC and heating continued until a clear solution was obtained. The mixture was cooled to room temperature and topped up to 20 ml with deionized water. About 0.6 g of Devardes alloy was added to the 20 ml digest followed by 30 ml of 10 M NaOH. The mixture was stirred and steam distilled for 15 minutes to collect the distillate (NH_3) into 50 ml boric acid solution in a 250 ml beaker. The resulting mixture was then titrated using standard 0.01M HCl and the mass of nitrogen calculated: Total mass of nitrogen (mg/100g), DM $= \frac{140{,}000x\ V_a x M}{M_O\ x\ M_S}$ 1

Where

V_a = volume of the acid used

M = molarity of the acid used

M_o = % moisture

M_s = mass of the sample used

The procedure was repeated with 0.5 g of biomass-based fertilizer formulated to establish the levels of nitrogen.

3.8.2 Determination of K, Ca and P

Phosphorous levels were measured by the molybdenum-blue colorimetric method while calcium with potassium permanganate titration method (after precipitation of calcium as oxalate) and potassium by a flame photometer (Sherwood classic model 410) after wet digestion (Walinga *et al*., 1995). A dry sample was weighed (0.5 g) in triplicate into separate digestion flasks. Lanthanum chloride solution (10 ml) and concentrated nitric acid (10 ml) were then added to the mixture and heated on a hot plate set at a temperature of 200 ^oC until brown fumes subsided. After cooling mixture to room temperature, 10 ml of

HNO_3 were added and again similarly heated to the same temperature. The mixture was again cooled and 2 ml of perchloric acid added before the mixture was heated until white fumes were seen. The resulting solution was filtered and made up to 100 ml with distilled water in a volumetric flask.

In the determination of phosphorous (P), Thakur, (2012) procedure was adopted. The digest solution (10 ml) was transferred into a 50 ml volumetric flask and ammonium molybdate vanadate solution (10 ml) added, the contents shaken before making up to the mark. Spectrophotometer readings (R) were taken alongside blank and standard solutions. Baghel, (2012) procedure was adopted in the determination of potassium. An aliquot was aspirated through a flame photometer. Emissions at 766 nm were recorded for both standards and samples.

The Tee *et al*., (1987) titrimetric procedure was adopted in the determination of calcium. An aliquot of the solution was reacted with ammonium oxalate solution to precipitate out the calcium. After centrifugation and decanting the supernatant liquid, the precipitate was re-dissolved in 4M H_2SO_4.

Calcium in solution was titrated against 0.01M potassium permanganate, with the solution kept at about 75-85°C through-out the titration. For each solution prepared, at least three titrations were carried out to determine the average titer. Standard solutions were similarly titrated.

The readings (R) taken were substituted in the relevant regression equations (section 3.7.1) obtaining levels of potassium, calcium and phosphorous in mg/100 g of the samples.

3.8.3 Determination of Soil pH

Preliminary soil pH tests in the study area were carried out to guide on the choice of appropriate BBF to be used. Soil samples were scooped with a hand trowel at depths in the range 0-15 cm at three randomly chosen spots of each plot. Pebbles in the soil samples were handpicked before the soils were stored in labelled clean dry plastic beakers. The soils were then air dried at 30-35 ^{o}C in the sun for three days (six hours a day) after which they were ground in a motor with a pestle and sieved with 2 mm sieve. Three representative samples (obtained by coning and quartering) of each soil were mixed and labelled. A soil sample was weighed (10 g) into 100 ml beaker and distilled water (10 ml) added and stirred with a glass rod. The suspension was allowed to stand for 30 minutes in a water bath at a temperature of 25 ^{o}C before pH measurement using pH meter calibrated with standard buffer solutions. The pH was recorded to decimal point accuracy within 45 seconds of insertion. The electrode was removed from the soil - water suspension, rinsed with distilled water and excess water blotted off with filter paper before standing it in a clean dry beaker

3.9 Chemical Decomposition of Agricultural Wastes

3.9.1 Lye Preparation

Maize cobs (50 Kg) were weighed onto a steel metallic sheet and ignited to burn in air to ashes. The ashes were transferred into a plastic container and the lye extracted thrice with three 8 liter portions of distilled water before filtering. The total lye collected was stored in a 30 liter plastic containers.

3.9.2 Decomposition of Sisal Leaf pulp

The effect of sun drying, shade drying, freshness, relative position of the leaf, and strength of the alkali in optimizing sisal leaf pulp decomposition were investigated.

3.9.2.1 Effect of mode of Drying and leaf position

Sets of sisal leaf pulp (25 g), in triplicate, made from central, middle and outer layer sisal leaves taken from the same sisal plants as fresh, sun and shade dried were separately soaked in 50 ml distilled water in 100 ml plastic beakers and left to stand on shelves for 40 days. The pH of each was taken every 48 hours with turning of the contents to allow partial aeration to uphold rapid composting principles. Set I were those samples soaked fresh, set II were of samples that had been sun dried and set III of shade dried.

Values obtained were plotted against period (days) to give trends of pH during decomposition. This was to guide on how sisal leaf biomass would be treated to enhance a quick access to macronutrients.

3.9.2.2 Effects of Lye and NaOH

Three sets of dry sisal leaf wastes (25 g) were separately mixed with 100 ml of water, lye and 2 M NaOH in 250 ml round bottomed flasks labeled SW (sisal wastes), CASD (cobs ash sisal digest) and NaD (sodium hydroxide digest). Each mixture was heated to half the contents, cooled before connecting to the gas collection set up. The peak of biomass decomposition is marked by production of methane gas. The gas generated upon decomposition was collected by 100 ml measuring cylinders inverted over 0.5 M HCl .

Volume of gas collected was recorded per day. Graphs of volume of methane gas against period of composting (days) were plotted.

3.9.3 Preparation of Cobs Ash Sisal Digest (CASD)

Ten (10.0) liters of lye prepared (section 3.7.1) was added to dry sisal biomass (1.5 kg) and boiled until frothing subsided. This was repeated for two other sets. The mixture in each case was placed on a black polythene paper and allowed to dry in the sun six hours daily for three days. Sisal fiber were physically removed by hand picking after drying to leave the residue as cobs ash sisal digests (CASD). The CASD was blended to a finer powder using a fruit mincer. The pulverized CASD was dried in the sun to constant weight. Samples (0.5 g) in triplicate were withdrawn from the digests and analyzed for macronutrients (sections 3.8.1 and 3.8.2). The dry CASD was stored in clean air tight plastic containers ready for use in fertilizer formulation.

3.9.4 Preparation of Horns/Hoof Digest (HD)

Two kilograms of a mixture of dry horns and hoofs (1:1 w/w) were in triplicate soaked in 3 litres of the peracetic acid solutions in open containers and left standing with periodic stirring. The digestion period was considered to have ended when all the hard tenacious material of horns and hooves was all quasi solid. The liquid in the mixture was decanted off, the residue rinsed three times with distilled water. The residue was sun dried to allow development of agglutinating properties through exposure to the atmosphere. Samples (0.5 g) in triplicate were withdrawn from the digests and analyzed for macronutrients (sections 3.8.1 and 3.8.2). The horn and hooves digests (HD) were kept in air tight plastic containers awaiting use in the formulation.

3.10 Formulation and characterization of biomass-based Fertilizer

3.10.1 Formulation of BBF

The formulation process involved blending HD with CASD with a view to beef up levels of nutrients. To establish the blending ratio (HD: CASD) the acidity of HD and alkalinity of CASD were determined. A mass of 0.6 g of Horn / Hoof Digest (HD) was weighed into 100 ml of standard 2 M NaOH solution in a beaker and heated to boiling until the level of the mixture was 30 to 40 ml when the vapour above the boiling mixture showed no more ammonia production (wet red litmus paper). The resulting mixture was topped up to 100 ml with distilled water. An aliquot (25 ml) of the mixture (in triplicate) was pipetted and titrated with standardized 2 M HCl. The average volume of HCl was used to establish the amount of NaOH (the alkalinity) needed to react with the Horn/Hoof Digest (HD) releasing maximum amount of ammonia. The moles of NaOH that reacted with 0.6 g HD was given as: Moles of NaOH that reacted with 0.6 g

$$\text{HD} = \frac{V_b^2 M_b - 100 V_a^2 M_a}{1000\ V_b} \text{ moles} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where,

V_b = volume of base used in the titration

M_b = molarity of base used in the back titration

V_a = volume of acid used in the back titration

M_a = molarity of acid used in titration

The alkalinity available from Cobs Ash and Sisal Digest (CASD) was equally determined. The CASD (0.6 g) was transferred into a beaker followed by 100 cm^3 of standardized 2 M

HCl. The moles of HCl that reacted with alkalinity in the CASD was calculated by the equation: Moles of HCl that reacted with 0.6 g

$$\text{CASD} = \frac{V_a^2 M_a - 100 V_b^2 M_b}{1000\ V_a} \text{ moles} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where,

V_b = volume of base used in the titration

M_b = molarity of base used in the back titration

V_a = volume of acid used in the back titration

M_a = molarity of acid used in titration

Biomass-based formulations (BBF_0, BBF_1, BBF_2, BBF_3, BBF_4 and BBF_5) were derived by mixing HD:CASD in the ratios 0:1, 1:1, 2:1, 3:1, 1:2 and 1:0 based on the ratio of moles of NaOH used on HD (equation 2) to moles of HCl used on CASD (equation 3) respectively.

3.10.2 Determination of pH and Macronutrient levels in BBF

The method described by Sawarkar, (2012) was adopted in the determination of pH of biomass-based formulations (BBF). Ten grams (10 g) each of the formulations (BBF_1, BBF_2, BBF_3, BBF_4 and BBF_5) was weighed in triplicate into 100 ml beakers followed by 20 ml of distilled water. The suspensions were stirred at a regular interval for 30 minutes. The pH values were determined by immersing electrodes into the suspension. The available macronutrients in BBF were determined as described in (Sections 3.8.1 and 3.8.2).

3.11 Efficacy of the BBF in Maize Growing

3.11.1 Land Preparation

The land was prepared by ploughing to an average depth of 15-20 cm just before the long rains and then subdivided into four blocks. Harrowing was done once to break the clods before furrows were made at a spacing of 75 cm and depth of 8 cm in readiness for planting and cultivation. Four plots measuring 2×1 m^2 were demarcated in each of the four blocks and labelled A, B, C and D. During field trials the plots were under separate fertilizer schedule treatments.

3.11.2 Efficacy Evaluation

Maize growing was done to compare the efficacy of BBF_1 with conventional inorganic fertilizers DAP/CAN. The biomass-based fertilizer (BBF_1) was used for both planting and side dressing maize in all plots labelled A across all the three blocks. Those plots labelled B in each block had nil fertilizer at planting but side dressed with a table spoonful of calcium ammonium nitrate (CAN) per hole. The maize in plots labelled C were planted with the biomass-based fertilizer formulation (BBF_1) and side dressed with CAN. The maize in plots labelled D were planted with a table spoonful Diammonium phosphate (DAP) and side dressed with calcium ammonium nitrate (CAN).

During planting, a step by step guide in planting maize (Hunt, 2016) was followed. Holes 6-7 cm deep at a spacing of 15 cm were dug, BBF (50 g) and DAP (10 g) were applied per hole, a little soil added to cover fertilizer to avoid direct contact with seeds. Two seeds (variety DK) were added per hole, covered with soil and allowed to germinate. Days taken before seedlings shooting above ground were recorded. Each plot hosted 40-45 maize

plants. Weeding was then done 18 days after germination to control weeds and improve soil tilts. Side dressing (2nd fertilizer application) was done 24 days after germination. Last weeding was done two weeks later.

The efficacy of BBF in promoting growth, averting deficiencies and consequently affecting yield were assessed. Promotion of growth was determined through direct height measurement from a common bottom boarder on the ground to the top of each plant stem's highest developed leaf (Wood and Roper, 2000). The heights were measured weekly using a meter rule/tape measure. Plants were observed too for deficiency symptoms, pest and insect (stalk borer) infestations for three months. Maize grains from each plant in designate plots under given treatments was harvested, shelled and dried in the sun with weighing for five days until constant weight was attained. The produce per plot on the whole was weighed before 100 seeds were randomly withdrawn and rotten seeds physically counted to evaluate percentage (%) impact of pests and stalk borer infestation during the growing of maize.

3.12 Data Analysis

The data generated in the study was analyzed by SPSS version 21.0 to guide the discussions. The mean levels of potassium, nitrogen, phosphorus and calcium in the biomass samples were determined with intention of guiding on suitability of the biomass to be used in the formulation of BBF. Analysis of variance (ANOVA) was used to measure variation in sample variety (maize), nature of edges and relative position (sisal leaves) on the levels of macronutrients. A post hoc analysis assuming Duncun's equal variances was done to help separate and identify the causes of variation. This was done to evaluate the formulation's efficacy against nil use and application of conventional inorganic fertilizers.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the results arranged according to the study objectives. The laboratory methods used were validated and the results are presented and discussed. The data is presented in tables, figures, graphs and plates.

4.2 Methods Validation

The methods used to determine levels of nutrients were validated using calibration procedures, recovery and precision studies through establishment of the R^2 (regression equations), RSD (recovery and precision). This was done to confirm the appropriateness of the procedures on materials used in the study. The data collected was analyzed and recorded as summarized in the Table 4.1.

Table 4. 2: Results of methods validation measured parameters

Analyte	Calibration Equations	R^2	Recovery	Precision			
			% Mean± SD	LoD	RSD[b]	Mean ± SD[a]	% RSD[b]
Nitrogen	-	-	97.19 ±1.55	0.0465	1.59	327.58±7.47	2.28
Phosphorous	y = 0.121x – 0.001	0.998	98.97±0.99	0.0297	0.39	46.74±.84	1.79
Potassium	y = 1.474x + 0.408	0.995	99.25± 0.67	0.0242	0.62	529.22±8.36	1.57
Calcium	y = 0.032x – 0.045	0.989	98.35 ±0.86	0.254	0.93	40.38±0.72	1.81

a-Limit of Detection, b-Relative Standard Deviation

4.2.1 Regression Equations

Regression equations (Table 4.1) generated out of plots of absorptions against concentration of standard solutions were used to determine the levels of macronutrients. The equations had positive slopes, 0.121 (P), 1.47 (K) and 0.032 (Ca), implying that a unit increase in the biomass accounts for increase in the concentration. The coefficient of determination values (R^2) of the plots were 0.998 (P), 0.995 (K) and Ca (0.989), meaning that 99.8 %, 99.5% and 98.9% of the variations in the absorbance could be explained by variations in concentrations. The closeness of the R^2 to 1 showed that absorbance was linearly correlated to the concentration of the ions (Frost, 2013). The regression equations therefore expressed direct proportionality between the instrument response and the concentration.

Regression equations are frequently used in estimating concentration of metal ions. Studies such as the removal of Cr (VI) from aqueous solutions by powdered potato peelings done earlier relied on regression equations (Mutongo, Olga, and Pardon, 2014). Other studies that also have used linear regression equations include Velasco, Goffman, and Heico, (1999) in a study to predict oil content and fatty acid composition in *Brassicaceae* germplasm using near infrared reflectance spectroscopy, Kopsell *et al*., (2006) when determining levels of Ca, Mg, K, Fe and Zn in 22 kale and collard cultivars using atomic spectrometry, and Aywa, Nawiri, and Nyambaka, (2012) when determining levels of selected nutrients (Cu, Fe, K and Ca) in varieties of *Ipomea batatas* grown in Vihiga County. The R^2 values in the study averaged 0.994 and so justified adoption of the methods. The linear equations were considered reliable for use.

The limits of detection (LoD) derived in the validation studies were determined as intercepts plus three standard deviations (Linskens and Jackson, 1997). The limits of detection (table 4.1) in the determinations of the total nitrogen by Kjeldahl's procedure (0.0465 µg/ml), phosphorous by uv-vis spectrophotometry (0.0297 mg/l), potassium by flame photometry (0.0297 mg/l) and calcium by titration (0.0254 ppm) were comparable with 0.01 µg/ml (nitrogen) to publications of National bureau of standards catalogue (Burris, 1977), 0.03 mg/l phosphorous (Termminghoff and Houba, 007), 0.005 ppm for potassium) and 0.04 ppm calcium (Adeyeye, 2005). The slight deviations between values in this study and other studies as well as recommendations by research institutes can be explained. Limits of detection depend critically on the details of the instrument used (Lindon, Tranter and Kopenaal, 2010). The proximity (closeness) of the values, however, enhanced the use of the procedures in the study.

4.2.2 Recovery Studies

The percentage recoveries were done using standard addition approach. The recoveries ranged between 97 and 99 %, which was within acceptable range of 97-103% for concentrations 1 mg/g ≤ analyte conc.≤ 10 g/100 g (Magnusson and Örnemark, 2014 and Pedro, Ernesto, Fabio and Jose, 2011). The recovery of nitrogen using the Kjeldahl's method in a study by Janssen and Koopmann, (2003) showed recoveries of 100.0% - 108.5% in soil samples while bio waste and sludge samples ranged 94.5% - 102.8%. Recovery values over 100 % mean that methods used make positive errors.

4.2.3 Precision

Six determinations of various nutrients in maize cobs variety 6213 were performed using the same reagents and apparatus to evaluate the methods precisions (reproducibility) and the results are given in Table 4.1. All the RSD values except for the Kjeldahls method were less than 2 % that is acceptability limit (Burges, 1997; Lanwaars, 1998; Amir, Taylebeh, Reza and Farzad, 2005). In the determination of total phosphorous, total nitrogen and nitrogen in fractions of soil, compost and sewage, Janssen and Koopmann, (2003) showed a standard deviation range of 0.01 - 0.06 and a maximum 8 % RSD. The RSD of 2.28 % found in this study using the same method indicated reproducibility. The uncertainty in detecting the end of titration given quantities used may explain the variation.

4.3 Macronutrients levels in Agricultural Biomass

4.3.1 Maize Stover

Levels of total nitrogen, phosphorus, potassium and calcium in maize cobs and stalks of different maize varieties from different farms are presented in Table 4.2.

Table 4. 1: Mean mass of total N, P, K and Ca in maize and cobs

Variety	Mean ± Std. Dev. (mg/100g), DM							
	Total Nitrogen in		Phosphorous in		Potassium in		Calcium in	
	Cobs	Stalks	Cobs	Stalks	Cobs	Stalks	Cobs	Stalks
H6213-F_1	326.290±10.616^{b}	541.74±12.09^{c}	36.446±0.154	49.329±0.950^{a}	529.22±68.83^{a}	737.52±4.93	195.909±0.281^{a}	458.387±21.575
H6213-F_2	327.580±19.969^{b}	549.35±14.16^{c}	39.190±1.239	72.006±0.190^{a}	595.46±15.11^{a}	335.51±10.37	153.299±0.196^{a}	458.387±21.575
H6213-F_3	323.360±8.091^{b}	453.11±12.96^{c}	31.685±1.399	62.445±1.210^{a}	493.00±15.49^{a}	635.51±9.35	187.157±0.614^{a}	507.387±11.975
H614-F_1	395.100±2.976^{a,b}	747.33±10.05^{b}	36.815±1.088	54.533±0.820^{a,b}	393.00±25.19^{a,b}	606.53±10.52	147.801±1.089^{a,b}	354.743±20.999
H614-F_2	387.840±13.658^{a,b}	775.44±12.86^{b}	42.411±3.292	69.123±1.010^{a,b}	595.52±37.08^{a,b}	636.65±50.09	170.538±0.531^{a,b}	364.092±10.942
H614-F_3	386.050±10.906^{a,b}	654.62±21.91^{b}	46.739±3.112	23.104±0.120^{a,b}	495.02±17.08^{a,b}	549.35±14.48	151.527±1.778^{a,b}	351.190±10.178
DK-F_1	436.480±5.052^{a,b}	907.93±12.41^{a}	70.793±1.263	53.069±0.680^{a,b}	426.96±26.05^{a,b}	717.82±3.29	166.801±1.233^{a,b}	461.584±10.834
DK-F_2	418.300±6.569^{a,b}	986.94±12.72^{a}	28.097±1.008	36.083±3.640^{a,b}	572.85±28.83^{a,b}	447.18±8.39	152.878±0.798^{a,b}	474.235±8.264
DK-F_3	417.320± 5.177^{a,b}	735.55±22.82^{a}	29.297±1.022	42.641±4.050^{a,b}	447.45±24.15^{a,b}	552.52±3.80	176.411±1.170^{a,b}	266.411±11.402
Oduma–F_1	215.030±15.078^{c}	504.46±22.14^{c}	46.236±1.703	54.113±1.790^{a,b}	383.31±21.21^{b}	485.55±16.78	140.383±0.753^{b,c}	369.948±21.535
H513-F_1	89.904±0.8728^{c}	398.82±9.74^{c}	27.285±0.256	45.612±1.210^{a,b}	405.15±10.52^{b}	535.42±7.86	136.159±1.841^{c,d}	301.020±14.801
H513-F_2	92.859± 2.944^{c}	332.24±11.58^{c}	23.698±1.641	48.911±1.090^{a,b}	425.09±.12.13^{b}	517.69±31.33	128.776±1.684^{c,d}	199.220±11.301
H513-F_3	103.870±8.124^{c}	353.43±14.20^{c}	20.644±1.047	44.133±0.800^{a,b}	410.29±23.83^{b}	539.48±6.42	91.445±1.510^{c,d}	249.671± 20.998
Pioneer-F_1	364.06±8.612^{a,b}	964.06±4.67^{a}	61.873±0.680	31.873±0.680^{c}	518.56±15.39^{a,b}	618.56±15.39	187.203±0.874^{a}	467.203±10.874
H505-F_2	115.52±2.418^{c}	595.52±23.47^{c}	29.123±1.710	49.103±1.710^{a,b}	382.27±10.49^{ab}	185.808±11.30	81.808±2.307^{d}	185.808±11.302
H505-F_3	109.86±6.845^{c}	409.86±18.34^{c}	23.104±0.120	24.204±0.120^{a,b}	376,22±11.09^{a,b}	365.808±16.30	95.008±1.302^{d}	365.808±16.302
H500-F_1	177.33±1.220^{c}	477.33±11.72^{c}	33.119±0.680	33.119±0.680^{c}	221.54±21.00^{c}	311.54±21.00	121.165±0,891^{c,d}	233.165±10.891
H500-F_2	96.48±5.036^{c}	396.48±22.03^{c}	36.183±3.640	26.183±3.640^{c}	242.73±9.07^{c}	342.73±9.07	103.768±0,622^{c,d}	253.768±20.622
H500-F_3	122.04±1.862^{c}	372.04±21.06^{c}	34.103±1.790	44.103±1.790^{c}	248.45±10.56^{c}	308.45±10.56	111.943±1.227^{c,d}	248.943±21.227
Overall	**258.170±136.316**	**587.17±211.89**	**36.676±11.92**	**45.46±14.08**	**429.570±111.21**	**525.22±138.62**	**142.104±34.459**	**345.730±103.33**
P- Value	**0.015**	**0.000**	**0.902**	**0.203**	**0.007**	**0.039**	**0.033**	**0.015**

N = 30, F_1, F_2 and F_3 represents farms that had designate variety; ^{a,b,c} and ^{d} post hoc analysis placement

The total nitrogen in the maize cobs was 258.170±136.316 mg/100 g DM, ranging within 89.90 - 436.48 mg/100 g. This result is in close agreement with a value of 220 mg/100 g reported by Knox and Geoff, (2007) in a study on the estimation of nutrients in baled corn stalks. The amounts of N found in the tested varieties were significantly different (p=0.015). The variety DK showed the highest amount of nitrogen, averaging 424.030±10.790 mg/100 g DM. This was followed by variety H614 that in general accumulated 389.660±4.790 mg/100 g. The other varieties had lower values with the least being variety H513 that showed an accumulated average of 94.48 mg/100 g.

Phosphorus in the maize cobs averaged 35.141±11.927 mg/100 g DM ranging from 20.644 to 70.793 mg/100 g (Table 4.2). An analysis of maize cob wastes for the biogas generation from maize wastes (cobs) and carrot leaves reported a level of 4 mg/100 g (Suleiman, Mohammed, Musa and Arzika 2013). In a separate study it was reported too that an accumulation of phosphorus by maize as a result of reduction in the potassium fertilizer averaged 50 mg/100 g (Skowrouska and Filipek, 2010). The variation of phosphorus in maize cobs of different varieties was insignificant (p=0.902). Unlike nitrogen there was no particular variety that out rightly showed low or high levels. Phosphorus in large quantities of cereal grains is mostly associated with phytic acid and its salts. The season, method and quantity of fertilizer application determine the phosphorus content (Umar *et al*., 2016). Other factors determine levels of phosphorus in plants, including interaction of phosphorus and calcium that causes desorption, the pH range, amount of organic matter and proper placement of fertilizer-phosphorus (USDA- NRCS, 2014).

The potassium in maize cobs of varieties sampled was 429.57±111.21 mg/100 g in a range of 221.54 – 595.46 mg/100 g, Table 4.2. Suleiman, *et al.,* (2013) reported potassium levels as 320 mg/100 g when investigating biogas generation from maize wastes (cobs) and carrot leaves. Potassium soil requirements is estimated to be 3 mg/100 g (Suleiman *et al.*, 2013) and the recommendation for crops like corn is 22.68-34.02 kg/acre for soils containing low levels (Bundy, 1998). There was significant variation (p=0.007) in the amount of potassium in the maize cobs of different maize varieties.

Calcium levels averaged 142.104±34.459 mg/100 g in a range from 81.808 mg/100 g in the variety $H505F_2$ to 195.909 mg/100 g levels in variety $6213F_1$. In a study on the feeding and economic value of maize meal for broiler chickens, the level of calcium in cobs was 110 mg/100 g (Ochetim, 1993). The levels of calcium depend in part on its availability in the soil. The levels of calcium in maize cobs from different cultivars varied significantly (p=0.033). A plant's variety and its environment play an important role in accumulation of nutrients (Grubben, 2004). The composition of maize cobs has also been reported to be affected by stage of maturity, climate, soils and production method (Szyszkowska, Sowinski and wierzbicki, 2007). This explains why significantly different values like 25 mg/100 g have been reported (Suleiman *et al*., 2013).

The levels of macronutrients, Table 4.2, in maize stalks of 8 cultivars analyzed averaged 587.17±211.89 mg/100 g (N), 45.46±14.08 mg/100 g (P), 525.22±138.62 mg/100 g (K) and 345.730±103.337 mg/100 g (Ca). The macronutrients levels significantly varied with maize varieties, total nitrogen (p=0.000), potassium (p=0.039) and calcium (p=0.015),

while phosphorus levels varied insignificantly ($p = 0.203$). The results compare well with levels reported in other studies.

Separate studies have reported varying values of macronutrients levels in maize stalks. Total nitrogen levels have been reported, 997 mg/100 g (Knox and Geoff, 2007), 448 mg/100 g (Skowrouska and Filipek, 2010) and 750 mg/100 g (Hoskinson, 2007). Phosphorous in maize stalks have been reported as 158 mg/100 g (Knox and Geoff, 2007) and 69.0 mg/100 g (Sawyer, 2017). Camberato, (2008), Hoskinson *et al*., (2007), Darwish, Bakr and Abdulla (2012) and Knox and Geoff, (2007) reported potassium levels 430 mg/100 g, 998.4 mg/100 g, 102 mg/100 g and 1204 mg/100 g respectively. Hoffman *et al*., (2011) reported an average of 1810 mg/100 g calcium in maize stalks. The variation in between studies can be explained as macronutrient levels in plants are affected by plant variety (Torelm and Danielsson, 1998), soil environment (Grubben, 2004), inputs including fertilizer application. Phosphorus accumulation is not necessarily dependent on the varieties (Syvalahti and Korkman, 1978).

Comparison between macronutrient levels in cobs and stalks equally showed significant differences. Maize stalks were generally high in macronutrients. Calcium level in maize is tissue based, decreasing in the order leaves, stems, cobs covering leaves and cobs (Szczepaniak, 2016). The decrease in calcium concentration in the vegetative tissues implies its high mobility from the cobs core and cob covering leaves to developing kernels considered as a final sink. In general plant's variety and its environment play an important role in accumulation of nutrients (Grubben, 2004). In a study on accumulation of nitrogen, phosphorus and potassium in mature maize under variable rates of mineral fertilization,

Kryzysztof, Reneta and Anna, (2016) reported that macronutrient concentration in the maize parts significantly decreased in the order grain > stems > leaves > husks > cob cores, giving an explanation as to the role of macronutrients in a plant's development.

This study established that maize cobs and stalks have significant levels of macronutrients for use in formulating a biomass-based fertilizer. Complete removal and non-reuse disadvantages farm soils as this amounts to macronutrient depletion and calls for more conventional fertilizers. Utilization of either of the biomass in formulating an efficient fertilizer returns macronutrients to the soils.

4.3.2 Macronutrients levels in the Cattle Hooves and Horns

Cattle horns and hooves collected from different slaughter houses in Lugari were analyzed for nitrogen, potassium, phosphorus and calcium levels and the results are summarized in Table 4.3.

Table 4. 2: The mean ± SD mass of macronutrients in the cattle horns and hoofs

	Mean ± standard deviations mg/100 g, DM			
Samples location	**Total nitrogen**	**Phosphorous**	**Potassium**	**Calcium**
Horn L_1	3166.90±19.876^{b}	81.342±1.656	11.74±0.465^{b}	72.080±5.442^{b}
Horn L_2	3177.60±14.666^{b}	36.285±5.814	11.83±0.920^{b}	84.643±2.342^{b}
Horn L_3	3070.40±41.585^{b}	63.723±1.599	11.13±0.577^{b}	90.847±1.353^{b}
Hoof L_1	4924.90±81.109^{a}	94.952±5.563	17.64±0.441^{a}	102.400±3.407^{a}
Hoof L_2	4490.10±26.147^{a}	94.832±12.853	12.11±0.214^{b}	99.531±1.742^{a}
Hoof L_3	4614.40±35.441^{a}	81.902±1.933	20.56±0.091^{a}	126.439±2.567^{a}
Hoof L_4	4749.80±23.761^{a}	60.501±0.618	19.64±0.111^{a}	123.845±0.907^{a}
Hoof L_5	4527.20±41.749^{a}	56.721±0.618	13.66±0.306^{ab}	105.432±1.111^{a}
Hoof L_6	4589.00±21.319^{a}	46.017±0.618	14.34±0.072^{ab}	111.457±1.002^{a}
Mixture mass(1:1)	4145.60±763.338	70.083±21.247	13.98±2.811	101.85±17.69
P –sample	**0.000**	**0.453**	**0.055**	**0.007**
P –S. house)	**0.206**	**0.167**	**0.541**	**0.018**

L-Lugari, G-Githurai. a and b same letters in a column indicate no significant difference, N=30

Horns had mean nitrogen levels of 3132.300±25.371 mg /100 g while hooves showed 4662.751±38.255 mg /100 g levels. Samples made by digesting horns and hooves mixture (1:1) by mass had levels 4145.60±763.338 mg /100 g. The mean levels of other macronutrients established included phosphorous (70.083±21.247 mg /100 g), potassium (13.98±2.811 mg /100 g) and calcium (101.85±17.69 mg /100 g). Analysis of variance (ANOVA) showed that the levels of nitrogen ($p=0.000$) and calcium ($p=0.007$) in hoofs and horns differed significantly. The slaughter houses where hoofs and horns were collected significantly ($p=0.018$) influenced levels of calcium perhaps not only due to the difference in types of cattle kept (indigenous and crossed) but also rearing practices like zero grazing. The other macronutrients did not differ significantly: N ($p=0.206$), P ($p=0.167$) and K ($p=0.541$).

Several studies have reported levels of the macronutrients which compare well with the findings of this study. Owen, Winsor, and Long, (1953) and Zoccolal, Awigi, and Tonin, (2009) in separate studies reported nitrogen to be in the range from 12.8% to 16.7% in keratin ($C_{28}H_{48}N_2O_{32}S_4$) found in exoskeleton materials like horns, hooves, hair, nail (Aluigi *et al.,* 2007). Phosphorous contents depend on hoof part. Penev *et al*., (2012) reported phosphorous in hoof walls to range from 25-70 mg/100 g while hoof soles to have 15-40 mg/100 g and heels 8-45 mg/100 g. In an independent study phosphorous content of the hoof characteristics of amiata donkey averaged 19.4±1.26 mg/100 g in the hoof walls and 23.43±1.26 mg/100 g in hoof soles (Sargentini, Tocci, Andrenelli and Giorgetti, 2012). In another study levels of phosphorous in hoofs of normal dairy cows without laminatis was reported to be 12.3 mg/kg (Barbosa *et al.*, 2016). These studies indicate the large variations of phosphorus in different parts of the hoof, which explains the large variations

observed in this study since different parts of the horns or hooves were used. The levels of calcium (80-132 mg/100g) too depend on the hoof part under consideration (Penev *et al*., 2012; Higuchi *et al*., 2009). Buddhachat *et al*., (2016) reported potassium levels 43.3 mg/100 g in horns of different animal species.

The chemical composition of hooves as well as the content of specific elements and fats is influenced by environment (Ministry of Agriculture and Foods for the Republic of Belarus, 2011). On the other hand quality and strength of the hoof capsule is influenced by metabolic, hormonal, genetic, environmental and nutritional factors such as fatty acids, minerals, vitamins and amino acids participate in the formation of the hoof (Muelling, 2009). Horns and hoofs have significant levels of macronutrients in contrast to the hypothesis that they can be used in a biomass formulation so as to facilitate recycling.

4.3.3 Macronutrients in Sisal Leaf and Sugar Cane Bagasse Biomass

Sisal (*Agave sisalana*) leaf pulp was analyzed for levels of nitrogen, phosphorus, potassium and calcium to determine the effects of different farms (F_1 to F_8) in different administrative units (wards-W), nature of the leaf edges (normal smooth-N or thorned-T) and leaf position on the plant (outer-O or central-Y) of sisal pulp (Table 4.4).

Table 4. 3: The mean levels of macronutrients in sisal leaf pulp

Sample	Mean macronutrient levels ± Standard deviation (mg/100g, DM)			
	Total Nitrogen	**Phosphorous**	**Potassium**	**Calcium**
F_3W_1SY	1310.80±9.504	361.27±3.050	2618.00±4.57	2800.8±174.10
F_3W_2SY	1322.20±15.124	417.75±5.41	1961.10±4.88	3180.8±3.46
F_2W_1SY	1264.40±24.364	459.41±12.12	2308.00±9.57	2643.4±57.14
F_2W_2SY	1040.10±23.473	419.25±21.79	1663.70±6.18	1945.2±14.582
F_1W_1SO	2459.60±86.483	244.85±18.78	2708.00±5.57	3898.1±0.864
F_1W_2SO	2154.40±147.394	176.50±11.72	2063.10±6.88	3959.0±7.029
F_4W_2SO	2044.90±34.573	110.01±0.71	1763.10±9.18	3827.2±94.69
F_5W_3TO	2155.20±31.573	206.87±11.04	2537.60± 0.88	6847.8±174.10
F_6W_1TY	1550.80±12.504	437.86±1.58	2708.00±5.57	5180.8±5.46
F_8W_3SY	1602.20±35.124	307.82±0.86	1863.10±6.88	2243.4±50.14
F_7W_3SO	2004.40±27.164	147.43±0.83	2062.10± 0.40	3945.2±114.582
F_5W_2TY	1246.70±13.073	405.21±20.57	2158.00±8.71	2858.1±0.864
F_4W_1SY	1499.60±82.183	286.58±0.69	1908.60± 6.13	2959.0±5.009
F_7W_4SO	2351.40±67.394	165.18±3.81	2190.30±16.27	3627.2±204.69
F_5W_4TO	1944.90±24.513	156.11±0.05	3023.00±156.46	5885.2±1.350
F_8W_4SO	2415.30±35.503	96.28±2.77	1579.10±1.39	3703.1±1.501
Mean -Sisal pulp	1772.93±469.573	274.90±127.59	2194.68±420.51	3719.02±1309.1
p-Farm	**0.027**	**0.018**	**0.173**	**0.022**
p-edge	**0.821**	**0.698**	**0.017**	**0.004**
p-position	**0.000**	**0.000**	**0.676**	**0.017**

F- Farm, W-Ward, T- Thorn edged, S-Smooth edged, O-outer layer, Y-central, N = 30.

The mean levels of total nitrogen in sisal pulp were 1772.930 ±469.574 mg /100 g, within a range of 1040.10 – 2459.60 mg/100 g while phosphorus averaged 274.90±127.595 mg/100 g with a range of 96.28-459.41 mg/100 g regardless of location, position or nature of the edge of the sisal leaf. Potassium level was 2154.90 ± 420.51 mg/100 g in a range from 1579.10 to 2708.00 mg/100 g while calcium levels averaged 3719.02±1309.17 mg/100 g in a range of 1945.2±14.58 to 6847.8±174.10 mg/100 g.

The findings of this study compare well with earlier studies. Mshandate, Kibozohi and Kivaisi, (2013) reported levels of 1460±200 mg/100 g and 250 mg/100 g for nitrogen and phosphorus respectively. Potassium levels in the study varied from 1340 mg/100 g in sisal bole wastes (SBW) to 5260 mg/100 g in remnant leaf stubs. Muthangya, Mshandate and Kivaisi, (2009) too reported levels of potassium in different sisal wastes as 5.56 g/100 g for sisal leaf decortication residues, 18 mg/l sisal leaf decortication (waste water), 4.28 mg/l sisal leaf decortication waste (fresh) and 9.96 mg/l sisal leaf decortication waste (dry). In a study on the integration of sisal production into livestock systems the levels of calcium in sisal leaves were reported as 5720 mg/100 g (Machin, 1991). The varying levels reported can be explained by the view that farm input and general plant environment influences levels of macronutrients in plants (Torelm and Danielsson, 1998). However this means sisal has significant amounts of macronutrients that need to be recycled.

A one way analysis of variance (ANOVA) at 95% confidence level indicates that the total nitrogen significantly varied with the plant environment ($P=0.027$) and position of the leaf ($p=0.000$) but was independent of the nature of the leaf edges ($p = 0.821$). Nitrogen levels were significantly high in outer (relatively older) leaves compared with the central (relatively younger) leaves from the same plant. This finding agrees with what other studies have reported. Ha and Chung, (1995) in a separate study reported nitrate content in petiole sap to be higher in older leaves of cucumber than in younger leaves. Breimer, (1982) too in a study on environmental factors and cultural measures affecting the nitrate content in spinach reported higher levels of nitrate in petioles and older leaves of spinach. The results mean that when nitrogen is the target macronutrient then old sisal leaves should be considered.

The phosphorus levels significantly varied with plant environment ($p = 0.018$) and relative position of the leaf on the plant ($p = 0.000$) but not the nature of the leaf edges ($p = 0.698$). Phosphorus readily trans-locates within the plant moving from outer leaves to central young tissues as the plant forms cells and develops root, stems and leaves. The central (relatively young) sisal leaves, actively growing plant tissues, have more abundant phosphorous than in outer old tissues (Mckenzie and Middleton, 2013). The leaf edges however significantly ($p=0.017$) affected the levels of potassium in the sisal biomass. Potassium is quite mobile and moves readily within the plant. Potassium deficiency symptoms appear in outer layer (old) plant tissues. Thus potassium concentration in sisal leaf tissues decrease with position of the leaf on the sisal plant as one moves from plant center outwards (Plank and Kissel, 2008; Besford and Maw, 1974).

In situations where phosphorus and potassium are required from decomposed biomass use of young sisal leaves are recommended. The levels of phosphorus in the study are within the levels in plants of 0.1-0.4% (100-400 mg/100g). The phosphorus content is in the range of soil requirement of 0.136 to 1.36 kg per acre (Mckenzie and Middleton, 2013) implying average 13.154 to 20.876 kg per acre of sisal leaf biomass can supplement 2.48% of phosphorus. Considering that the wastes generated annually, 611,875 tonnes in Kenya (Muthangya *et al.*, 2013) and 1,222,000 tonnes in Tanzania (Mshandate and Kivaisi, 2012) their utilization then would go a long way to improve crop production. The calcium levels in sisal pulp varied significantly with nature of the edges ($p = 0.004$), plant environment ($p=0.022$) and relative leaf position on the plant ($p=0.017$).

The levels of nitrogen in sugarcane bagasse averaged 371.316±14.430 mg/100 g in a range of 324.381 to 401.222, mg/100 g DM. Heuze, Tran and Archimede, (2012) reported levels of nitrogen to be 288 mg/100 g sugarcane bagasse, while Keir, Nguyen, Preston and Orskov, (1997) reported 473.6 mg/100 g. The variation in crude protein in crops like sugarcane, rye and sorghum are not only dependent on growth stage but also variety, climate, harvest conditions (Edmisten, Green, Mueller and Burns, 1998).

The phosphorus levels averaged 45.12±14.419 mg/100 g ranging from 30.628 to 53.902 mg/100 g, DM. Keir *et al*., (1997) in a separate study reported levels of phosphorus in sugar cane bagasse as 62 mg/100 g, DM. The level of potassium in the same samples of sugarcane bagasse was found to average 157.045±3.658 mg/100 g compared to 130 mg/100 g reported by Heuze *et al.* (2012). The chemical composition of sugarcane bagasse varies widely according to variety and climatic conditions as reported by El-morsy, (1980). The same explains the difference seen in calcium levels of this study (73.088±11.567 mg/100 g) compared with the one reported in another study of 140 mg/100 g (Heuze *et al.*, 2012). The levels of nitrogen and potassium in sugarcane bagasse were lower than in other farm biomass.

4.3.4 Selection of the Biomass for Formulation

Farm biomasses analyzed for macronutrients (N, P, K and Ca) were compared with a view of selecting those to be used in the fertilizer formulation (Figure 4.1).

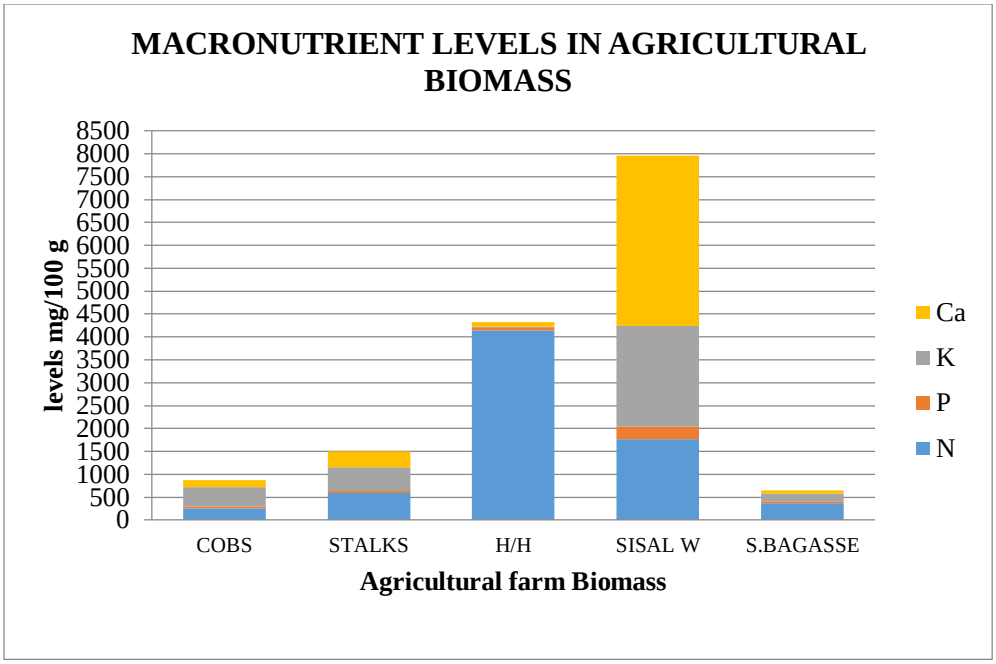

Figure 4. 1: A stack column diagram comparing levels of macronutrients

All the biomass analyzed had significant levels of macronutrients that varied significantly. Maize cobs had higher levels of K and Ca compared to sugarcane bagasse which on the other hand were higher in nitrogen. This is probably due to regular application of urea and ammonia based fertilizers on sugarcane while both DAP and CAN are mainly used on maize.

The horns and hooves are a good source of nitrogen compared to other biomass analyzed. On the other hand sisal pulp exhibited the highest levels of each macronutrient and therefore distinguishing itself as a key material for fertilizer formulation. Different biomass materials were blended to complement each other in the provision of macronutrients during formulation. Each material was therefore pre-treated chemically to maximize the level of macronutrients. Maize cobs were preferred over maize stalks as a source of ash to produce lye for decomposing sisal wastes. Since sisal leaf wastes are high in calcium (Table 4.1)

any material to blend with was to be with lower levels. Horns and hoofs were used to supply nitrogen levels in the fertilizer formulation.

4.3.5 Optimum decomposition conditions of Agricultural biomass

4.3.5.1 The pH Changes in Decomposing Sisal Leaf Pulp

The variation in pH of pre-treated (shade or sun dried) and non-pre-treated (fresh) sisal leaf pulp (from different relative positions on the plant) when soaked in water were investigated to establish the optimum conditions that would favor speedy decomposition. Table 4.5 shows pH results of treated sisal leaf pulp soaked in water for the first 14 days.

Table 4. 4: Mean ± SD pH of pre-treated and non-treated soaked sisal leaf pulp.

Treatment	Days/ Relative position	Mean ± SD pH every two days of soaking								
		0	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**p-value (days)**
Fresh	outer	4.19 ±0.19^{ab}	3.66± 0.21^{bc}	3.30± 0.15^{c}	3.30± 0.16^{c}	3.31± 0.16^{c}	3.71± 0.52^{b}	4.03± 0.44^{ab}	4.60± 0.98^{a}	**0.012**
	mid	4.23 ±0.24^{b}	3.62± 0.10^{bc}	3.33± 0.13^{c}	3.38± 0.09^{c}	3.43± 0.13^{c}	3.80± 0.29^{bc}	4.63± 0.84^{a}	5.22± 0.68^{a}	**0.000**
	central	4.26 ±0.28^{b}	3.77± 0.25^{b}	3.71± 0.38^{b}	3.65± 0.43^{b}	3.67± 0.48^{b}	4.20± 0.61^{b}	5.27± 0.82^{a}	5.40± 0.69^{a}	**0.000**
	Mean pH(plant)	4.22 ±0.22	3.67± 0.21	3.41± 0.28	3.44± 0.32	3.46± 0.34	3.91± 0.54	4.61± 1.04	5.03± 0.87	**0.003**
	P-value	**0.848**	**0.451**	**0.131**	**0.248**	**0.119**	**0.210**	**0.194**	**0.185**	
Sun Drying	Outer	4.38 ±0.29^{xb}	4.15± 0.13^{b}	3.90± 0.21^{b}	4.18± 0.51^{b}	4.50± 0.73^{b}	5.63± 1.02^{a}	6.18± 0.87^{a}	6.60± 0.98^{a}	**0.001**
	mid	4.43 ±0.38^{x}	4.23± 0.22^{c}	3.95± 0.10^{c}	3.93± 0.25^{c}	4.35± 0.57^{c}	5.95± 0.54^{b}	6.65± 0.34^{ab}	6.90± 0.46^{a}	**0.000**
	central	5.30 ±0.56^{ybc}	4.38± 0.23^{cd}	4.13± 0.32^{d}	4.43± 0.55^{cd}	4.77± 0.80^{c}	5.63± 0.40^{bc}	6.17± 0.40^{ab}	6.47± 0.50^{a}	**0.001**
	Mean pH(plant)	4.65 ±0.56	4.23± 0.19	3.98± 0.22	4.15± 0.44	4.52± 0.65	5.75± 0.67	6.31± 0.58	6.67± 0.66	**0.000**
	P-value	**0.042**	**0.033**	**0.025**	**0.122**	**0.445**	**0.448**	**0.519**	**0.754**	
Shade drying	Outer	4.36 ±0.34^{c}	4.13± 0.10^{bc}	3.86± 0.19^{c}	4.11± 0.47^{c}	4.44± 0.63^{bc}	5.43± 1.03^{b}	6.08± 0.91^{a}	6.46± 0.95^{a}	**0.001**
	Mid	4.43 ±0.38^{c}	4.23± 0.22^{c}	3.95± 0.10^{c}	3.93± 0.25^{c}	4.35± 0.57^{c}	5.95± 0.54^{b}	6.55± 0.34^{ab}	6.90± 0.45^{a}	**0.000**
	central	5.33 ±0.45^{b}	4.66± 0.36^{b}	4.40± 0.65^{b}	4.81± 0.69^{b}	5.07± 0.68^{b}	5.91± 0.67^{a}	6.46± 0.53^{a}	6.86± 0.61^{a}	**0.001**
	Mean pH(plant)	4.73 ±0.59	4.33± 0.40	4.08± 0.47	4.33± 0.64	4.65± 0.69	5.72± 0.82	6.32± 0.69	6.70± 0.74	**0.000**
	P-value	**0.035**	**0.499**	**0.391**	**0.366**	**0.742**	**0.790**	**0.629**	**0.713**	
Overall	**P--value**	**0.359**	**0.009**	**0.028**	**0.036**	**0.004**	**0.000**	**0.003**	**0.001**	

Same letters in rows (a, b, c) and columns (x, y) showed no significant differences, N=30.

The initial mean pH values of fresh, sun dried and shade dried sisal leaf biomass were 4.22±0.22, 4.65±0.56 and 4.73±0.59 respectively (Table 4.5). Other studies report sisal leaf pH value of 4.0 (Kategile, 1986) and 4.8 (Purseglove, 1992), which are similar to the obtained results. Sisal leaf wastes have sufficient levels of oxalic acid and other organic acids that are responsible for the initial low pH of sisal leaf biomass.

The pH values in the entire period of compositing significantly ($p < 0.05$) varied regardless of the relative position of the sisal leaf on the plant, but rose in all samples to a pH above 7. A daily assessment of the effect of the position of the leaf on the individual sisal plant showed significant ($p < 0.05$) difference in initial pH values of samples sun and shade dried. However sun drying had more effect than shade drying as pH values varied significantly for a few days in samples sun dried. Sun drying greatly affected young leaves causing an overall difference in pH, young sisal leaves have tender tissues and so the extend of effect by the sun drying was more compared to those relatively older leaves. On the other hand shade dried samples showed significant difference ($p < 0.035$) only between the initial pH values of samples as separated by relative position of the leaves. Shade drying does not crystalize as much of oxalic acid in the young leaves as does sun drying. Moreover the level of oxalic acid in sisal leaves varies with the maturity of the plant (Rahman and Kawamura, 2011).

An overall assessment of the effect of sample pre-treatments of sisal leaf wastes before soaking showed no significant difference ($p=0.359$) only on day one but there was significant difference ($p < 0.05$) in successive daily pH values. The pH trends during decomposition of sisal pulp are shown in Fig 4.2.

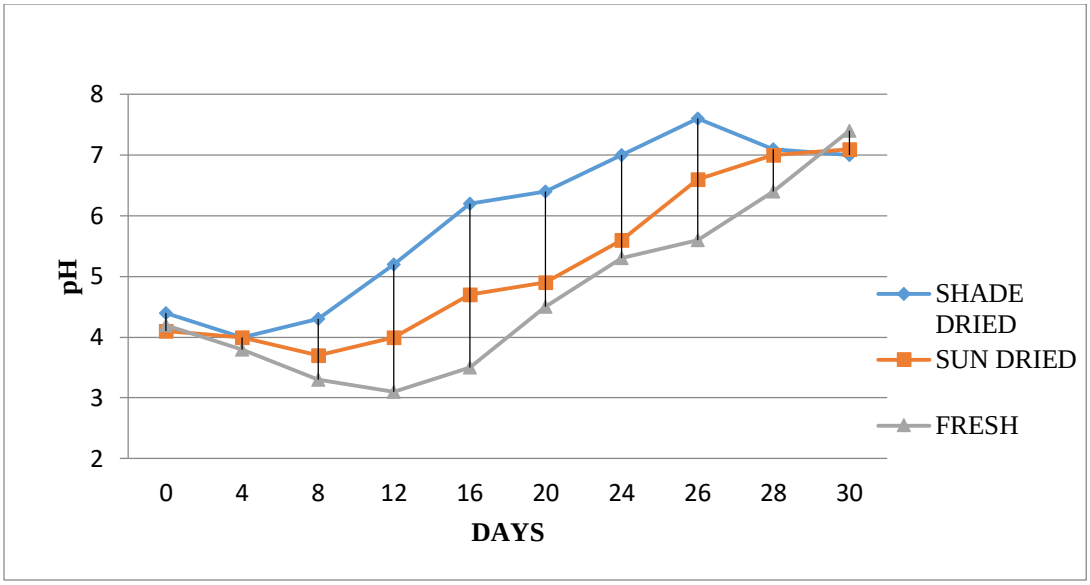

Figure 4. 2: Changes in pH of fresh and pre-treated soaked sisal pulp with time (days)

The pH of the soaked sisal pulp reduced in the initial period in all the samples and then rose steadily to a steady value after 30 days. Fresh sisal pulp contains at least 10% soluble sugars (DM) which fall to less than 1% after few days (Herrera *et al*., 1981). This is due to rapid fermentation that produces lactic acid which in turn lowers the pH (Preston and Leng, 1987). When sisal leaf wastes are soaked, hydrolysis that involves liquefaction of the biodegradable organic carbon (DOC) producing soluble sugars, amino acids and long chain fatty acids which on the whole lowers the pH (Sleat and Mah, 2006). The rise in pH that follows the initial drop is due to methanogenesis, a process that leads to production of methane and carbon (IV) oxide (Salum and Hodes, 2007). However the rate of pH increase is affected by pulp pre-treatment, with the shade dried pulp showing a faster trend.

Drying significantly reduces acid level of plant materials partly due crystallization or oxidation processes, with the greatest effect seen on younger leaf wastes (Hassan *et al*., 2007). Gebremariam and Machin, (2008) observed that sun drying does not affect pH but only promotes crystallization of the acids in the sisal wastes. This explains why the pH was

the same after soaking for 30 days. Sun drying quickly lowers the amounts of water, inactivating destructive enzymes (Hassain *et al.*, 2010) unlike shade drying which allows destructive enzymes to remain active for long thus causing minimal initial change in pH. This rise in pH is due to bacterial breakdown of the amino acids as well as the long fatty acids responsible for the lower pH (Sleat and Mah, 2006). The continued soaking will experience a pH drop that can be explained as acidogenesis in which acidogenic (acid forming) bacteria form hydrogen, short chain volatile fatty acids including acetic acid and alcohols from the soluble compounds earlier formed (Sleat and Mah, 2006).

The trends in pH as affected by the relative position of the sisal leaf was studied and are illustrated in figure 4.3.

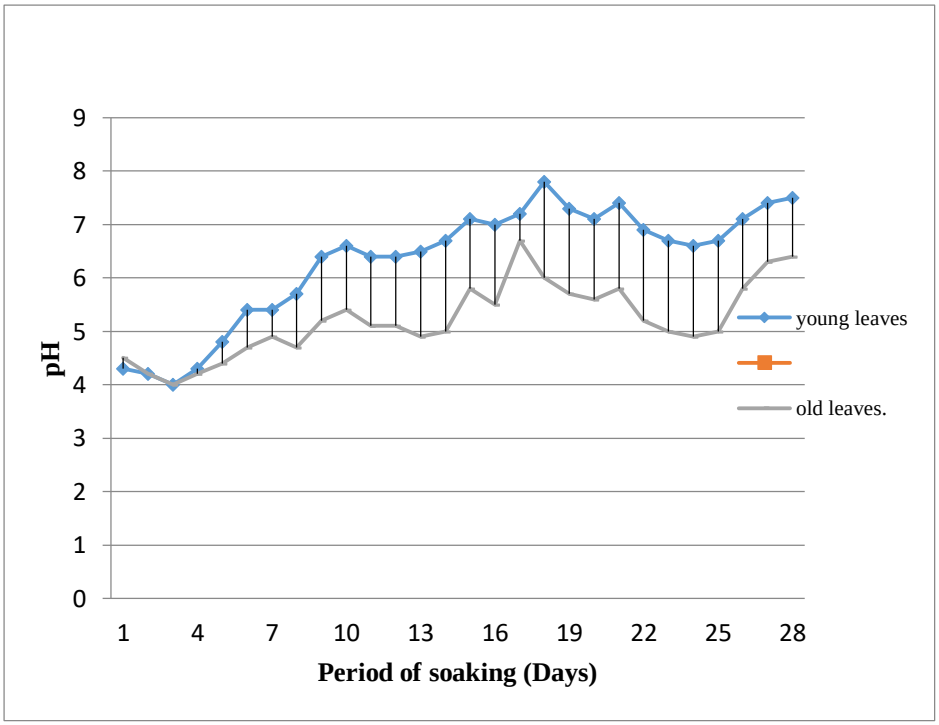

Figure 4. 3: pH trend curves for old and young sisal leaves

Similar trends to those seen in the pre-treatment effects were also observed in the deteriorations of sisal pulp samples separated by relative position of the leaf (outer- old, middle and central-young) on the sisal plant. It became apparent that sisal decomposition is accompanied by an increase in pH. Thus an alkaline environment is suggestively a condition for rapid decomposition of sisal pulp samples.

4.3.6 Effect of Alkali strength on Decomposition of Sisal

The study compared the decomposition of sisal pulp under different conditions, plain water, lye (weak base) and NaOH (strong base). Since production of biogas marks end of decomposition, the volume of the gas generated under different conditions was recorded and plotted against period of composting (Fig 4.4).

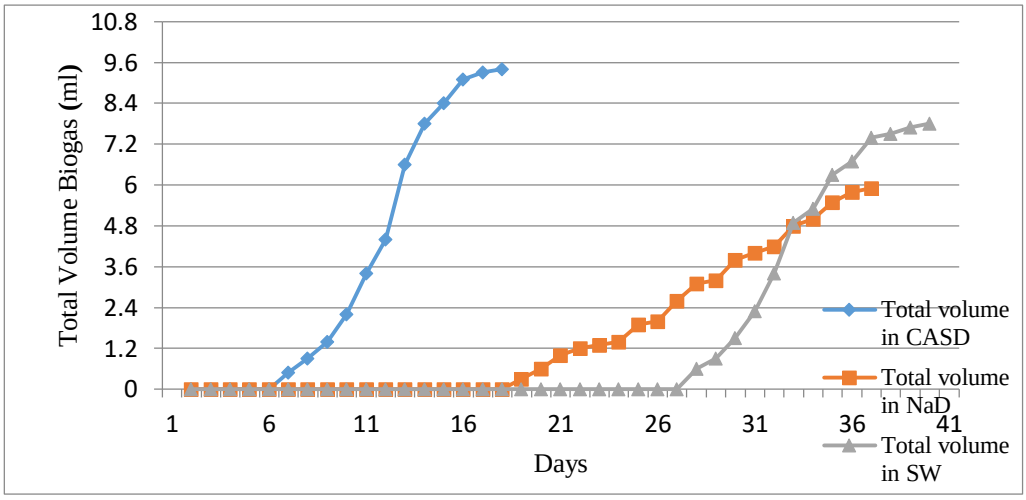

Figure 4. 4: Effect of sisal leaves pre-treatment on decomposition

A significant amount of biogas was collected after 6 days in the leaf pulp boiled in lye (labeled CASD). The sisal leaf pulp boiled in 2 M NaOH (labeled NaD) had biogas produced after 18 days while where water was used took 26 days for methanogenic phase to set in. The lye not only breaks down the lignocellulosic materials through potassium and

sodium carbonates that hydrolyze in water to give hydrogen carbonates and hydroxides but also provides a favourable pH range 6.5 - 7.8 required for the methanogenesis phase (Lettinga and Haandel, 1993; Jiunn-JyiLay, Yu-YouLi and Tatsuya, 1997). Strong alkalis such as 2 M NaOH also breaks down the lignocellulosic material and provide pH a range well above 12 that does not favour methanogenic process.

The alkaline medium, lye, extracted from maize cobs ash decomposes sisal pulp faster compared to both distilled water and 2 M NaOH. The rate of decomposition is usually dependent on temperature, moisture, aeration and pH (Lines-Kelly, 1993; Walls-thumma, 2000). Comparing quantities of biogas produced it was noted that there was 35 % increase in biogas produced when lye was used instead of 2 M NaOH and 60 % increase over use of distilled water. In a comparative evaluation of different pre-treatment methods on biogas production from paddy straw reported an increase of 49.7% when a 2% concentration NaOH was used (Vishwas, Rouf and Urmila, 2017). A separate study reported a significant enhancement in the production biogas when potassium hydrogen carbonate was used for pretreatment of sugar beet silage (Demirel and Schever, 2008). This study therefore proposed use of lye extract in pre-treatment of sisal pulp for rapid decomposition. The lye from maize cobs ash was boiled with dry sisal leaf wastes to generate the cobs ash sisal digest (CASD).

4.3.7 Rapid Decomposition conditions for Horns and Hooves

The period for complete decomposition of 2 Kg of a mixture of horns and hoofs submerged in 3 liters of peracetic solutions was monitored at 25 ^{o}C and days taken for complete conversion to a semi solid form were recorded and are as summarized in Table 4.6.

Table 4. 5: Digestion Period (Horns and hooves) in varied Peracetic solutions

H_2O_2 : CH_3COOH Ratios	Period (days) taken for complete digestion		
	30 % H_2O_2	70 % H_2O_2	90 % H_2O_2
1:1	21-25	20-23	17-21
2:1	19-25	18-22	13-15
3:2	19-23	16-20	10-13

It was observed that mixing 95 ml glacial acetic acid with 95 ml 90 % hydrogen peroxide raised peracetic acid that took the shortest period (days) for complete digestion of the horns and hooves. It is also conclusive that a mixing ratio 3:2 of peroxide : acetic acid was better and would take at most two weeks compared with a 1:1 ratio that took three weeks.

4.4 Formulation and Characterization of Biomass-Based Fertilizer

4.4.1 Formulation Ratios for BBF

Formulation of the biomass-based fertilizer was done by blending of the chemically decomposed agricultural waste materials in specific ratios to achieve acidic, basic or neutral fertilizer formulations. The quantities of digests required to produce fertilizer with definite desirable characteristics were determined by back titrating HD and CASD with HCl and NaOH respectively. The back titration results are summarized in Table 4.7.

Moles of acidity (HD), alkalinity (CASD) and mixing ratios in BBF

Table 4. 6: Moles of acidity (HD), alkalinity (CASD) and mixing ratios in BBF

Materials	Horn and Hoof Digest-HD (Acidic)	Cobs Ash Sisal Digest-CASD (Basic)
Mass (Kg)	1.755±0.121	1.052±0.039
Moles	1.33±0.090	2.40±0.15
Mixing Ratio	2	1

A 100 g of HD requires 1.33 moles of alkalinity for neutralization but the CASD avails 2.4 moles alkalinity implying the ratio HD: CASD as 2:1. This mixture as would be expected was neutral and ideal for neutral soils. Several mixtures ideal for soils of pH lower than 7 (acidic) and those above 7 (basic soils) were made too.

4.4.2 Characterization of Biomass-Based Fertilizer Formulation

Formulations derived by combining different quantities of HD and CASD were characterized in terms of their pH and % levels of macronutrients (Table 4.8).

Table 4. 7: pH and Percentage Macronutrient levels in BBF formulations

Formulation HD:CASD	Fertilizer label	pH (N=10)	% Macronutrients for plant growth in formulations (100 g)			
			N	P	K	Ca
0:1	BBF_0	8.41±0.27	3.68	0.17	6.30	9.20
1:1	BBF_1	8.06±0.21	2.31	0.08	2.50	3.46
2:1	BBF_2	7.15±0.18	1.46	0.04	1.34	1.97
3:1	BBF_3	7.10±0.20	1.17	0.03	0.94	1.37
1:2	BBF_4	8.23±0.25	2.68	0.07	3.13	4.57
1:0	BBF_5	6.82±0.15	3.96	0.002	0.001	0.08
P- value		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

The formulations contained macronutrients in the ranges of 1.0-3.5 % (N), 0.002-0.17 % (P), 0.001-6.30 % (K), 0.08-9.20 % (Ca). Typical concentrations of macronutrients sufficient for plant growth are 15000 mg/kg (1.5%) nitrogen, 2,000 mg/kg (0.2%) phosphorous, 10,000 mg/kg (1.0%) potassium (Epstein, 1972).

The CASD avails alkaline conditions that activates decomposition of HD in the formulation. The formulations BBF_0 and BBF_4 are basic (pH 8.41±0.27 and 8.23±0.25 respectively) and therefore ideal for strongly acidic soils. BBF_2 and BBF_3 formulations are neutral and ideal for neutral soils while BBF_5, that is acidic, mainly a source of nitrogen,

would be good for basic soils. DAP, with a pH of 7.5-8.0 is a common conventional source of nitrogen and phosphorous. Its nitrogen is present as ammonium ion that is gradually converted to nitrate by soil bacteria resulting in a subsequent drop in pH. In BBF nitrogen is present as nitrates and amine units. The later react with alkaline medium generating ammonia.

In practice a tea spoonful of DAP (10 g) is applied per plant space. From its composition label 18% N and 46% P_2O_5 it is implied that each plant environment receives 1.8 g N and 1.971 g P. On the other hand application of 100 g of BBF_1, with pH of 8.06± 0.21, would provide 2.31 g N, 0.08 g P, 2.50 g K and 3.46 g Ca. CAN used for side dressing provides 2.7 g N per plant (27 % N). Though BBF is low in phosphorous it simultaneously offers all the macronutrients on every application moreover bulky use enriches the soil with humus improving soil aeration.

The cobs ash sisal digest (CASD) alone provides the highest percentage of macronutrients (section 3.10.2): nitrogen (3.68%), phosphorous (0.17%), potassium (6.30%) and calcium (9.20%). It, however, would not be ideal for it is a strongly basic formulation (pH 8.41±0.27), limiting its use to strongly acidic soils. The pH value range for proper growth of most plants is 6.5-7.0 (Njinga, Moyo, and Abdul, 2013). It also has high levels of calcium compared with other macronutrients.

The horns and hoofs digests (HD) were strongly acidic (pH 6.82) and contained about 4 % nitrogen with very minute amounts of P, K and Ca. It was mainly used to modulate the pH of the CASD and act as a filler in the formulation of the biomass-based fertilizer. An increase in the amounts of HD in the formulation while holding constant the amount of

CASD (basic) led to a mixture with lower pH. The use of HD for bulking reduces the percentage of macronutrients like calcium from 9.20 % to 3.46 %. High calcium levels are associated with high pH values above 7.0 (USDA- NRCS, 2017). Typical calcium concentrations for plant growth are in the range 0.1-0.5 % (Epstein, 1972; Filby, 1995).

It is important to note that availability of phosphate to plants is pH sensitive and its availability in soil increases with rise in soil pH. However, if pH is unduly increased, phosphates tie up elements such as boron, iron, manganese, copper, potassium, magnesium and zinc in soluble forms. This makes the- elements unavailable to plants and deficiencies occur (Kinsey, 2015).

4.5 Efficacy of Biomass-Based Fertilizer

The ability of the biomass-based fertilizer (BBF) to produce desired results in terms of plant health and improved yield was evaluated. The selection of the type of BBF used was based on the pH of the soil. In this section soil pH of study site, growth characteristics and yield were monitored.

4.5.1 Soil pH

The pH of soil samples taken from prepared plots at the study site, Lugari Sub-county were determined by standard procedures and the results are summarized in Table 4.9.

Table 4. 8: The mean soil pH values (± SD) of field study site plots

Plot Label	pH (Mean ± SD)
A1	5.377±0.154
A2	5.923±0.180
A3	5.630±0.237
B1	6.713±0.226
B2	5.923±0.180
B3	5.937±0.152
C1	6.053±0.133
C2	6.13±0.880
C3	6.200±0.257
Mean pH value	5.9873±0.3721
P – value	**0.136**

The soils showed a mean pH of 5.9873±0.3721 in the range 5.377 ± 0.154 to 6.713±0.226. This implied that soils were moderately acidic (Kenya Soil Survey, 2011 and Omwoma, 2014). The soil acidity in some sections of Lugari is due to the nearby Rai Paper factory that releases SO_2 and Cl_2 gases into its environs and affects the soils through acid rain. Besides long term use of nitrogen fertilizers especially ammonium based ones that increases soil acidity by the conversion of ammonium to nitrates (nitrification) and H^+ ions are released to the soils. Legumes (beans and soya) grown as intercrops with maize in this area too increases acidity since these plants take up more cations in proportion to the anions (Yan *et al*., 1996). This causes H^+ to be released from plant roots to maintain electrochemical balance within their tissues

4.5.2 Growth Characteristics of Maize Plants

To evaluate the efficacy of BBF_1 formulation, the study considered height attainment, deficiency symptoms, insect infestation and yield of maize seeds in field trials.

4.5.2.1 Plant Height Measurements

Plant height was measured (Plate 4.1) at the end of every week using a meter rule up to

Week 12.

Plate 4. 1: Plant height measuring

The mean ± SD height attainments of maize plants under the test schedules are summarized in Table 4.10.

Table 4. 9: Heights (cm) of maize plants under different fertilizer schedules

Fertilizer schedule	days to sprout	Week 3	Week 4	Week 5	Week 6	Week 67	Week 8	Week 9	Week 10	Week 11
BBF_1/BBF_1	13	6.700±3.001^{ab}	27.750±4.503^{a}	39.850±6.469^{b}	73.525±12.391^{b}	102.800±16.732^{b}	135.413±22.917^{b}	146.118±12.017^{b}	147.865±22.917^{b}	151.222±3.235^{b}
NIL/CAN	9	8.759 ±2.868^{a}	27.164±6.424^{ab}	36.977±9.941^{b}	62.600±12.243^{b}	90.641±14.809^{b}	121.250±17.179^{b}	122.645±23.149^{b}	124.102±11.009^{b}	125.150±1.154^{b}
DAP/CAN	10	7.923±2.837^{a}	33.023±7.191^{a}	52.509±8.783^{a}	96.764±13.754^{a}	137.74112.423^{a}	163.377±22.604^{a}	171.300±12.264^{a}	177.271±9.514^{a}	179.113±1.124^{a}
BBF/CAN	13	5.250±2.350^{b}	22.250±7.409^{b}	28.817±8.313^{c}	49.117±14.025^{c}	73.400±23.931^{c}	95.867±32.774^{c}	103.167±22.572^{c}	106.107±2.134^{c}	107.006±3.121^{c}
Mean±SD		7.662 ±2.993	28.812±7.079	42.109±11.615	72.986±21.508	105.055±28.232	133.024±31.363	139.224±32.466	141.023±31.363	142.900±31.363
P -Value	**0.000**	**0.030**	**0.001**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	**0.002**

N=40, ANOVA: Those with same suffixes had no significance difference

Maize seeds planted under designate fertilizer schedules significantly varied ($p = 0.000$) in the period (days) taken before sprouting. Plots under NIL/CAN and DAP/CAN schedules took 9 and 10 days respectively to germinate out of the soil. Those under BBF_1/BBF_1 and BBF_1/CAN significantly differed ($p = 0.000$) from the NIL/CAN and DAP/CAN schedules plots as most plants took 13 days. Seed germination depends on the fertilizer used due to differences in hygroscopic characteristics (Muhammed, S., Muhammed, I. and Azar, 2017). Hegarty, (1976) reported that use of high fertilizer levels and low moisture content in the soil results in reduced seedlings emergence. A pH range of 7.0 – 7.5 favours prompt germination of maize seeds (Sikalengo, 2016). Thus, apart from pH (8.06±0.21) as a possible cause for delay in germination, BBF_1 being hygroscopic and therefore absorbing moisture creates an osmotic potential dehydrating the seed environment causing delay in germination. Seed germination and emergence is affected by osmotic potential (stress) in its environment (Parminder and Amit, 2016).

The maize seedlings under BBF_1/BBF_1 treatment had a mean height of 6.700±3.001cm, which was not significantly different from the seedlings under BBF_1/CAN (5.250±2.350) three weeks after planting. The mean heights of plants under BBF_1/CAN schedule were significantly different from NIL/CAN and DAP/CAN ($p<0.05$). This meant that the maize seeds planted with BBF_1 delayed in germinating compared to those controls of NIL fertilizer at planting as well the ones in which DAP were used. The seedlings under NIL/CAN and DAP/CAN attained greater heights of 8.759±2.868 and 7.923±2.837 respectively in the same period (3 weeks). It is however notable that initial heights of plants

under both BBF_1/BBF_1 and DAP/CAN were lower than those planted with no fertilizer. This implies both BBF_1 and DAP had some delay effects on germination.

Crops of different species respond differently to pH reflecting the genetic diversity among the species (Fageria and Zimmerman, 2008). The study site soils were acidic with pH range 5.923-6.437 (Table 4.9) and use of BBF_1 provided an alkaline environment that neutralized or made the soil alkaline. Alkaline soil conditions could have caused the delay in germination. The effectiveness of cultivating and treatment of maize cultivars require moderately acidic to neutral soils in the pH ranges 5.5-7.5, normally managed by organic and inorganic fertilizers treatments. A study on effects of long application of organic and inorganic fertilizers on soil organic and physical properties in maize-wheat rotation found that balanced fertilization improves soil physical properties including pH (Singh B., Singh J., Singh G. and Kaur, 2015).

The mean heights attained by each schedule per week across entire period increased significantly ($p \leq 0.05$) as expected of monocots like maize (Wuyts, Dhoudt, and Inze, 2015). Further, the heights attained by maize every week under different schedules differed significantly, indicating difference in nutrients availed for plant growth. Despite the initial heights of BBF_1/BBF_1 (6.700 ±3.001cm) being lower than NIL/CAN and DAP/CAN and BBF_1/CAN maize plant heights (8.759±2.868 and 7.923±2.837 cm), the formulation plants recovered and rapidly grew reaching a height of 151.222 ± 3.235 cm by the 11^{th} week. Though this height was lower than DAP/CAN schedule maize plants that attained 179.113 ± 1.124 cm it was significantly higher than those of BBF_1/CAN (107.006 ± 3.121) and NIL/CAN (125.150±1.154 cm) schedule heights.

This high height attainment in DAP/CAN schedule compared to BBF_1/BBF_1 can be attributed to the definite levels of phosphorous in the conventional inorganic fertilizer DAP used. The rapid growth was boosted with nitrogen from CAN. As reported in earlier studies, plants need phosphorus for strong root growth, fruit, stem and seed development, disease resistance and general plant vigor (Whitman and Dejohn, 2009).

Differences within BBF_1/BBF_1 plants reflect variations in age of organic material, rate of decomposition, application method and timing and incorporation time as earlier observed by Ross and Karen, (2003). The closeness to DAP/CAN schedule values signified resemblance in availability of the necessary plant macronutrients during the period.

A post hoc separation of Plots A under BBF_1/BBF_1, Plots B under NIL/CAN, plots C under BBF_1/CAN and plots D under DAP/CAN assuming Duncan's equal variances was done with a view to show the individual plots ranking to establish the cause of the differences (Table 4.11).

Table 4. 10: Plots ranking from the least to the highest mean height per week

Rank Least-highest	Week				
	3	5	7	9	11
1	C	C	C	C	C
2	A	B	B	B	B
3	D	A	A	A	A
4	B	D	D	D	D

Duncan's Statistical ranking of the height attainments showed that the maize planted with formulation (BBF_1) and side dressed with CAN trailed throughout compared with other schedules. This implied that the fertilizer schedule of planting with the formulation (BBF_1) and side dressing with CAN in part did not provide sufficient macronutrients to support fast growth. Soil pH is important because it influences several soil factors affecting plant growth, such as soil bacteria, nutrient leaching, nutrient availability, toxic elements and soil structure (Perry, 2015). Bacterial activity that releases nitrogen from organic matter and certain fertilizers is particularly affected by soil pH, for operates best in the pH range of 5.5 to 7.0. The rise in soil pH surrounding DAP granules due ammonia generated from ammonium with alkaline conditions is a temporary effect. Seedlings and plant roots nearest the volatile ammonia are easily harmed. Larger quantities of ammonia are produced when BBF_1 is applied and without sufficient soil water to hydrate it and remains volatile thereby delaying root development. This consequently delayed germination of the maize compared with that planted with DAP. The same was observed of the maize in plots labeled C that were under the formulation for planting and side dressed with CAN. It was further seen that just before side dressing in the 4^{th} week the heights of these maize had almost caught up with the maize in plots labeled D under DAP and CAN schedule. But when side dressing was done the increase in heights attained by maize under the formulation reduced as in the 4^{th}-5^{th} week due to the alkalinity effect but recovered in the 5^{th}-6^{th} weeks onwards. The fact that height attainment was higher a week after application attests BBF_1 as a rapidly decomposing fertilizer.

4.5.2.2 Leaf characteristics

Leaf properties indicate deficiencies or otherwise of macronutrients in plants (Shanyn & Bradly, 1999). Colourations of the leaf of maize plants under different treatments were periodically checked. Purple colour on the leaves was observed during 2nd and 3rd weeks in plots A (BBF/BBF), B (NIL/CAN) and C (BBF/CAN) but not in those in plots D under DAP/CAN (Plate 4.2).

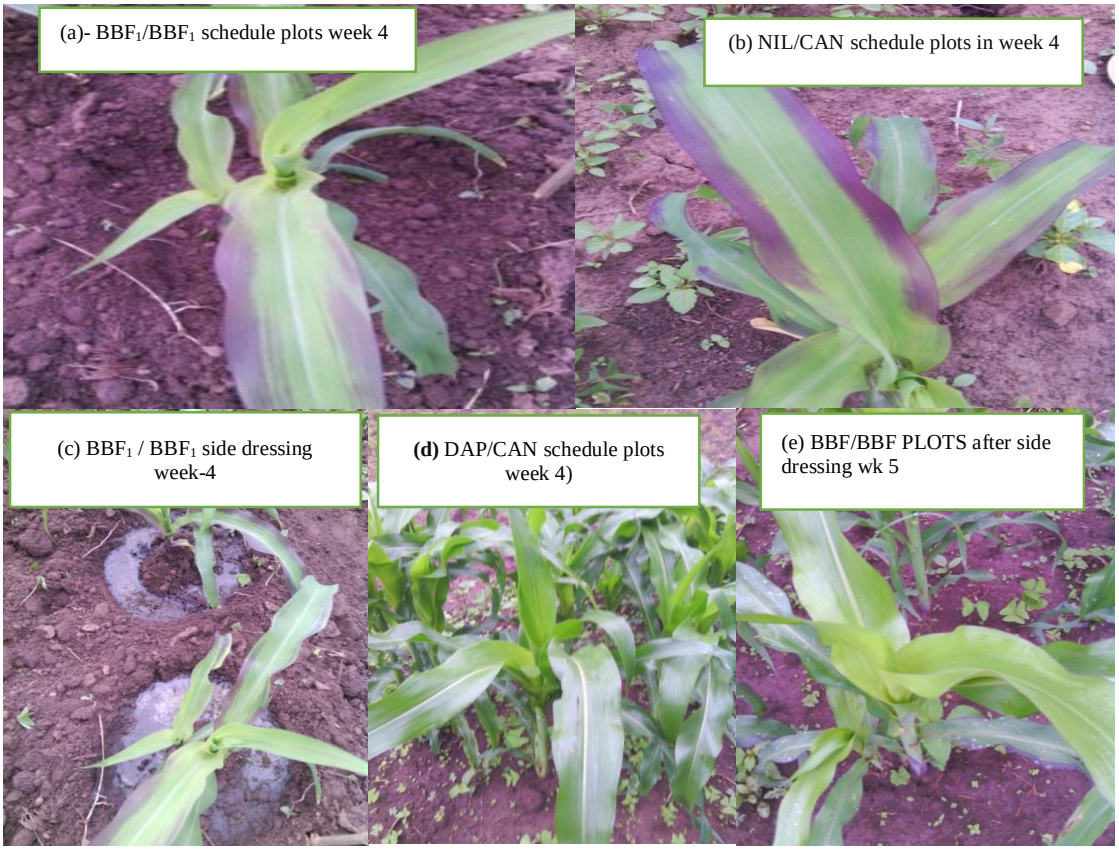

Plate 4. 2: Leaf properties of maize under different fertilizer schedules

Purple colouration in the maize leaves implied phosphorous deficiencies that is essential in the process of photosynthesis, by changing light energy into chemical energy, and assisting in rapid growth as well as plant and root development (Alison, 2016). When side dressing with BBF_1 was done on the affected maize (Plate 4.2 c), the purple coloration on

the new leaves was eliminated a week later (Plate 4.2 e). This showed that BBF_1 is a rapidly decomposing fertilizer, releases macronutrients to support growth of crops. The maize plants under DAP schedule had sufficient amount of phosphorus and therefore did not show phosphorous deficiency (Plate 4.2 d). .

4.5.2.3 Pest Infestation

Stems, fruits and tassels of maize plants under different treatments were scrutinized weekly for signs of pest infestation. This was with a view to establish if there was any deterrence in use of biomass-based fertilizer (BBF_1). Plate 4.3 exhibit the observations made.

Plate 4. 3: Stalk borer effect on (a) stems (b) fruits (c) tassels

Plant stems, fruits and tassels were considered as visible parts affected by the stalk borer. The percentage of maize plants viewed as attacked by the stalk borer on plots under different fertilizer schedules were noted and results are summarized in Table 4.12.

Table 4. 11: The plants (%) attacked with stalk borer

Plot No.	Treatment Schedule Planting and side dressing	% plants attacked
A	BBF_1/BBF_1	14.3
B	NIL/CAN	77.8
C	BBF_1/CAN	33.2
D	DAP/CAN	4.2

The number of maize plants in plots labeled D with (DAP) / (CAN) treatment was the least attacked (4.2 %) by the stalk borer. This can be explained as due to sufficient amounts of available nitrogen from DAP) / (CAN that limited attack. Gunewardena and Madugalla (2014), and Wale, Schulthes, Kairu and Omwenga, (2006) established that high nitrogen levels of 200 kg/ha or more minimizes the attack, while doses lower than 200 kg/ha nitrogen made the maize susceptible to attack. Limited levels of nitrogen through restricted fertilizer application certainly then accounts for the high attack (77.8%) in plots labeled B. Plots A on BBF_1/ BBF_1 had 14.3% of maize attacked which was much lower than in plots B. Substituting BBF_1 with CAN during side dressing in plots labeled C resulted in a larger effect (33.2 %) implying that use of BBF_1 was better than CAN. The low attack on the plants using BBF formulation schedule could also be explained on the basis of insecticidal characteristics of the materials used in the formulation. Gunewardena and Madugalla, (2010) reported that treatment of the soil in the crop environment with diazinon in addition

to right quantities of nitrogen fertilizer significantly reduced the damage by the stalk borers. The insecticidal properties in the formulation must be from sisal (*Agave sisalana*) and maize cobs ash. Singh, Mittel, Gauvar and Dhiman, (2014) reported that a leaf extract of *Agave sisalana* had a significant activity against Anopheles *stephensi*, culex *guinquefasciatus* and *Aedes aegypti* larvae. Both Pedrode, (2011) and Pizarro *et al.*, (1999) reported sisal waste to have insecticidal properties. The study on the phytochemical and anti-microbial screening of *Agave sisalana* perrine juice (waste) reported presence of saponins, glycosides, phlobatannins, terpenoids and flavonoids all of which act against insects (Ade-Ajayi *et al*., 2011). The effectiveness of maize cob powder in controlling weevils in stored maize grain has also been reported indicating its importance in the formulation (Gadzirayi *et al.*, 2006).

4.5.2.4 Maize Yield

Maize from designate plots was harvested, labeled, shelled and dried to a standard maximum moisture content of 13 % (Baloch, 2010). Plate 4.4 shows how drying was done.

Plate 4. 4: Maize aired in the sun for drying

The dried maize were weighed per plot with a view to establish if any significant impacts were made on the yield by the varying fertilizer schedules. Table 4.13 shows the results.

Table 4. 12: Mean yield ± SD and % rot of maize

Plot label	Fertilizer schedule	Mean yield± SD (Kg / 2 m^2)	% Rot	Projected Yield 90 kg Bags/Acre
A	BBF_1/BBF_1	1.794±0.68	12.0	20.3
B	NIL/CAN	1.040±0.22	72.0	12.0
C	BBF_1/CAN	1.509±0.45	28.5	17.0
D	DAP/CAN	1.954±0.72	6.5	22.0
P - value		**0.002**	**0.000**	**0.003**

The mean yield of maize in plots under different treatments significantly differed (p=0.002). Plots A under BBF_1/BBF_1 produced 1.794±0.68 Kg per plot, which was closer to that of plots D under DAP/CAN (1.954±0.72 Kg) but significantly higher than in plots B and C. Maize yield is influenced by the presence of available and sufficient levels of phosphorous and potassium. Maize seeds are significantly higher in phosphorous (299.6 mg/100 g) and potassium (324.8 mg/100g) compared to calcium that is only 48.3 mg/100 g (FAO, 1992).

The impact of stalk borer (*Papaipema nebris*) on the maize yield from the plots under varied fertilizer schedules was evaluated. This was through determining percentage rot in the yields using standard procedures (FAO/IPGRI, 1994) (Table 4.13). It was observed that grains from BBF_1 / BBF_1 schedules exhibited an average of 12 % rot, significantly higher than DAP/CAN fertilizer schedule (6.5%) but lower than schedules BBF /CAN (28.5%) and NIL/CAN (72.5%). The stalk borer causes injury to maize either by feeding on the

leaves or stalk tunneling. The stalk tunneling destroys the growing point causing the whorl to die (Rubink and McCaartney, 1982), affecting the yield of the maize seed. The impact of rot in maize yield was evident in samples of maize yields (plate 4.5) from plots under the different fertilizer schedules.

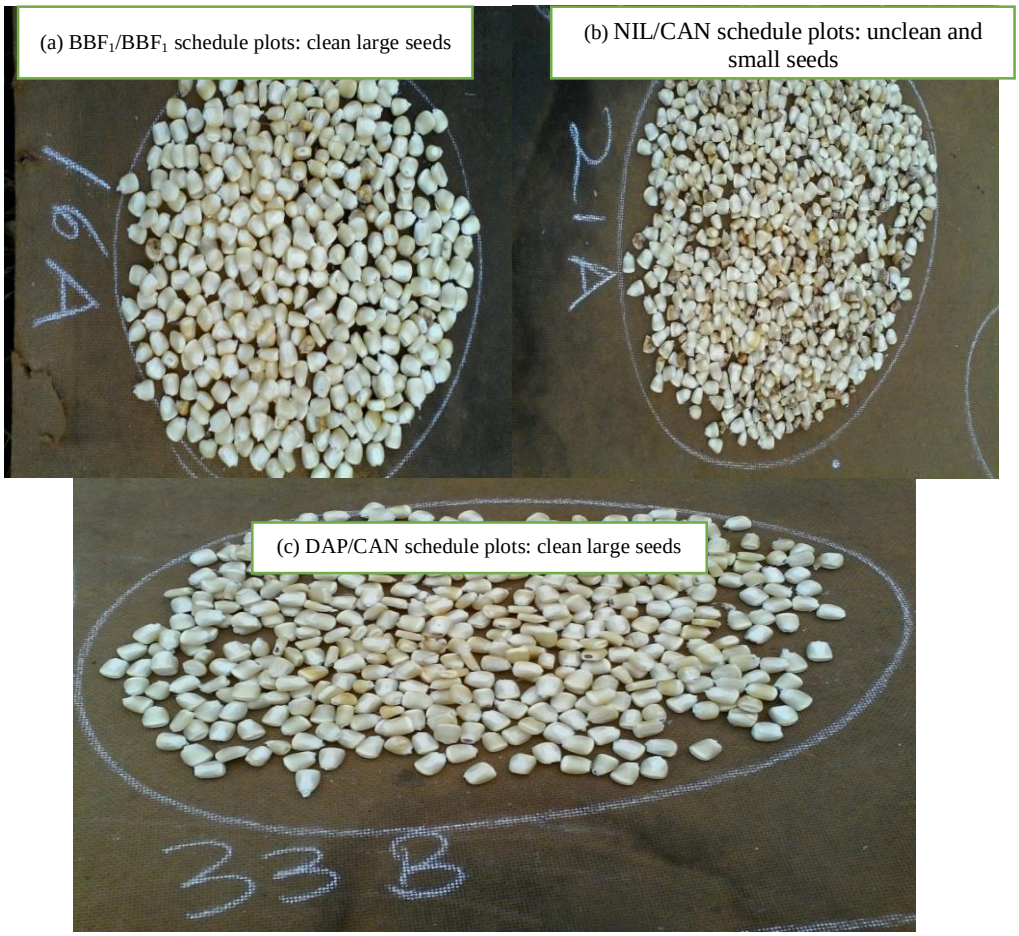

Plate 4. 5: Maize yields from plots under different schedules.

Bailey and Pedigo, (1986) reported a maize grain reduction range 49-89% of the yield due to stalk borer attack. Many methods of controlling stalk borer infestation including use of biological and environmental influence (Lasack and Pedigo, 1987), cultural practices like planting date or weed control and use of herbicides (Rubink and McCaartney, 1982) and use mixtures of herbicides and insecticides (Rice and Pope, 2006) have been reported. Mixed herbicides and insecticides not only destroy weeds that act as pre-host but also

suppress the development of the larval stage. BBF/BBF schedule's impact in minimizing the rot in the yield arises from the insecticidal properties of sisal leaf wastes (Singh R.K *et al*., 2014) and maize cobs powder (Gadzirayi *et al*., 2006) used in the formulation. The results imply that the formulation has the ability to minimize stalk borer attack.

The yield per plot (2x1 m^2) under the same treatment in different sets was weighed and used to calculate projected yield (90 kg bags) per acre (Table 4.13). The use of DAP/CAN schedule produced the highest number of 90 kg bags (22) per acre, followed by the formulation schedule (BBF_1/BBF_1) with 20.3 of 90 kg bags of maize per acre. The yield range 16-22 bags per acre are in the range of maize production per acre in the study area where a production of 15-30 bags per acre has been reported in high potential zones (Nyoro, Kirimi and Jayne, 2004). The results of this study indicate that the formulation (BBF) is as good as conventional inorganic fertilizers in supporting growth and yield of maize.

CHAPTER FIVE

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study set out to formulate a fertilizer from chemically decomposed agricultural wastes and evaluate its efficacy in the growing of maize. On the basis of the results that have been discussed in the foregoing chapters, the following conclusions are made:

i) The agricultural farm biomass materials (maize stover, livestock horn and hooves, sisal leaf pulp and sugar cane bagasse) were evaluated for the macronutrient levels as a criterion for use in the formulation. The horn and hoof digests contained the highest amounts of total nitrogen (4145.60±763.34 mg/100 g) while sisal leaf pulp had highest levels of P (274.90±127.585 mg/100 g), K (2194.68 mg/100g) and Ca (3719.02±1309.171 mg/100 g). These were therefore used in the formulation of the biomass-based fertilizer (BBF).

ii) In determining the optimum conditions for the chemical decomposition of select agricultural biomass, rapid decomposition of sisal leaf pulp was established to be at a pH range $7.5 \leq pH \leq 10.0$ attainable by boiling pulp with lye from maize cob ashes. Peracetic acid prepared by mixing glacial acetic acid with hydrogen peroxide (90 % by volume) in the ratio 3:2 was found to be more efficient in rapidly decomposing horns and hooves.

iii) The biomass-based fertilizer formulation was developed by blending chemically decomposed biomass materials of cattle horns and hooves digests (HD) and cobs ash sisal digests (CASD) in different ratios. Different fertilizers formulated on the basis of blending HD: CASD in designate ratios were characterized. The

formulations had pH values ranging from 6.82 to 8.41 thereby ideal for acidic, neutral or basic soils. They had macronutrients in the ranges of 1.0-3.9 g (N), 0.002-0.17 g (P), 0.001-6.30 g (K) and 0.08-9.20 g (Ca) per plant environment. These were comparable to levels available from conventional inorganic fertilizers DAP (1.8 g N and 1.971 g P) and CAN (2.1-2.7 g N and 0.8 g Ca) per plant.

iv) The fertilizer formulation, BBF_1 of pH 8.06± 0.21 macronutrients 2.31 g N, 0.08 g P, 2.50 g K and 3.46 g Ca per plant was selected for efficacy evaluation based on field soils that were moderately acidic. There was no significant difference in height attainment and yield between maize under BBF_1 (planting and side dressing) and that of conventional DAP/CAN schedule. Purple leaf colouration due phosphorous deficiency observed in maize grown under schedules BBF or nil fertilizers was able to clear after one week of applying freshly prepared BBF_1. This implied that in its prepared state the formulation rapidly avails macronutrients.

On the whole, chemical decomposition significantly reduces composting period and that the biomass-based fertilizer formulation from the chemically decomposed agricultural wastes is as efficacious as the conventional commercial fertilizers in supporting growth and yield of crops.

5.2 Recommendations

5.2.1 Recommendations for large scale production

i) The biomass-based fertilizers formulated from chemically decomposed agricultural wastes have high levels of macronutrients comparable to convectional fertilizers. It is recommended that a pilot production of BBF_1 formulation by the County

Government of Kakamega for use by small scale farmers (as a large scale testing) be encouraged. Other formulations can also be produced depending on soil pH for mass testing.

ii) Enhancement of sisal growing through recruitment of more farmers is recommended as this will reinforce production of BBF_0 that purely contains CASD whose specification would be N (3.68%), P (0.17%), K (6.30%) and Ca (9.20%) and can be used independently in calcium deficient soils or side dressing. A policy to periodically train farmers would then be necessary to ensure maximizing the output.

5.2.2 Recommendations for further studies

i) The various BBF formulations contain phosphorus levels that require boosting. Studies to be done on adding proportionate phosphorous rock to boost the P levels and examine the viability of the product. This can be done before production and distribution to smallholder farmers for use. In evaluation of efficacy, BBF_1 was used in the growing of maize under rain fed agriculture. It is recommended that the same and or other formulations be tried under irrigation and greenhouse settings on maize and other crops.

ii) It is recommended that studies be done to evaluate correlation between different BBF formulation / controls and pest infestation.

iii) Studies be done comparing microbial activities during traditional composting and BBF.

iv) Compare nutrient uptake and root development in different formulations with both negative and positive controls and examine extent of hygroscopic properties of BBF and how they influence seed germination.

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