UNIVERSITY OF NAIROBI

DETERMINATION OF EFFICACY OF BIO-FERTILIZER FROM BIO-GAS DIGESTERS FOR REGENERATION OF SOILS

BY

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I56/75522/2014

A Thesis Submitted in Partial Fulfilment of the Requirements for Award of the Degree of Master of Science in Environmental Chemistry of the University of Nairobi

2018
DECLARATION

I declare that this thesis is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people’s work or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi’s requirements.

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DEDICATION

This work is dedicated to my mother, Jane Wakuyu; my sister, Jackline Wanjira, my husband Isaac Mwangi, my daughter Leanne Wangeci and to all my friends for their immense support, both financially and mentally, that saw me through my course.
ACKNOWLEDGEMENT

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ABSTRACT

Life on earth cannot be sustained without food and people have to employ all known tactics to improve food production. Farmers generally use inorganic fertilizers and compost manure for the improvement in food production. The compost manure is obtained directly from animal waste. Animal waste is also used to generate biogas. If the by-products of biogas production can be utilized as manure, it would be more economical to utilize all the animal waste in biogas production and use the by-products as manure. The main aim of this study was to determine the efficacy of bio-fertilizer from biogas digesters for regeneration of soils. The nutrient quality of the soil was determined by measuring the levels major, macro- and micro- elements in the experimental plots both before and after application of the different fertilizers. The study took place in a farm in Nyeri County, between the months of September to November 2015. The experiment was done in a plot that had not been cultivated before. The plot was subdivided into 3 different blocks each having its own treatments and crops in a well-planned array. The first block (A) was treated with bio-fertilizer, the second block (B) was treated with no fertilizer and hence acted as the control block, and the third block (C) was treated with the conventional inorganic fertilizers as per agricultural recommendations. Seven crops were grown in the plots and managed as per agronomic requirements of each specific crop. pH of the soils was determined using standard procedure. The major nutrients Nitrogen (N), Phosphorous (P) and Potassium (K) content of the bio-fertilizer were quantitatively determined by Kjeldahl method; UV-VIS Spectrometer and flame Emission spectrometer respectively. The macro and micro elements such as calcium, magnesium, manganese, iron and zinc were determined by Flame Atomic Absorption Spectrophotometer. Bio-fertilizer use led to a very significant increase in crop yields by 106.7% as compared to not using it, while synthetic fertilizer increased the yields by only 32.7%. This shows that there is a margin difference of 74% meaning that bio-fertilizer is way better than synthetic fertilizer use when it comes to crop growth and yields. The data collected from this study can be very useful in advising farmers on cost effective application of bio-fertilizers to improve crop productivity.
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<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
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<tbody>
<tr>
<td>AD</td>
<td>Anaerobic Digestion</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis Of Variance</td>
</tr>
<tr>
<td>C</td>
<td>Carbon</td>
</tr>
<tr>
<td>Ca</td>
<td>Calcium</td>
</tr>
<tr>
<td>CAD</td>
<td>Centralised Anaerobic Digestion</td>
</tr>
<tr>
<td>CBD</td>
<td>Complete Block Design</td>
</tr>
<tr>
<td>FAAS</td>
<td>Flame Atomic Absorption Spectrophotometer</td>
</tr>
<tr>
<td>FRV</td>
<td>Fertilizer Replacement Value</td>
</tr>
<tr>
<td>EDTA</td>
<td>Ethylene Diamine Tetra acetic Acid</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>K</td>
<td>Potassium</td>
</tr>
<tr>
<td>KENDBIP</td>
<td>Kenya National Domestic Biogas Programme</td>
</tr>
<tr>
<td>KNFF</td>
<td>Kenya National Farmers Federation</td>
</tr>
<tr>
<td>LS</td>
<td>Leaf Size</td>
</tr>
<tr>
<td>LSD</td>
<td>Least Square Deviation</td>
</tr>
<tr>
<td>Mg</td>
<td>Magnesium</td>
</tr>
<tr>
<td>N</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>NH₄-N</td>
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</tr>
<tr>
<td>NL</td>
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</tr>
<tr>
<td>P</td>
<td>Phosphorus</td>
</tr>
<tr>
<td>PH</td>
<td>Plant Height</td>
</tr>
<tr>
<td>SAED</td>
<td>Sustainable Agriculture for Economic Development</td>
</tr>
<tr>
<td>Zn</td>
<td>Zinc</td>
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</table>
CHAPTER ONE
INTRODUCTION

1.1 Background of the study

Like many other third world countries, Kenya’s population is exponentially growing, with a net effect of increasing the national food demands. The national staple food is Ugali which is prepared from corn flour. It is only in Western Kenya that maize farming has thrived due to the conducive climatic conditions for agricultural production. The region does not only produce maize but also many other food stuffs like sorghum, cassava, common beans, field peas, potato, finger millet, coffee and bananas. As such, it has been christened the country’s food basket (Esipisu, 2011). The favourable conditions have given rise to increased population for both human and animal production and a large proportion of the population here is engaged in a wide range of agricultural activities. Crop production in Western Kenya involves the growth of both food and cash crops.

This also helps to address the energy crisis and high cost of electricity, most of the farmers in commercial and semi commercial establishments have been embracing conversion of waste to energy. This also helps to deal with solid waste management and high fertilizer costs. This has seen the installation of biogas systems on the farms as an alternative form of energy. The system provides biogas energy as well as bio fertilizer that if well processed and packaged, will see the cost of production reduced enormously in terms of farm inputs. However, the by-product of biogas production, bio-fertilizer, has not been used and explored as an alternative organic fertilizer. During anaerobic fermentation of livestock wastes to produce biogas, fermented slurry also called biogas slurry or bio-slurry is formed. The biogas slurry then undergoes aerobic fermentation which results to the formation of a fertilizer known as bio-fertilizer.

Due to unknown chemical composition of the bio-fertilizer, it has not been effectively utilized by local farmers as organic fertilizer and an alternative to synthetic/mineral fertilizer. This could have resulted from lack of knowledge on its benefits. The continued application of synthetic fertilizer in agriculture over the years has brought more problems than solutions. The problems are such as global warming resulting to climate change, soil infertility, contamination of water and pesticides ending up in the food chain are some of the negative effects resulting
from use of synthetic fertilizers in agriculture (Vasudeo, 2004). Many technical organization such as Kenya National Domestic Biogas Programme (KENDBIP) and Kenya National Farmers Federation (KNFF) which provides a lot of support to farmers on extension services, Universities and small holders are unaware of the many advantages of bio-fertilizer application hence its potential has always been overlooked. Bio-fertilizer maybe considered a good quality organic fertilizer in sustainable agriculture for maintaining the quality of produce (Kumar et al, 2015).

1.2 Statement of the Problem

Agriculture contributes a lot to Kenya’s Gross Domestic Product (GDP) and thus it can be said to be the backbone of Kenya’s economy. Kenya’s population is exponentially growing just like many other African countries. This has a huge impact on the food demand of the country. With the growing population, there has been a problem of food insecurity since Kenya’s food basket (Western, Central and Rift Valley regions) has been affected by the increase in acidity of the soils. According to Esipisu (2011), findings from a research established that soils’ pH in Western Kenya had decreased for maize production due to excessive use of nitrogenous fertilizers and climatic factors. The soil pH in the region was established as 4.5 meaning that such soils can hardly support maize growing (Esipisu, 2011). Scientifically, the neutral pH level is supposed to be seven which means that it is neither acidic nor alkaline (Esipisu, 2011).

Decrease in soil pH is a widespread limitation to crop production worldwide (Van Straten, 2007). Acidic soils are known to have a low Phosphorus fixation and Aluminium toxicity. The “caked” soils have no mechanisms for regeneration. Meanwhile the reviving of degraded soils and maintenance of fertile soils is important all over the world. Rejuvenation of soils enriches soil quality by improving its physiochemical and biological properties. Utilization of bio-fertilizer yields better produce to farmers and leads to growth of the national economy (Nayak and Patangray, 2015). The use of nutrient rich organic fertilizer which are cheaper can reduce dependence on expensive chemical fertilizers. The use of organic amendment results in self-sufficiency in crop farming (Timsina and Conner, 2001).

Most farmers in third world countries are not interested in using organic fertilizers, partly because of knowledge gaps (Bonten et al, 2014). In Kenya, farmers in maize growing areas have resolved into adding more inorganic fertilizer than they initially used, to try to increase their harvest but this is worsening the problem as it is resulting in reduction in soil fertility. Declining soil nutrient content is a major cause of food insecurity in the Southern part of the Sahara desert
Inorganic fertilizer manufacturers have resolved into adding lime to the fertilizers to try to counteract the increase in acidity of the soils (Esipisu, 2011). This combination not only has it seen the reduction in crop yield but also interfered with the soil profiles including the micro-organisms that are a necessity for proper agricultural production. Improving soil fertility is of importance thereby increasing food security of third world countries (MNES, 2004). Since continued use of mineral fertilizers has its negative side effects, it is important to find natural alternatives. Bio-fertilizer could be this alternative. Its use could also be a solution to waste disposal.

1.3 Hypothesis

Null hypothesis: Bio-fertilizer has the same composition and nutrient levels as synthetic fertilizers and can be applied as alternative to synthetic fertilizers.

Alternative hypothesis: The composition and nutrient levels in bio-fertilizers is significantly different from inorganic fertilizers and therefore cannot be used as an alternative for rejuvenation of soil.

1.4 Objectives

The study was guided by the objectives

1.4.1 General Objective

Determination of the efficacy of bio-fertilizer from biogas digesters for regeneration of soils.

1.4.2 Specific Objectives

i) To determine the effects of bio-fertilizer, nil fertilizer and inorganic fertilizer on the soil nutrient quality.

ii) To establish the effect of using either fertilizer on the crop growth and yields.

iii) To compare the benefits (both economic and environmental) of using bio-fertilizer with those of using inorganic fertilizers.

iv) To determine the effect of bio-fertilizers on soil acidity.

1.5 Justification and Significance

Prolonged use of synthetic fertilizer has proven to have a long time effect on plants, soil and environment as a whole. This has resulted in the declining yield of crops in Kenya’s food basket due to decrease in soil fertility. The final result of using the chemical fertilizers is the decrease in pH of the soils resulting to acidic soils which can no longer support the flora and fauna. Additionally, production of chemical fertilizers globally, have led to production of greenhouse
gases which contributes to climate change. There are evidences from countries where biogas technology is well developed which suggest that agricultural produce can be increased with the use of bio-fertilizer produced from biogas plant.

Bio-fertilizer is environmental friendly and can easily replace the use of inorganic fertilizer. The use of bio-fertilizer can provide a beneficial way for farmers, community, reduce burden on economy of a country and improve sustainability of agriculture because it’s environmentally friendly and has no toxic effects. Due to substantial amounts of plant nutrients bio-fertilizer results to increased agricultural production. Thus use of organic fertilizer can significantly lower the use of inorganic fertilizers.
CHAPTER TWO
LITERATURE REVIEW

2.1 Use of Bio-gas as an Energy Source in Rural Kenya

Most of the Kenyan population is concentrated in the rural areas, with agricultural activities as their main occupation. Most of the regions in the rural areas are not connected to electricity and thus they use alternative forms of energy which is wood fuel mostly, to cater for their needs which include cooking, lighting, warming and drying. Though wood fuel is the principal farm based source of energy, it is often in short supply. The rate of use of wood as fuel is higher than the rate of replacement meaning that available wood fuel stocks are rapidly diminishing (Masso et al, 2015). Kerosene is also used mostly for lighting but it is expensive for the smallholder farmers. It is not a sustainable form of energy since it is non-renewable.

There is therefore need to come up with a form of energy which is renewable and more sustainable. The Kenya National Domestic Biogas Programme (KENDBIP) which was established in 2009 has promoted the installation of biogas systems in a number of farms in the country. The biogas system comprises of biogas digesters which digest the animal waste resulting to biogas production as well as a by-product known as bio-fertilizer. Much is known about biogas as it is a more sustainable and renewable form of energy which can be used to produce electricity.

The by-product, bio-fertilizer, has not been studied much and less information on its benefits is available. Bio-fertilizer is a material which contains micro-organisms which, when applied to the soil promotes crop growth as it contains readily available plant nutrients (KEBS, 2011). Fermented fertilizer, is a by-product of the biogas digester and can increase crop produce and lead to prolonged soil fertility (Lekhakul, 1988).

2.2 Bio-fertilizer as a Sustainable Agricultural Input

Successful agriculture should be able to sustain food security while preserving the natural resources and the ecosystem. It should balance both the socio-economic factors and the ecosystem as well (Nayak and Patangray, 2015). The use of bio-fertilizers is cost effective since they are renewable and can improve agriculture (TNAU, 2014). Bio-fertilizer in itself is a very sustainable fertilizer as it is produced as a by-product and thus it doesn’t require any industrial processes and hence reducing the cost of its production. This is unlike synthetic fertilizers
whose manufacture is expensive due to importation of raw materials. The industrial processing for production of just a minimal amount of fertilizer utilizes a lot of energy (Nayak and Patangray, 2015). Another problem with synthetic fertilizers is that they can be washed down water sources resulting to harmful effects both to the humans and to aquaculture too. Synthetic fertilizers’ use has led to more negative effects rather than solving problems facing the agricultural sector. They have contributed to global warming and gradual loss of soil fertility among others are some of the negative effects that result from synthetic agriculture (Vasudeo et al, 2004).

2.3 Bio-fertilizer Formation

A biogas digester is filled with cow dung and/or pig waste. During fermentation, a small percentage of the animal waste is converted to biogas while the rest of the solids is what is referred to as biogas slurry (Gurung, 1998). The composition of bio-slurry depends upon several factors: the kind of dung (animal, human, or other feedstock), water, breeds and ages of the animals, types of feed and feeding rate. Addition of urine leads to an increase in nitrogen in the slurry which then speeds up the compost-making process. The slurry then undergoes fermentation anaerobically after which it is removed and kept in the open to then ferment aerobically. Under tropical conditions, the degradation process is normally fast. Bio-fertilizer is the material that remains after aerobic degradation of organic matter which is a readily spreadable fertilizer.

2.4 Nutrient Composition of Bio-fertilizer

Data derived for nutrient composition of bio-fertilizer is limited, because the main focus of much of the research has been on digester performance in terms of energy balance. In recent years, there has been increasing interest in centralized anaerobic digestion (CAD) plants. Data from two CAD plants are presented in Table 1 (Holsworthy and Cumby, 2004; Holm-Nielsen et al., 1997).

<p>| Table 1 | Comparison of digestate analysis for two centralised anaerobic digestion (CAD) plants |  |</p>
<table>
<thead>
<tr>
<th>CAD Plant</th>
<th>Total-N</th>
<th>NH₄-N</th>
<th>NH₄-N/N</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>DM</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Holsworthy¹ (England)</td>
<td>6.6</td>
<td>5.0</td>
<td>75.8</td>
<td>3.3</td>
<td>4.5</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>Ribe – average 1992-96 (Denmark)</td>
<td>4.9</td>
<td>3.2</td>
<td>65.3</td>
<td>2.4</td>
<td>4.2</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>Ribe2 – 1992 (Denmark)</td>
<td>4.6</td>
<td>3.1</td>
<td>67.4</td>
<td>2.1</td>
<td>4.2</td>
<td>6.4</td>
<td></td>
</tr>
<tr>
<td>Cattle slurry (Denmark)</td>
<td>4.7</td>
<td>2.7</td>
<td>57.4</td>
<td>1.4</td>
<td>5.3</td>
<td>8.5</td>
<td></td>
</tr>
<tr>
<td>Pig slurry (Denmark)</td>
<td>5.3</td>
<td>3.7</td>
<td>3.4</td>
<td>69.8</td>
<td>2.8</td>
<td>6.0</td>
<td></td>
</tr>
</tbody>
</table>

¹Feedstocks by volume 57% dairy cow slurry, 19% blood, 11% food waste, 8% chicken manure, 5% other non-farm waste. Results relate to May 2004.
The total N content in the CAD plant is higher as well as NH$_4$-N/N is also high. Since the two are very important for plant growth. Thus this shows that cattle dung is a very useful in the production of bio-fertilizer as compared to pig slurry.

### 2.5 Influence of Organic Fertilizer on Crop Yield and Growth

Bio-fertilizers have more advantages in terms of supplying important plant nutrients as compared to chemical fertilizers. Research was carried out by (Isfahani and Besharati, 2012) to establish the effect of use of organic fertilizer and inorganic fertilizers in different treatments on yield of cucumber by using incompletely randomized block design in the field. The results showed that the cucumbers on the plot with bio-fertilizer had the best yield, and control treatments had the least yield (1.40g/m$^3$) (Isfahani and Besharati, 2012). Cucumbers on the bio-fertilizer plot had the most length of plant and the chemical fertilizer treatment had the least length of plant, crops in the bio-fertilizer plot had the most amount of chlorophyll and the control had the least chlorophyll.

The bio-fertilizer treatment had more shoot biomass and the control had the least shoots’ biomass. The bio-fertilizer had the most roots dry weight and chemical fertilizer treatment had the least roots dry weight. Cucumbers in the bio-fertilizer treatment had the most roots fresh weight, whereas chemical fertilizer treatment had the least roots fresh weight suggesting that application of organic fertilizers has resulted in increased yield of cucumber significantly suggesting that the presence of bacteria has increased the growth factors of cucumber (Isfahani and Besharati, 2012). From the results of these studies, biological fertilizers is more advantageous both to the economy and the environment in comparison to chemical fertilizers. Thus bio-fertilizers use can bring about better crop production (Isfahani and Besharati, 2012).

### 2.6 Methods of Applying Bio-fertilizer

Bio-fertilizer must be applied before planting with appropriate equipment to ensure that it thoroughly mixes with the soil and that it’s evenly distributed in the field. This also minimizes ammonia from being volatilized (Lukehurst et al, 2010). Digestate if appropriately applied percolates more quickly into the soil thus reducing any odour nuisance after spreading. The chances for ammonia volatilisation during and after application are higher since digestate due to higher ammonia content than raw slurry. The best methods of application are those that ensure proper mixing of the soil with the digestate while minimizing ammonia volatilization (trailing hoses, trailing-shoes, and injection) (Lukehurst et al, 2010).
Although the above methods are more costly as compared with others, they are more advantageous as they result to less pollution, less nutrient losses and higher utilisation of the nutrients in the digestate (Wulf et al., 2002). The nutrients in the fermented fertilizer are readily available and thus can be directly applied in liquid form to the plants (Mikled, 1994).

2.7 The Nutrient Uptake Process
Roots do not necessarily grow towards a nutrient source (Atwell et al., 1999). The individual nutrient ion must be in position adjacent to the root for nutrient uptake to occur. This can occur by one or more of the following processes.

Root Interception: The root can come across the ion as it grows through the soil. A research by Barber estimates that perhaps one percent of the nutrients in a corn plant come from the root interception process (Atwell et al., 1999).

Mass Flow: This is the flow of nutrients that are soluble in soil to the root as water is taken up. Nutrients such as nitrate-N, calcium and sulfur are normally supplied by this process (Atwell et al., 1999).

Diffusion: Nutrients that are only present in small quantities in the soil solution are absorbed to the root by diffusion (Atwell et al., 1999). The concentration in the soil solution in close proximity to the root decreases as the uptake of the nutrients occurs at the root, thus creating a gradient for the nutrient to diffuse through the soil solution from a zone of high concentration to the depleted solution adjacent to the root. Diffusion is responsible for the majority of the P, K and Zn moving to the root for uptake. Table 2 gives the relative importance of each mechanism in positioning nutrients adjacent to plant roots for uptake.
Table 2  Percent of nutrients taken up by a corn crop normally supplied by root interception, mass flow and diffusion

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Root interception</th>
<th>Mass flow</th>
<th>Diffusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>&lt;1</td>
<td>80</td>
<td>19</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>2</td>
<td>5</td>
<td>93</td>
</tr>
<tr>
<td>Potassium</td>
<td>2</td>
<td>18</td>
<td>80</td>
</tr>
<tr>
<td>Calcium</td>
<td>150</td>
<td>375</td>
<td>0</td>
</tr>
<tr>
<td>Magnesium</td>
<td>33</td>
<td>600</td>
<td>0</td>
</tr>
<tr>
<td>Sulfur</td>
<td>5</td>
<td>300</td>
<td>0</td>
</tr>
</tbody>
</table>

2.8  Environmental Effects of using Bio-fertilizer

A lot of environmental benefits arise from best management practices through use of digestate as a fertilizer. Such practices will result in lower gaseous emission into the atmosphere as well as in less diffuse pollution from surface runoff and leaching. These major benefits will help in GHGs reduction by governments (Atwell et al, 1999). Other major environmental benefits associated with using digestate as a bio-fertiliser rather than untreated manures include: the reduction of weed seeds and plant pathogen reduction.

2.8.1  Odours

Many organic wastes including animal manures contain volatile organic substances that can produce unwanted odours. (Hansen et al., 2009) showed that digestion significantly reduced concentrations of many of these compounds, thus reducing their potential for giving rise to offensive odours during storage and spreading.

2.8.2  Veterinary Safety

The application of digestate, as well as of raw manure and waste products as fertiliser, may pose health risks for animals and humans. For this reason, the use of digestate as fertiliser is usually governed by regulations and standards that protect animal and human health as well as the quality of crops. Each country has its own standards, such as KEBS Regulation No 2356:2011; this applies to all Kenyan farmers. Anaerobic digestion is very effective at lowering the pathogen load in the digestate. The eggs of common gastrointestinal worms and larvae of lungworm are inactivated in less than 4 hours at 53°C and after 8 days at 35°C. (Lukehurst et al, 2010). Anaerobic digestion (particularly thermophilic) can offer a useful means of reducing numbers of pathogens that could otherwise lower the productivity of livestock farms or present a risk to human health.
2.8.3 Plant Pathogen Reduction

There are relatively few studies that have tested the effect of anaerobic digestion on the survival rate of pathogens that affect plants. While plant pathogens can be treated by fungicides, many farmers try to avoid their use due to environmental concerns and expense. Two recent studies in Sweden by (Haraldsson and Zetterstrom, 2008) showed that common fungal diseases of plants are irreversibly inhibited or killed during mesophilic digestion with a hydraulic retention time of between 25–30 days. Both these studies highlighted the fact that the digester temperature alone is not responsible for the destruction of the spores (Haraldsson and Zetterstrom, 2008). The evidence suggested that it is the combination of the conditions in the digester – pH level, quantities of volatile fatty acids, the negative effect of ammonium and hydrogen sulphide together with time and temperature that combine to create the hostile environment in which the spores are unable to survive. This in itself demonstrates the need for caution in making generalisations, since the conditions inside the digester can vary between digesters and between feedstock (Haraldsson and Zetterstrom, 2008).

Nevertheless, it is reasonable to conclude from the Swedish work that farms with a mesophilic digester would benefit from a significant or total destruction of many disease-spreading spores that can affect their crops (Haraldsson and Zetterstrom, 2008). Anaerobic Digestion (AD) therefore has the potential to offer real benefit to organic farmers and those wishing to reduce the use of fungicides.

2.8.4 Reduction of Weed Seeds

The reduction in the number of viable weed seeds in digestate will lower their dispersal by land spreading and as a consequence there will be less need for herbicides (Engeli et al, 1993). The limited number of studies on the destruction of weed seeds by AD indicates that mesophilic anaerobic digestion can reduce the viability of the weed seeds and also of some crop seeds. Inactivation time at thermophilic temperatures is shorter than at mesophilic temperatures (Engeli et al, 1993).

2.9 Comparison of bio-fertilizer and chemical fertilizer

Fertilizers act as catalysts in providing nutrients to plants for their optimum growth and yield. Nitrogen, phosphorus and potassium are essential nutrients for plants in a fertilizer. Plants are capable of absorbing nitrogen in its mineral form ($\text{NH}_4$-N) for their vital functions. The proportion of mineral nitrogen increases by about 20% through a process of anaerobic fermentation. Liquid and solid manure that has not been fermented contains more nitrogen in organic
form, the mineralization of which may take several years. That is why the fertilizing properties of the digestate on agricultural land are better than those of liquid or solid manure. Apart from the NH$_4$-N, digestate contains phosphorus and potassium, which are the two other essential nutrients. Compared with liquid and solid manure, the ratio of phosphorus to potassium in the digestate is generally better suited for satisfying the nutritional needs of the plant (Bondgaard, 2011). This in turn means that for digestate, the need for additional mineral fertilizer is not as high as for liquid and solid manures that have not been fermented. Part of the organically bound nitrogen is converted by digesting the slurry, and the proportion of inorganic nitrogen is increased. The effect on nitrogen leaching will depend on the supply of nitrogen from fertilizers.

There will be an increase in the total supply of inorganic nitrogen with the same amount of nitrogen in the fertilizer as usual, but as a result of the expected yield increases, there will probably be no immediate effect on nitrogen leaching. However, the increased fertilizer value must be considered in the fertilizer plan for the farm. As a result of the decreased supply of organically bound nitrogen in the longer term, a slight reduction in leaching might be expected. A reduction in leaching can be expected because of the reduced supply of organic N, if the supply of nitrogen in fertilizers is adjusted so that the total amount of supplied inorganic nitrogen remains the same, (Bondgaard, 2011).

2.9.1. The Advantages of Using Chemical Fertilizer

- Nutrients are in a soluble state and thus readily available to plants.
- Have a high nutrient content though crop growth only requires a small amount.

2.9.2 The Disadvantages of Using Chemical Fertilizer

- Overuse can result in negative effects that may result to irreparable damage to the overall ecosystem.
- Oversupply of nitrogen leads to softening of plant tissue resulting in increased susceptibility to diseases and pests.
- They reduce the colonization of plant roots with mycorrhiza and inhibit symbiotic nitrogen fixation by Rhizobia due to high nitrogen fertilization.
- Leads to degradation of oil structure by enhancing the decomposition of soil.
- Nutrients are easily lost from soils which can lead to reduced fertilizer efficiency.
- Some fertilizers are more acidifying than others hence the need to use sparingly on low pH soils.
The use of fertilizers on a global scale emits significant quantities of greenhouse gases into the atmosphere which is known to cause climate change.

Ever increasing prices of the chemical fertilizers, their scarcity, the burden on Government in the name of subsidy on these chemical fertilizers presses the need to look for alternatives.

2.9.3. The Advantages of Using Bio-fertilizers

- Helps in keeping plants healthy since the nutrient supply is more balanced.
- They enhance soil biological activity, which improves nutrient mobilization in the soil.
- They enhance the colonization of mycorrhiza, which improves phosphorous supply.
- They enhance soil structure, leading to better root growth.
- They increase the organic matter content of the soil (Vasudeo, 2004).
- They release nutrients slowly and contribute to the residual pool of organic nitrogen and phosphorous in the soil, reducing nitrogen leaching loss and phosphorous fixation (Lukehurst, 2010).
- They encourage the growth of beneficial micro-organisms and earthworms.
- They help to suppress certain soil-borne plant diseases and parasites.
- They help to save on cost as compared to expensive chemical fertilizers.
- Non-pollutant and non-carcinogenic.
- Increase crop yield by 20-30 %. (Vasudeo, 2004)

2.9.4. The Disadvantages of Using Bio-fertilizer

- Comparatively low in nutrient content thus a larger volume is needed to provide enough nutrients for crop growth.
- Short shelf life, lack of suitable carrier materials, susceptibility to high temperature, problems in transportation and storage are all bio-fertilizer bottlenecks that still need to be solved in order to promote effective inoculation (Chen, 2006).

2.10 Rejuvenating Sustainable Agriculture for Economic Development (SAED)

Rejuvenation leads to increased yields that in turn leads to more profits. It is less risky than New Product Development, cost effective, saves time and helps gain market share (Bonten, 2014). Sustainable development is a mode of human development which aims to meet human needs while preserving the environment (Mikled, 1994). Sustainable development has three constituent parts: environmental sustainability, economic sustainability, and socio-political sustainability.
Achieving this sustainability in agriculture is important as the economy of Kenya depends mainly on agriculture (Esipisu, 2011). Sustainable agriculture can be defined as methods of farming that are environmentally friendly and that allow the production of livestock and crops without damage to human or natural systems. Furthermore, the concept of sustainable agriculture means passing on a conserved or improved natural resource, biotic, or economic base instead of one that has been depleted or polluted (Mishra and Dash, 2014). Combining agriculture and economy, the term sustainable agriculture economic development (SAED) has been coined as used in the study. This study also formulates strategies for SAED by comparing bio-fertilizer to mineral fertilizer.
CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Experimental Site
The research was conducted at Kamatongu farm in Nyeri County, Kenya- between the months of September to November 2015. The region was selected because there are a lot of agricultural activities carried out in these region and also considerably three biogas digesters systems have been set up in the farm. The region has a characteristic clay-loam type of soil with a pH of 5.5.

3.2 Experimental layout and Design
The experiment was set up in a Complete Block Design (CBD) with a split plot arrangement of 1 replica in 21 experimental plots. The main plot was subdivided into 3 different blocks each having its own treatments. Each block had 7 experimental plots, each plot having own crop. The experimental area measured 36 m by 24 m with 3 blocks each measuring 10 m by 24 m and one block contained 7 main plots. Each experimental unit measured 10 m by 3 m. The blocks were separated by paths measuring 1.5 m and the experimental units were separated by paths of 0.5 m. The entire experimental field was surrounded by 4 lines of Capsicum serving as a border crop.

3.3 Treatments
Three treatments were applied in the experiment.

1) The first block (A) was treated with bio-fertilizer whereby the fertilizer was pumped into the block for four times at an interval of 3 days to ensure drying of the bio fertilizer before applying the next time. At each time of application turning of the soil was done ensuring thorough mixing of the plot with the bio-fertilizer. Application of the bio-fertilizer was done four times to ensure that any minerals contained in the soil were leached.

2) The second block (B) was the control whereby no fertilizer was applied in this block. The crops were planted without any fertilizer application or any other treatment other than digging and furrowing.

3) The third block (C) is where conventional farming was practiced whereby DAP fertilizer was applied before planting and CAN was applied during topdressing according to every crops’ fertilizer recommendation.
3.4 Crops Grown
Seven crops were planted in each of the three blocks of the main experimental plot. The 7 crops were; cabbage, kales, spinach, maize, field beans, tomatoes and French beans. The crops were managed as per agronomic requirements of each specific crop. Application of water was solely dependent on drip irrigation although it had no direct effect on the research objective. Other agronomic practices were kept constant and in accordance with agronomical practices. These practices included weeding, staking, insect, pest and disease control.

3.5 Sampling
Collection and treatment of soil and plant samples were done as described.

3.5.1 Soil sampling
The soil samples were gathered at different intervals of the research. The first samples were collected from the entire field before it was subdivided into 3 different blocks. The second samples were collected from block (A) that had been applied with bio-fertilizer. The third and final samples were amassed after the final harvest of the crops. The samples were from the different blocks after removing the crops from the field. The collected samples were scooped and placed into carefully labelled polyethylene bags and were transported to Kenya Industrial Research and Development Institute-Laboratories (KIRDI-L) where the pH was measured and the samples preserved prior to analysis.

3.5.2 Crop sampling
This was done after the crops had reached their maturity and were ready for harvesting. Leaf samples were taken to the KIRDI- Laboratories for leaf nutrient analysis. The specific crops from which sampling was done were selected randomly to avoid biasness.

3.6 Experimental techniques
Standard and well established techniques were employed during analysis. pH of the soils was determined using the electrochemical method of analysis. The major nutrients content of the bio-fertilizer were quantitatively determined by Kjeldahl method; UV-VIS Spectrometer and flame Emission spectrometer respectively for quantitative data. The macro and micro elements such as calcium, magnesium, manganese, iron and zinc were determined by Flame AAS Certified Reference Materials (CRM) were incorporated at intervals for quality control purposes.
3.6.1 Determination of pH

pH measurements were done using a pH meter model IQ150. The pH meter probe was immersed in a solution of 2 grams sample in de-ionized water.

3.6.2 Nitrogen determination by Kjeldahl

The most widely used method for determining total nitrogen content in a sample was the Kjeldahl method. This is a wet digestion method in which the sample to be analyzed was first digested for several hours using Concentrated Sulphuric acid. The standard Kjeldahl method is a two-step analysis process:-

(i) Digestion of the sample to convert Nitrogen into Ammonium ion.
(ii) Determination of the amount of ammonium ion in the digest.

In this study, the reagents used for digestion were:-

Concentrated 36 N Sulphuric acid (H₂SO₄)
Mixed Catalyst: Prepared by mixing 160.0 g of Potassium Sulphate, 10.0 g of Copper II Sulphate (CuSO₄, 5H₂O) and 3.0 g of Selenium powder.
10 N Sodium Hydroxide: 420 g of NaOH was dissolved in a liter of deionized H₂O.
Boric acid: 20.0 g of H₃BO₃ was dissolved in 1 liter of deionized water.
Indicator solution: 0.12 g methyl red was dissolved and 0.8 g methyl blue in 100 ml of 95% methanol or alternatively by dissolving all the above with 0.1g bromcresol green.

Digestion means the process in which the sieved sample is subjected to heating in the presence of concentrated Sulphuric acid. This heat treatment with acid is done primarily so as to convert the organic nitrogen in the sample into ammonium. The procedure employed was as follows:-

Exactly 10 g of air dry sample was ground to fine particles. The sample was weighed out and carefully transferred to a 500 mL Kjeldahl flask. 10.0 g of mixed catalyst was added and washed in with 5-7 mL of distilled water. 20 mL of concentrated 36 N H₂SO₄ from a graduated cylinder was added and the acid and sample mixed by gently shaking and allowing to stand for 20 minutes.

The flask was heated gently and cautiously on a digestion stand or in a fume cupboard. Caution was taken at this stage due to the production of dangerous sulphur trioxide (SO₃) fumes. At first there was some frothing but after the frothing had ceased the temperature was then increased until the digest ‘cleared’. The digest was assumed to have cleared when it ceased to
loose color and becomes relatively devoid of suspended material. After clearing, the mixture was left to boil for at least 2 hr. 30 min. The heat was regulated such that the H2SO4 condenses at about a third of the neck of the flask.

When digestion was completed, the flask was allowed to cool. After cooling, 100 mL water was added and shaken to mix. The mixture was then transferred to a 250 mL volumetric flask and filled up to the mark. For one to do this properly the contents of the Kjeldahl flask were first transferred to a large conical flask and the liquid digest then decanted off followed by about four further washings of the residue and subsequent decantation and filtering so as to get the entire digest into the volumetric flask and leave only the washed residue.

The percentage nitrogen was calculated using equation (1).

\[
\% N = \frac{\text{Titre} \times \text{Normality of acid} \times \text{dilution} \times 0.014}{\text{aliquot taken}} \times 100
\]

(1)

3.6.2.1 Determination of Ammonium (NH₄⁺) in the digest by distillation

This step involved the determination of the ammonium present in the digest by distillation with an alkali and the subsequent titration of the distillation product. The small aliquot distillation is a micro-distillation which was normally done in specially designed apparatus and was normally done swiftly. Macro-distillations on the other hand are normally much slower however they do tend to have the advantage of giving more accurate results. The procedure used was as follows:-

50.0 mL of the digest was pipetted into a Kjeldahl flask; 200 mL of distilled water and two glass beads were then added. The distillation apparatus was set up with the lower end of the Liebig condenser leading into a 500 mL conical flask containing 50 ml of 2% boric acid solution and a few drops of mixed indicator.

The Kjeldahl flask was held at about 45° inclination and 25 mL of the 10N NaOH gently poured down the neck of the flask and then immediately connected to the distillation apparatus. The flask was swirled to mix the contents and commence distillation. The flame was regulated so that the distillate was not too hot above 35° C. The distillation continued until close to half of the liquid in the Kjeldahl flask had been distilled over.

The receiver flask was lowered so that the end of the condenser was out of the liquid before stopping the distillation in order to prevent sucking back. The amount of Ammonium in the
distillate was determined by titration with 0.01N HCl or H$_2$SO$_4$. The colour change at the end point was from green to grey to pink.

1 mL of 0.01N acid in the titration is equivalent to 0.14 mg Ammonium. If a 10.0 g sample was used to give 250 mL of digest from which a 50 ml aliquot was distilled, then the % N in the sample is:

\[
\% N = \frac{mL\text{ acid} \times 5 \times 0.14}{\text{Wt. of soil (in mg)}} \times 100
\]

(2)

Assuming a reading of 30 ml of 0.01N acid and 10.0 g of soil, then the calculation is

\[
\text{mg N} = \frac{30 \times 5 \times 0.14}{\text{mg Sample} \times 10000} = \frac{21}{10000} = 0.21 \%
\]

(3)

### 3.6.3 Determination of Phosphorus

One of the simplest and most reproducible methods for the determining Phosphorus was the Colorimetric method (Pierzynski, 2000). This colorimetric method is also known as the Double Acid Extraction method. It involves the use of a Spectrophotometer to get an absorbance versus concentration plot from which the Phosphorus in the sample was obtained.

The **double Acid** used was composed of 0.95N HCl in 0.025N H$_2$SO$_4$. It was prepared by putting 15 liters of distilled water into a 20 litre bottle and adding 14 mL of conc H$_2$SO$_4$ and 83 mL of concentrated HCl. The volume in the bottle was adjusted to 20 liters and thoroughly mixed.

**Reagent A**: 12 g of Ammonium Molybdate [(NH$_4$)$_6$Mo$_7$O$_{24}$] was added in a 250 mL of distilled H$_2$O. 0.29089 g of Potassium Antimony Tartarate was dissolved in 100 ml distilled H$_2$O. 5N H$_2$SO$_4$ was prepared by diluting approximately 148 ml of concentrated H$_2$SO$_4$ in 1000 mL distilled water. The solutions were mixed together in a 2L volumetric flask and the contents filled to the mark with distilled water.

**Reagent B**: This reagent was prepared by dissolving 1.056 g of Ascorbic acid for every 200 mL of Reagent A as it was always freshly prepared from Reagent A each time before it was used.
Standard Phosphorus stock solution: 9.4393 g of monobasic Potassium Phosphate (KH$_2$PO$_4$) was weighed and put in a one liter volumetric flask. 500 mL of distilled H$_2$O was added in the volumetric flask and the contents shaken until the salt dissolved. 5 drops of Toluene was added to the flask so as to kill any microbes. The contents were then topped to the mark yielding exactly 0.1 mg P/mL which was equal to 100 ppm or 100 µg/L. A Secondary Phosphorus standard Solution was made from the 100 ppm P stock solution by pipetting 5 mL of the 100 ppm solution into a 100 mL volumetric flask and topping up the contents to the mark using de-ionized water. This yielded a 5 ppm secondary standard solution.

A set of standard Phosphorus solutions were prepared by pipetting 0, 1, 2, 3, 4 and 5 mL of the 5 ppm secondary standard. The pipetted solutions were then put into 50 mL volumetric flasks and 5 mL of double acid added to each of the flasks followed by 20 mL of distilled water. 8 mL of Reagent B was then added to each flask and immediately made to the mark with distilled water while mixing. The content stood for 15 minutes before the absorbance readings were taken with the spectrophotometer. The data obtained was used to draw a calibration curve by plotting absorbance (Y-axis) versus P concentration (X-axis) of the standards (Figure 1).

![Absorbance vs. Concentration](image)

**Figure 1: Absorbance versus Concentration in Phosphorous standards**

Sample Extraction: 5 g of the sample was weighed into a 100 mL extracting tube. To the extracting tube, 50 ml of the double acid reagent was added after being accurately measured by pipetting. The extracting tubes were stoppered tightly and placed horizontally on a mechanical reciprocating shaker. They were swirled for 30 minutes. The contents were filtered through a Whatman No. 42 filter paper. The filtrate was then collected in specimen bottles.
A suitable aliquot of the sample extracted was pipetted into a 50 mL volumetric flask. To the flask, 25 mL of distilled water was then added. 8 mL of Reagent B was then added in the flask and distilled water was then immediately added to the mark and the contents thoroughly mixed. The mixture was allowed to stand for 25 minutes. Contents were then run through a spectrophotometer and absorbance readings recorded. The concentration of phosphorous was obtained from the absorbance by extrapolating the calibration curve.

3.6.4 Analysis of Potassium

The exchangeable potassium present in the sample was determined in the Ammonium Ethanoate leachate using a flame photometer. The reagents used included Standard K solutions, 0-10 µg K⁺ mL⁻¹ prepared from a volumetric standard containing 1 mg K⁺ mL⁻¹. This was made from dry potassium nitrate KNO₃ at 105°C for 1 hour before being cooled in a desiccator. The reagent Ammonium Ethanoate solution of 1M concentration was made by diluting 230 mL of glacial ethanoic acid to 1L. Approximately 220 mL of ammonia solution (approximately 35% m/m NH₃) was added to 1L. The two solutions were mixed together and the pH adjusted to 7.0 with ammonia. It was then diluted to 4 liters. Potassium chloride solution was prepared by dissolving approximately 100 g of KCl in water and made up to 1L and 2.5 mL of 1M HCl added.

The sample was extracted adding 20 mL of ammonium ethanoate solution to 5 g of dry sample (air dried, less than 2 mm diameter) in a 100 mL beaker. The solution was stirred and allowed to stand. The suspension that resulted was transferred to a filter funnel fitted with a Whitman No. 44 filter paper standing over a 250 mL volumetric flask. The beaker and funnel were thoroughly washed with the Ammonium Ethanoate before use. The sample was leached with successive 25 mL volumes of Ammonium Ethanoate while allowing the funnel to drain between each addition. This was done until 250 mL of the filtrate was collected.

The standard was prepared by weighing 1.293 g of KNO₃ into a 100 mL beaker and adding 1mL of HCl (approximately 36% m/m HCl). The HCl was used as preservative for solutions that were stored for a few days. The contents were transferred with washings into a 500 mL volumetric flask and the flask topped up to the mark using de-ionized water. 10 mL of the solution from the volumetric flask was pipetted into a 100 mL flask and topped up to the mark with ammonium ethanoate solution: The resulting solution contained 100 µg K⁺ mL⁻¹.
Volumes of 0, 2, 4, 6, 8 and 10 mL were drawn from the 100 mL flask and each put in a 100 mL flask. Each flask was topped to the mark with ammonium ethanoate solution. These flasks thus contained 0, 2, 4, 6, 8 and 10 µg K⁺ mL⁻¹ respectively.

A Flame Photometer was used to analyse the standards and the samples. Solution containing K⁺ was sprayed into a gas-air mixture. The amount of light emitted was dependent on the flame conditions and on the rate at which K⁺ entered the flame. Following the manufacturer’s instructions and with a K⁺ filter in place, the milliammeter was set to read zero to correspond with the zero K⁺ standard. The same was done on the full scale deflection to correspond with the 10 µg K⁺ mL⁻¹ standard. The stability of the instrument was checked by spraying the zero and maximum standards again. A calibration curve for the photometer (Y-axis) versus Potassium concentration (X-axis) was plotted. It was a straight line connecting all the points of the standards. The sample was sprayed on the photometer and reading taken. From the calibration curve, the corresponding potassium concentration was obtained by checking against the photometer reading.

**3.6.5 Determination of Ca²⁺ and Mg²⁺**

These were determined together by a titration method. The titration method involved chelation of the cations with ethylene diamine tetra-acetic acid (EDTA). The procedure was normally to determine the Ca²⁺ and Mg²⁺ together by the use of solochrome black indicator. The principle behind this method was based on the fact that in an alkaline solution, the solochrome black forms a red complex with Ca²⁺ and Mg²⁺. EDTA however had a stronger complexing power for both the magnesium and calcium ions and thus takes them away from the indicator. After all the Ca²⁺ and Mg²⁺ have been removed, the solochrome black reverts to its normal colour (Rayment & Lyons, 2011).

To make 0.005 M solution of EDTA, the salt was dried at 105°C for an hour and then cooled in a desiccator. 1.86 g of the disodium salt (RFM 372.24 g) was weighed and dissolved in water in a 250 ml beaker which was transferred by washing into a 1L volumetric flask and made up to the mark. A buffer solution was prepared by dissolving 17.5 g of NH₄Cl in water in a 250 ml beaker which was then transferred with washing into a 250 ml volumetric flask. 143 ml of ammonia solution (approximately 35% NH₃ m/m) was added and made to the volume. This solution was handled in a fume chamber. Solochrome black indicator was made by dissolving 0.25 g of solochrome black in 190 ml of tri-ethylamine and 63 mL of ethanol.
250 µg Ca\(^{2+}\) mL\(^{-1}\) calcium solution was made from a volumetric standard containing Ca\(^{2+}\) mL\(^{-1}\) that was prepared by drying anhydrous calcium nitrate (Ca(NO\(_3\))\(_2\)) for 1 hour at 105°C and later cooling in a desiccator. 2.05 g of the Ca (NO\(_3\))\(_2\) was dissolved in water in a 100 mL beaker and to it 1 mL of HCl (approximately 36% m/m HCl) was added as a preservative. The solution was transferred with washing to a 500 mL volumetric flask and filled to the mark with distilled water.

To a 250 mL conical flask, 25 mL of the calcium solution was pipetted. 2 mL of the buffer solution was added to the conical flask and a few drops of solochrome black indicator. The contents of the conical flask were titrated using 0.005 M EDTA until there was a colour change from the purple-red to a pale, slightly greenish blue. The end-point was determined when the last trace of pink disappeared from the blue colour.

25 mL of the extract was pipetted into a conical flask. 2 mL of the buffer solution was added to the conical flask plus a few drops of solochrome black. The contents of the conical flask were then titrated using 0.005 M EDTA until there was a colour change from the purple-red to a pale, slightly greenish blue. The end-point was when the last trace of pink disappeared from the blue colour.

**Note:** Acidic samples required only 1-2 mL of EDTA while neutral or alkaline samples required up to 80 mL. Due to this large range, titration was done quickly so as to obtain an approximate end-point and then the titration was repeated appropriately so as to obtain the sample end-point. Also it was noted that the colour change observed in the sample was remarkably less clear than for the clean solution. It was for this reason that an initial quick titration was needed so as to allow the change to be seen more easily. It was necessary to add more of the indicator.

### 3.6.6 Determination of Total Organic Carbon

The Walkley – Black Method was used for this analysis.

The method of analysis used will be Walkley-Black method.

The reagents used included 0.1 % Barium diphenylamine Sulphate solution in 5% Barium Chloride, 0.2 g diphenylamine dissolved in 20 ml distilled water and made up to 100 mL, 0.5N ferrous sulphate prepared by dissolving 140g of reagent grade FeSO\(_4\) \(\cdot\) 7H\(_2\)O in distilled water and to it added 5ml conc. H\(_2\)SO\(_4\). The solution is then cooled and made to a litre. This reagent
was standardized each time before being used for organic carbon determination by titrating against 10 mL IN K$_2$Cr$_2$O$_7$).

Soil sample was taken and ground to fine particles. 1g of the sample was weighed in duplicate and transferred to a 300ml Erlenmeyer flask. 10 mL of 1 N K$_2$Cr$_2$O$_7$ solution was accurately weighed and put in the flask where it was gently swirled to disperse the soil and to come into contact with the whole sample. Caution was taken to avoid the soil sticking to the side of the flask where it was out of contact with the reagent. 20 mL of conc. 36 N H$_2$SO$_4$ (sg 1.84) was rapidly added using a measuring cylinder while directing the stream into the mixture. The flask was immediately swirled gently until the soil and reagents were mixed. The mixture was swirled more vigorously for one minute. The flask was then rotated and allowed to cool on an asbestos sheet for 30 minutes. 100 mL of distilled water and 5.0 mL conc. Orthophosphoric acid (H$_3$PO$_4$) was added in order to obtain a clear end point during filtration. 4 drops of diphenylamine indicator were added and titration with 0.5 N ferrous sulphate solution done. As the end point approached, the turbid dark blue colour became greenish and eventually changed to a clear pale green quite sharply at the end point. A blank titrate was done in the same manner without the soil so as to standardize the dichromate. The results obtained were calculated according to the formula.

\[
\% \text{ organic C in soil} = \frac{(\text{Me K}_2\text{Cr}_2\text{O}_7 - \text{Me FeSO}_4)}{\text{g of air dry soil}} \times 0.3
\]

(4)

Where: Me = Normality of solution x ml of solution used.

1 ml of IN K$_2$Cr$_2$O$_7$ oxidizes 3 mg of carbon (So 0.003 x 100 = 0.3).

The figure obtained this way gave the actual amount of carbon oxidized by the dichromate. This is at times referred to as uncorrected Walkley - Black value, since it does not take into account the fact that average recovery is about 77%. Using the conventional factor for Walkley – Black method (1.33), the result obtained with the above formula must be multiplied by 1.33 (100/75). Alternatively, the 0.3 used in the formula is changed to 0.399 i.e. 1.33 x 0.3 = 0.399

3.7 Data Collected

In this the plant height/ length of the shoot was measured using a meter rule (100cm) from ground point to the apex/ terminal bud during the following intervals; 4 weeks after planting, 6 weeks after planting and at harvesting time. The number of leaves were counted physically.
The yield was measured during harvesting time. The leaf nutrient analysis was done after harvest maturity.

3.8 Statistical Data Analysis
Data was analyzed both qualitatively and qualitatively and subjecting it to analysis of variance (ANOVA). The difference among treatment means was compared using Fisher’s Protected Least Square Deviation (LSD) test at 5% Probability Levels.
CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Interactions of Different parameters of crop growth from the bio fertilizer block and the synthetic fertilizer block against the control

4.1.1 Cabbage

Cabbage is an important vegetable crop in our nation and its market is continuous throughout the year. It is very rare not to find cabbages in the market as and when you need them. It is one of the hardiest of the vegetables and thus cannot be referred as delicate. It is one of the most important of all vegetable crops and is universally cultivated for different purposes (Shoemaker, 2009). Leaf sizes from all the three different treatments, were compared and results were as in Table 3.

Table 3: Comparison of PH, NL and LS of Cabbages from the three different blocks

<table>
<thead>
<tr>
<th>Crop variety</th>
<th>Plant_ID</th>
<th>rep</th>
<th>Treatment</th>
<th>PH_1</th>
<th>PH_2</th>
<th>PH_3</th>
<th>NL_1</th>
<th>NL_2</th>
<th>NL_3</th>
<th>LS_1</th>
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<th>LS_3</th>
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<tbody>
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</tbody>
</table>

The table showed that on average the leaf sizes from the block that had bio fertilizer (B1) was higher than the control block (B2). Leaf Size for block 2 (LS2) and Leaf Size for block 3 (LS3) were both higher than the control. It was also found out that the leaf size of the vegetables from synthetic fertilizer block LS1 and LS2 were higher than the control block leaf sizes. The above data was then represented graphically in line graphs for better interpretation as shown in appendix 2. The number of leaves for block B1 was higher than for block B2 as shown by the graphs for NL1 and NL3. But they were lower for NL2. While those for block B3 were higher in all the three NL graphs than those of block B2.
The plant height for block B1 was higher in all the three graphs as compared to those of block B2. The plant height for block B3 was higher than for block B2 as shown in graph PH1 but was lower in PH2 and PH3.

### 4.1.2 Field beans

Field beans can grow virtually on any soil however, flat, well-drained land, free of stones is ideal. The type of bean that was planted in all the blocks was Cranberry. It was noted that field beans could not tolerate wet soils and were grown in rows set 30 to 36 inches.

Leaf sizes, the number of leaves and the plant height from all the three blocks were compared and the results of the comparison are as in Table 4.

### Table 4: Comparison of PH, NL and LS of Field beans from the three different blocks

<table>
<thead>
<tr>
<th>Crop variety</th>
<th>Plant_ID</th>
<th>rep</th>
<th>Treatment</th>
<th>PH_1</th>
<th>PH_2</th>
<th>PH_3</th>
<th>NL_1</th>
<th>NL_2</th>
<th>NL_3</th>
<th>LS_1</th>
<th>LS_2</th>
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</tr>
</tbody>
</table>

From the table, it can be deduced that the leaf size from B1 was higher than B2 as observed from LS1, LS2 and LS3. LS3 was way higher than the rest. The leaf size for B3 was lower than the control for both LS1 and LS2 while the leaf size was equal for LS3. Number of leaves for block B1 was high in all the three sampled plants as depicted by the data in Table 4 as compared to block B2. Plants sampled in block B3 had more number of leaves as shown. NL2 and NL3 and lower in NL1 in comparison to block B2. The sampled plants had a higher height in block B1 as compared to block B2 as shown in the data. The height was also slightly higher in block B3 as compared to block B2. The data was then drawn into line graphs which brought out a better comparison as observed in Appendix 2.

### 4.1.3 French beans

French beans also known as green beans, and locally as *mishiri*, are a major export crop. Interest in the crop is fast growing in Kenya for both fresh consumption and processing. Irrigation
was essential since it needed continuous supply of water. The soil pH was favourable for its growth as it does well in slightly acidic soils though it can tolerate a low pH of up to 4.5. There are several varieties of French beans but we planted Serengeti as it had a good history in the area as compared to the rest. Leaf sizes, the number of leaves and the plant height from all the three blocks were compared and the results of the comparison are as in Table 5.

Table 5  Comparison of PH, NL and LS of French beans from the three different blocks

<table>
<thead>
<tr>
<th>Crop variety</th>
<th>Plant_ID</th>
<th>rep</th>
<th>Treatment</th>
<th>PH_1</th>
<th>PH_2</th>
<th>PH_3</th>
<th>NL_1</th>
<th>NL_2</th>
<th>NL_3</th>
<th>LS_1</th>
<th>LS_2</th>
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</table>

Leaf size from B1 was higher than the control in all the three leaf sizes as shown in Table 6. It was also higher than that of B3. The leaf size from B3 was lower than that of the control in LS1, LS2 and LS3. It was also found out that B3 had the lowest leaf size in all the three blocks. The number of leaves were many in block B1 as compared to block B2. They were slightly many as in NL2 and NL3 and less in NL1 as compared to the plant in block B2. The plants had a higher height in block B1 than in block B2. The same was observed for block B3 as the plants had a higher height than B2. The above was true even when the data was graphically represented on line graphs as shown in Appendix 2.

4.1.4 Kales

Kale is a cool-weather crop that requires two months of to reach harvest. The seeds were sown in a seed nursery and transplanted into the farm when the seedlings were 6 weeks old. The kales were harvested for the first time 55 days from transplanting. This was done by cutting individual leaves that were 8 to 10 inches high and leaving the rest to reach full maturity. Harvesting also took place 2 more times after the first harvest.

Leaf sizes, the number of leaves and the plant height from all the three blocks were compared and the results of the comparison are as in Table 6.
From Table 6 it can be observed that LS1, LS2 and LS3 were all higher for B1 than the control block, B2. LS1 and LS2 are lower for B3 than the control block while LS3 is slightly higher than the control. Kales had more number of leaves on average in B1 than in B2 as depicted by the data. The plant height for plant 2 and plant 3 was higher in block B1 than in block B2 while plant 1 had a lower height than in block B2. On average, the plant height for kales was lower in block B3 than in block B2. This is also the case in Appendix 2.

4.1.5 Maize

Maize is the staple food in Kenya mainly grown in the Kenya’s food basket of the Rift valley and Western Kenya. It is cold-intolerant and is planted during the rainy season and stays for 9 months before it attains maturity. Maize is produced under diverse environments. It majorly relies on soil moisture. It utilizes sunlight more effectively than any other crops and it has the highest yield per ha of all grain crops (Jean du Plessis, 2003). Leaf sizes, the number of leaves and the plant height from all the three blocks were compared and the results of the comparison are as in Table 7.

<table>
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<tr>
<th>Crop variety</th>
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<th>Treatment</th>
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<th>PH_2</th>
<th>PH_3</th>
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<th>NL_2</th>
<th>NL_3</th>
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</table>

| MAIZE        | 1        | 2   | B1        | 20   | 114  | 165  | 8    | 14   | 20   | 30   | 50   | 66   |
|              | 2        | 1   | B1        | 11   | 95   | 140  | 7    | 12   | 14   | 41   | 54   | 68   |
|              | 3        | 1   | B1        | 21   | 116  | 170  | 7    | 13   | 13   | 45   | 60   | 70   |
|              | 4        | 1   | B1        | 22   | 120  | 178  | 7    | 14   | 14   | 34   | 42   | 64   |
|              | 5        | 1   | B1        | 19   | 118  | 158  | 7    | 11   | 12   | 41   | 55   | 73   |
|              | 1        | 2   | B2        | 25   | 90   | 139  | 7    | 7    | 9    | 45   | 50   | 64   |
|              | 2        | 1   | B2        | 14   | 78   | 125  | 7    | 9    | 10   | 22   | 35   | 66   |
|              | 3        | 1   | B2        | 23   | 88   | 126  | 7    | 9    | 10   | 43   | 48   | 55   |
|              | 4        | 1   | B2        | 11   | 82   | 115  | 8    | 10   | 11   | 46   | 50   | 60   |
|              | 5        | 1   | B2        | 16   | 70   | 110  | 6    | 8    | 9    | 30   | 38   | 45   |
|              | 1        | 3   | B3        | 13   | 68   | 105  | 6    | 8    | 18   | 24   | 30   | 40   |
|              | 2        | 1   | B3        | 12   | 74   | 103  | 8    | 13   | 15   | 21   | 34   | 42   |
|              | 3        | 1   | B3        | 17   | 84   | 99   | 8    | 10   | 12   | 29   | 36   | 50   |
|              | 4        | 1   | B3        | 12   | 68   | 87   | 7    | 10   | 12   | 36   | 41   | 46   |
|              | 5        | 1   | B3        | 15   | 60   | 71   | 8    | 10   | 12   | 38   | 44   | 51   |

LS1, LS2 and LS3 were higher for B1 than for B2 while all the three leaf sizes for B3 was lower than for B2 as shown in the data from Table 7. Block B1 had more number of leaves in
the plants sampled more than block B2. The number of leaves in every plant sampled in block B3 was more than in block B2. Maize had a higher height in block B1 than in Block B2 whereas the same case was observed for block B3. This was also depicted in the line graphs in Appendix 2.

4.1.6 Onions

Onions are widely grown across a range of climates but thrive best when temperatures are cool during early development and then warmer and sunny during maturity. They are easy to grow because of their hardiness.

Leaf sizes, the number of leaves and the plant height from all the three blocks were compared and the results of the comparison are as in Table 8.

<table>
<thead>
<tr>
<th>Crop variety</th>
<th>Plant ID</th>
<th>rep</th>
<th>Treatment</th>
<th>PH_1</th>
<th>PH_2</th>
<th>PH_3</th>
<th>NL_1</th>
<th>NL_2</th>
<th>NL_3</th>
<th>LS_1</th>
<th>LS_2</th>
<th>LS_3</th>
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</table>

From Table 8, the data showed that LS1, LS2 and LS3 were all higher for both block B1 and B3 as compared to B2. The number of leaves was more on the plants sampled in block B1 than those sampled in block B2. The same case was observed for plants sampled from block B3. The sampled plants had a longer height in both blocks B1 and B3 as compared to the plants in block B2. As well illustrated in Appendix 2.

4.1.7 Spinach

Spinach grows most quickly in soils rich in organic matter and that are well-drained. It grows fast and produces many leaves in a short time. The seedlings were first planted in a nursery and then transplanted to the main field after 6 weeks. Harvesting is done when the leaves are mature by plucking the leaves and it was done at 3 different times.

Leaf sizes, the number of leaves and the plant height from all the three blocks were compared and the results of the comparison are as in Table 9.
Table 9: Comparison of PH, NL and LS of Spinach from the three different blocks

<table>
<thead>
<tr>
<th>Crop variety</th>
<th>Plant_ID</th>
<th>rep</th>
<th>Treatment</th>
<th>PH_1</th>
<th>PH_2</th>
<th>PH_3</th>
<th>NL_1</th>
<th>NL_2</th>
<th>NL_3</th>
<th>LS_1</th>
<th>LS_2</th>
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</tbody>
</table>

LS1, LS2 and LS3 were higher for both B1 and B3 as compared to B2 as shown in Table 10. More number of leaves were observed from the plants that were sampled both from block B1 and B3 as compared to the plants in block B2. The plants sampled had a higher height in both block B1 and B3 as compared to block B2. The line graphs in Appendix 2 clearly represented data from Table 9.

4.1.8 Factors Affecting the above Parameters of Growth

4.1.8.1 Soil Moisture

Water is essential for all living organisms. Brown (1977) reported that water availability is an important environmental factor that can limit growth and survival of plants. Water deficits develop in plant tissues when the rate of transpiration exceeds that of water absorption. Increasing the soil moisture leads to an increase in the surface area of the leaf. In some plants the increase in leaf size results from multiplication of cells only, while in other plants both cell size and cell number leads to a larger leaf surface area (Melchers, 2013). In the three different block treatments (Bio fertilizer B1, Control B2, and Synthetic block B3) the bio fertilizer block had the highest leaf size as compared to the control block. This can be due to the fact that the total number of cells per leaf and the cell size must have been considerably greater in the plants that were in the bio fertilizer block. The other factor that could have led to this was that the nutrient ratio of the bio fertilizer block was higher than that of the control block.

4.1.8.2 Temperature

Researchers have recognized the importance of temperature in influencing growth and development of plants (Haferkamp, 1988). Larcher (1980) stated that for life, sufficient amount of light is a basic prerequisite for life. The optimum warmth for growth ranges from 20°C to 25°C.
for most crops. Growth rate drops rapidly as the temperature decreases. Cold temperature leads
to a delay in initiation of growth since the duration of daily photosynthesis is reduced.

4.1.8.3 Light
The supply of light to growing crops is very essential for plant growth since cloud cover causes
the only serious variation in light climate at any point on the surface of the earth (Harper, 1977).
Light varies in quality and intensity in both daily and annual cycles. Solar radiation capture by
individual plants depends on several factors including leaf size among others (Risser, 1985).

4.1.8.4 Nutrients
The amount of nutrients available in the soil is a main determinant factor for plant growth.
Among the various important nutrients limiting plant growth is nitrogen. It is well known that
there are 16 essential plant nutrients that are required for proper crop growth. The nutrients can
be classified into primary, secondary and micro-nutrients depending on their functions. The
primary nutrients are Nitrogen, Phosphorus and Potassium. They are required in great quanti-
ties by plants. Secondary nutrients are Calcium, Magnesium and Sulphur and are less required
than the primary nutrients. Micro-nutrients are Boron, Chlorine, Copper, Iron, Manganese,
Molybdenum and Zinc. They are used in very small amounts, but are just as important to plant
development as the major nutrients. Rapid increase in the height of a plant and an increase in
the number of leaves is an indication of enhanced nutrient intake (Oseni et al., 2010).

4.2 Comparison of the Nutritional value of Bio-fertilizer, Nil Fertilizer and Synthetic
Fertilizer on Soil Nutrient Quality
The nutritional values were compared as shown in Table 3 whereby the levels of P and K in
B1 increased after addition of bio fertilizer as compared to block B2. This is in agreement with
the findings by Oenema and Tamminga, 2005, who found out that animals excrete high pro-
portions of these nutrients as they don’t utilize them efficiently even though all forms of plant,
bacterial life and animals require micro-nutrients for survival. Animal manures and slurries are
rich in plant nutrients which is also the case for bio fertilizer, making it valuable (Lukehurst et
al, 2010).
Table 10 Soil nutrient analysis for Bio-fertilizer, Control and the Synthetic Blocks

<table>
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<th>B 1</th>
<th>B 2</th>
<th>B 3</th>
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<td>17.90</td>
<td>High</td>
<td>16.30</td>
</tr>
<tr>
<td>Magnesium me%</td>
<td>4.86</td>
<td>High</td>
<td>4.48</td>
</tr>
<tr>
<td>Manganese me%</td>
<td>2.00</td>
<td>Adequate</td>
<td>1.76</td>
</tr>
<tr>
<td>Copper ppm</td>
<td>4.14</td>
<td>Adequate</td>
<td>3.70</td>
</tr>
<tr>
<td>Iron ppm</td>
<td>90.20</td>
<td>Adequate</td>
<td>85.80</td>
</tr>
<tr>
<td>Zinc ppm</td>
<td>7.50</td>
<td>Adequate</td>
<td>5.30</td>
</tr>
<tr>
<td>Sodium me%</td>
<td>1.55</td>
<td>Adequate</td>
<td>0.97</td>
</tr>
</tbody>
</table>

B1- Bio-fertilizer Block

B2- Control/nil fertilizer Block

B3- Synthetic/ Inorganic fertilizer Block

From Table 3, it can be deduced that the addition of both bio fertilizer and synthetic fertilizer in the respective blocks caused a slight increase of the different essential nutrients as illustrated, though the increase of the nutrients in B1 was more significant as compared to the increase in B3. For instance, the level of Phosphorus increased from 70 ppm to 85 ppm in B1 as compared to B3 which had only 25 ppm. Also the level of Iron in B1 was significantly higher than the synthetic block (B3). But the total organic carbon reduced in both blocks (B1 and B3) as compared to initially when the soil had not been added anything (B2). Apart from the fact that the total Nitrogen % was relatively low than the recommended, all the other nutrients were either high or adequate in the soil.

Möller and Müller (2012) showed in a literature review that the Nitrogen uptake after application of bio-slurries was lower than that after application with the same amount of N via mineral fertilizer. Thus, it can be concluded that the availability of Nitrogen in bio-slurry is lower than that in mineral fertilizer, because part of the Nitrogen is present as organic N (Bonten et al, 2014). In general, the value of bio-slurry as fertilizer is fairly high, because the nutrients are in a readily available form unlike in mineral fertilizers (Bonten et al, 2014).

From the above observations, we can conclude that the level of nutrients in digestate from the biogas plants was relatively high and also that they were well absorbed in the soil. The addition of the digestate led to the increase of nutrients in the soil. As for the addition of synthetic
fertilizer, it also led to the slight increase in nutrients in the soil though it also led to reduction of some, for example Iron. But the increase in nutrient level in B3 was not highly significant than that of B1. Thus in conclusion, we can comfortably say that the digestate was very rich in minerals hence it was readily absorbed by plants from the soil.

4.3 Comparison of Crop Yields between the Three Blocks (B1, B2 and B3)
Organic agricultural practices aim to produce better crop yields which are economically sustainable while conserving the ecosystem at the same time (Samman et al, 2008). Organic fertilizers have been considered as valuable input to agriculture as it is known to increase crop yields. Appropriate use of animal manure according to each farm’s requirements while enhancing soil quality and maximizing farm profits relates to manure management (Akbari et al, 2011).

According to the Charts below, the yields of crops in B1 (bio fertilizer block) were high than the other blocks. If we take for instance Kales, B1 had 310 kgs, B2 had 199 kgs while B3 had 150 kgs showing that the yield was high for B1 than for B2 by 106.6%. B3 was higher than B2 by only 32.7%. On average all the 7 crops had higher yields in B1 followed by B3 and lastly by B2. The comparison proved that the bio fertilizer block had better yields as compared to the synthetic block.

This demonstrated that bio fertilizer has the ability or rather the potential of increasing the crop yields by a wider margin than synthetic fertilizer. This could be due to the uptake of readily available nutrients. This was also reported by Tiwari and Parihar (1992), (Ramesh et al, 1999), (Gorttapah et al, 2000), (Saeed et al, 2002), who concluded that organic manure alone or in combination with synthetic fertilizers significantly increased yields against control. Bio fertilizers not only provide nitrogen, but also produces a variety of growth-promoting substances that enhance plant growth (Wu et al., 2005).
Figure 2  Chart on Yields of Cabbages, Kales, Spinach and Onions from Blocks B1, B2 and B3

Figure 3 Chart on Yields of Maize, Field beans and French beans from Blocks B1, B2 and B3

4.4  Comparison of Nutrient Content of Plant Tissues between the three Blocks

Plant samples from all the three blocks were taken for tissue analysis in order to determine the amount of nutrients in the plants for purposes of comparison. It was demonstrated that the plant
samples that were in B1 had more nutrients as compared to that of B2 and B3 as shown in Tables’ 11 through 15.

Analysis was done to find out the nutrient content of the cabbages sampled. The results were then tabulated on a table as below.

**Table 11: Plant Tissue analysis of Cabbage Samples**

<table>
<thead>
<tr>
<th>Analytical data (Test results)</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab No/2016</td>
<td>68</td>
<td>69</td>
<td>70</td>
</tr>
<tr>
<td>Nitrogen%</td>
<td>2.80</td>
<td>1.75</td>
<td>2.45</td>
</tr>
<tr>
<td>Phosphorus%</td>
<td>5.14</td>
<td>5.32</td>
<td>4.45</td>
</tr>
<tr>
<td>Potassium%</td>
<td>2.93</td>
<td>2.33</td>
<td>2.33</td>
</tr>
<tr>
<td>Calcium%</td>
<td>2.65</td>
<td>2.78</td>
<td>4.78</td>
</tr>
<tr>
<td>Magnesium%</td>
<td>0.15</td>
<td>0.11</td>
<td>0.12</td>
</tr>
<tr>
<td>Iron mg/kg</td>
<td>228</td>
<td>157</td>
<td>135</td>
</tr>
<tr>
<td>Copper mg/kg</td>
<td>6.67</td>
<td>10.0</td>
<td>8.33</td>
</tr>
<tr>
<td>Manganese mg/kg</td>
<td>70.0</td>
<td>35.0</td>
<td>30.0</td>
</tr>
<tr>
<td>Zinc mg/kg</td>
<td>28.3</td>
<td>21.7</td>
<td>23.3</td>
</tr>
</tbody>
</table>

There is a very clear comparison between the crops in the different blocks. The Iron content for example was higher in B1 followed by B2 then B3. This shows that bio-fertilizer had a higher iron content than the synthetic fertilizer. The same is depicted by the Manganese content which is even double that of synthetic fertilizer.

After harvesting, some bean samples were taken from the three blocks and transported to the laboratory where they were treated for analysis of nutrient content. The results were then tabulated as shown.

**Table 12: Plant Tissue analysis of Bean Samples**

<table>
<thead>
<tr>
<th>Analytical data (Test results)</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab No/2016</td>
<td>71</td>
<td>72</td>
<td>73</td>
</tr>
<tr>
<td>Nitrogen%</td>
<td>5.95</td>
<td>3.50</td>
<td>4.90</td>
</tr>
<tr>
<td>Phosphorus%</td>
<td>5.83</td>
<td>5.60</td>
<td>5.44</td>
</tr>
<tr>
<td>Potassium%</td>
<td>1.53</td>
<td>1.43</td>
<td>1.49</td>
</tr>
<tr>
<td>Calcium%</td>
<td>0.90</td>
<td>0.71</td>
<td>0.56</td>
</tr>
<tr>
<td>Magnesium%</td>
<td>0.12</td>
<td>0.12</td>
<td>0.18</td>
</tr>
<tr>
<td>Iron mg/kg</td>
<td>250.00</td>
<td>188.00</td>
<td>208.00</td>
</tr>
<tr>
<td>Copper mg/kg</td>
<td>5.00</td>
<td>5.00</td>
<td>3.33</td>
</tr>
<tr>
<td>Manganese mg/kg</td>
<td>20.00</td>
<td>20.00</td>
<td>11.70</td>
</tr>
<tr>
<td>Zinc mg/kg</td>
<td>35.30</td>
<td>30.00</td>
<td>35.00</td>
</tr>
</tbody>
</table>
From table 12 above it can be deduced that the bean samples from the bio-fertilizer block had a higher nutrient content than the rest of the blocks. Though there was no big comparison for some of the nutrients like Zinc and Copper as they were almost the same. But in most of the nutrient values obtained the comparison came out clearly as depicted in the above table.

Onion samples were taken from each field after maturity and prepared for laboratory analysis. The results were as shown in table 13 below.

**Table 13: Plant Tissue analysis of Onion Samples**

<table>
<thead>
<tr>
<th>Sample description</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab No/2016</td>
<td>74</td>
<td>75</td>
<td>76</td>
</tr>
<tr>
<td>Nitrogen%</td>
<td>2.80</td>
<td>2.35</td>
<td>2.10</td>
</tr>
<tr>
<td>Phosphorus%</td>
<td>4.33</td>
<td>3.97</td>
<td>4.09</td>
</tr>
<tr>
<td>Potassium%</td>
<td>1.73</td>
<td>1.66</td>
<td>1.33</td>
</tr>
<tr>
<td>Calcium%</td>
<td>1.36</td>
<td>1.52</td>
<td>1.55</td>
</tr>
<tr>
<td>Magnesium%</td>
<td>0.10</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td>Iron mg/kg</td>
<td>143.00</td>
<td>165.00</td>
<td>133.00</td>
</tr>
<tr>
<td>Copper mg/kg</td>
<td>1.67</td>
<td>1.67</td>
<td>1.67</td>
</tr>
<tr>
<td>Manganese mg/kg</td>
<td>16.70</td>
<td>21.70</td>
<td>20.00</td>
</tr>
<tr>
<td>Zinc mg/kg</td>
<td>25.00</td>
<td>21.70</td>
<td>21.70</td>
</tr>
</tbody>
</table>

Bio fertilizers contain fungi and bacteria that are capable of facilitating the decomposition of complex organic material and increasing the uptake of nitrogen from the soil. The findings of (Leigh et al, 2008) indicate that the uptake of organic nitrogen is essential for plant-fungal symbiosis. This might be the reason why the plants tissues from B1 had a higher number of nutrients as compared to the other blocks.

Laboratory analysis of the maize was conducted after harvesting the dry maize in its comb and grounding them while still in the comb. This was necessary because the comb also carries nutrients that are in the maize. The results after analysis were as in table 14.

**Table 14: Plant Tissue analysis of Maize Grain Samples**

<table>
<thead>
<tr>
<th>Sample description</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab No /2016</td>
<td>1077</td>
<td>1078</td>
<td>1079</td>
</tr>
<tr>
<td>Nitrogen %</td>
<td>2.10</td>
<td>1.40</td>
<td>2.10</td>
</tr>
<tr>
<td>Phosphorus%</td>
<td>6.15</td>
<td>0.56</td>
<td>0.62</td>
</tr>
<tr>
<td>Potassium%</td>
<td>0.71</td>
<td>0.39</td>
<td>0.39</td>
</tr>
<tr>
<td>Calcium%</td>
<td>0.03</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Magnesium%</td>
<td>0.09</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>Iron mg/kg</td>
<td>447.00</td>
<td>130.00</td>
<td>222.00</td>
</tr>
<tr>
<td>Copper mg/kg</td>
<td>1.67</td>
<td>5.00</td>
<td>3.33</td>
</tr>
<tr>
<td>Manganese mg/kg</td>
<td>25.00</td>
<td>10.00</td>
<td>21.70</td>
</tr>
<tr>
<td>Zinc mg/kg</td>
<td>51.70</td>
<td>35.00</td>
<td>25.00</td>
</tr>
</tbody>
</table>
Most of the nutrients from samples in B1 were higher while some were lower. The Magnesium content in the plant tissues from B1 was higher as compared to B2 and B3 whose values were the same.

On the other hand, plant tissues from B3 had also more nutrients though the growth rate was lower. Too much synthetic fertilizer added to the soil as some farmers do may be stressful to the plants hence, may result to unfavourable fruit yield (Too Much Fertilizer Can Cause Gardening Problems, 1997).

After weight of the harvested spinach was taken, some samples from each block were taken, dried and digestion was later done for purposes of analysis. The results were then put in a table as shown below.

**Table 15: Plant Tissue analysis of Spinach Samples**

<table>
<thead>
<tr>
<th>Sample description</th>
<th>B1</th>
<th>B 2</th>
<th>B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab No /2015</td>
<td>8144</td>
<td>8148</td>
<td>8151</td>
</tr>
<tr>
<td>Nitrogen %</td>
<td>3.85</td>
<td>3.50</td>
<td>3.50</td>
</tr>
<tr>
<td>Phosphorus%</td>
<td>0.47</td>
<td>0.52</td>
<td>0.42</td>
</tr>
<tr>
<td>Potassium%</td>
<td>2.69</td>
<td>8.84</td>
<td>8.17</td>
</tr>
<tr>
<td>Calcium%</td>
<td>4.33</td>
<td>4.55</td>
<td>4.97</td>
</tr>
<tr>
<td>Magnesium%</td>
<td>1.17</td>
<td>0.99</td>
<td>1.14</td>
</tr>
<tr>
<td>Iron mg/kg</td>
<td>176.70</td>
<td>236.70</td>
<td>253.30</td>
</tr>
<tr>
<td>Copper mg/kg</td>
<td>18.30</td>
<td>15.00</td>
<td>15.00</td>
</tr>
<tr>
<td>Manganese mg/kg</td>
<td>182.00</td>
<td>203.30</td>
<td>206.70</td>
</tr>
<tr>
<td>Zinc mg/kg</td>
<td>31.70</td>
<td>36.70</td>
<td>28.70</td>
</tr>
</tbody>
</table>

The analysis showed that the nutrients in the plant samples were B1>B3>B2. Nutrients from B1 are readily available to the plants from the soil in sufficient amounts unlike in synthetic fertilizers whereby the nutrients are in complex form. Abundance of macronutrients like nitrogen together with water can promote fast vegetative growth (Relf, McDaniel and Morse, 2014).

4.5 **The Benefits of Using Bio-fertilizer as an Alternative to Inorganic Fertilizers**

Bio fertilizer refers to the use of organic substances that improve nutrients absorption as opposed to inorganic fertilizers that simply provide more nutrients. Bio fertilizers help to increase levels of nutrients like nitrogen and phosphorus, prevent diseases or provide essential elements in the soil.

The main advantage of using bio-fertilizers is that they have less negative impacts in the environment. Synthetic fertilizers are known to decrease the amount of nutrients in the soil after prolonged use thus reducing soil fertility. Unlike bio-fertilizers which neither cause any known effect either in the air nor affect water quality. In fact, it promotes aquaculture.
On the other hand synthetic fertilizers aid in the growth of plants but do not sustain the soil. Repeated applications may lead to a build-up of toxic chemicals which can eventually make their way into the plants being grown. The manufacture of synthetic fertilizers is an energy intensive process which involves the use of fossil fuels which we all know produce greenhouse gases that lead to global warming.

The crops from B1 had a higher yield than from B3 which in the market could fetch a high price. Bio fertilizer that was used came from cow waste and thus we did not have to incur costs of purchasing unlike synthetic fertilizers. They also reduce on the cost as there is no need of using pesticides. Thus bio fertilizers are more economical to use than synthetic fertilizers. As a result, they can be utilized to achieve sustainable agriculture (Saeed et al, 2015) as well as preserving the nutrient content of the soil.

4.6 **Effect of Bio fertilizers on Soil Acidity**

Soil acidity hinder crop production in many areas of the country as a result of the continuous use of inorganic substances such as NPK. Nitrogen is the main nutrient affecting soil pH, and thus determines the acidity or alkalinity of the soil depending on the type of nitrogen fertilizer used. Soil acidification due to use of phosphorus fertilizers is small due to lower amounts of this nutrient used and the lower acidification per kg phosphorus while potassium fertilizers have little or no effect on soil pH (Fertilizer Technology Research Centre, 2013). Lime is being used in Western Kenya to remedy the problem though it is not proving to be effective. According to Table 3, the pH of the soil was initially 6.22 before addition of either bio fertilizer or synthetic fertilizer. On addition of bio fertilizer to B1 the pH increased to 7.08 while on addition of synthetic fertilizer to B3, the pH reduced to 6.05. When manure decomposes anaerobically, organic solids are converted to volatile fatty acids (VFA), which are then converted to methane by the help of methanogenic microorganisms. The pH of the effluent increases during the conversion due to the consumption of protons in the process (Mölle and Müller, 2012).

An increase in soil pH has been reported from farmers that use digester effluent on their fields in the US (Penn State Institute for Energy and the Environment, 2013). The digestate pH is also affected by the concentration of base cations (e.g. Ca, K) which increase the pH. (Mölle and Müller, 2012). By properly utilizing digestate as a bio fertilizer, nutrients are retained in the soil to replace those of inorganic fertilizer (Lukehurst et al, 2010).
From the results in Table 3 and previously done research, it is observed that the continuous use of inorganic fertilizer over a long period of time leads to further soil acidity. On the other hand, bio fertilizer has the ability to increase the soil pH. Thus, in other words it reduces the soil acidity. This therefore can in turn lead to the regeneration of soils by leading to an increase in the amount of nutrients in the soil as well as the rise in soil pH.
CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS
The farm that was used for this research proved to be slightly deficient of some of the major macro-nutrients that are necessary for crop growth. This is consistent to the qualitative and quantitative results from B2 which was the block that was used as the control. Also this was a demonstrated by the soil nutrient analysis of the same block. The yield and also the plant tissue analysis showed that the soil was not efficient enough to promote plant growth to maximum level. It was also observed that the block was severally attacked by weeds and pests and thus required regular spraying and weeding to counteract the same.

On application of bio fertilizer to B1 the soil nutrient content increased as well as the yield from the same plot. This proved that bio fertilizer had readily available and sufficient amount of nutrients for uptake by plants, as was demonstrated by the plants’ leaf tissue analysis. There was no major attack by weeds and pests from this block and spraying was not necessary. As for B3, the nutrient content both in the soil and the plants slightly increased though the block required regular weeding and spraying against pests.

From this we can conclude that bio fertilizer had a higher nutritional value than synthetic fertilizer. It can also be concluded that bio fertilizer use led to a very significant increase in crop yields by 106.7% as compared to not using it, while synthetic fertilizer increase the yields by only 32.7%. This shows that there is a margin difference of 74% meaning that bio fertilizer is way better than synthetic fertilizer use when it comes to crop growth and yields.

The soil was slightly acidic before any treatment with a pH of 6.22 and it rose to 7.08 on addition of bio fertilizer, but dropped to 6.05 on application of synthetic fertilizer. It can therefore be concluded that the use of bio fertilizer can lead to an increase in soil pH thus; reduction in soil acidity will be achieved. As stated earlier, the use of bio fertilizer did not necessitate spraying against pests and labour for regular weeding as compared to the other blocks. Also, bio fertilizer was readily available for use as it didn’t require any manufacturing unlike synthetic fertilizer.
Since costs for use of bio fertilizer were greatly reduced, we can conclude that it is much economical than the use of synthetic fertilizer. Bio fertilizer is environmental friendly since it sustains the soil nutrients unlike synthetic fertilizers which lead to depletion of nutrients if continuously used and a further increase in soil acidity. Thus bio fertilizer from biogas digesters is highly efficient for regeneration of soils.

RECOMMENDATIONS

- From this research it was observed that the use of bio fertilizer led to an increase in crop growth and yield. As a result I would like to recommend farmers in Nyeri and Kenya as a whole to use bio fertilizer in order to achieve higher quality production. I would also like to recommend that:
  - To raise awareness on the use of bio fertilizer, the Government through the Ministry of Agriculture should establish demonstration fields in various regions.
  - The Ministry of Agriculture should formulate guidelines or best practices for the application of bio fertilizer in practice as bio fertilizer might be suitable for some crops than for other crops.
  - More research on ways of preventing NH₃ volatilization should be conducted; as little has been done on its reduction.
REFERENCES


APPENDICES

Appendix 1  Field Experimentation Layout

**Key:** B1 - Bio fertilizer treatment; B2 - Control treatment; B3 - Conventional/ synthetic/ chemical fertilizer treatment; C4 – Spinach; C5 - French beans; 6 – Tomatoes; C7 – Cabbage
Appendix 2  Blocks’ Parameters’ Results

1. CABBAGES

Interaction Plot for LS_1

Interaction Plot for LS_3

57
Interaction Plot for NL_3

Interaction Plot for PH_1
2. FIELD BEANS

A. LEAF SIZE (LS) COMPARISON

Interaction Plot for LS_1

Interaction Plot for LS_2
B. NUMBER OF LEAVES (NL) COMPARISON
C. PLANT HEIGHT (PH) COMPARISON
3. FRENCH BEANS

A. LEAF SIZE (LS) COMPARISON

Interaction Plot for LS_1

Interaction Plot for LS_2

Treatment

B1

B2

B3
B. **NUMBER OF LEAVES (NL) COMPARISON**
C. PLANT HEIGHT (PH) COMPARISON

Interaction Plot for PH_1

Interaction Plot for PH_2
4. **KALES**

A. **LEAF SIZE (LS) COMPARISON**
B. NUMBER OF LEAVES (NL) COMPARISON

Interaction Plot for NL_1

Interaction Plot for NL_2
C. PLANT HEIGHT (PH) COMPARISON
5. MAIZE

A. LEAF SIZE (LS) COMPARISON
B. NUMBER OF LEAVES (NL) COMPARISON
C. PLANT HEIGHT (PH) COMPARISON
6. ONIONS

A. LEAF SIZE (LS) COMPARISON
B. **NUMBER OF LEAVES (NL) COMPARISON**

![Interaction Plot for NL_1](image1)

![Interaction Plot for NL_2](image2)
C. PLANT HEIGHT (PH) COMPARISON
7. SPINACH

A. LEAF SIZE (LS) COMPARISON

Interaction Plot for LS_1

Interaction Plot for LS_2

Treatment B1 ——— B2 ———— B3
B. NUMBER OF LEAVES (NL) COMPARISON
C. PLANT HEIGHT (PH) COMPARISON

Interaction Plot for PH_1

Interaction Plot for PH_2
Interaction Plot for PH_3

PH_3

rep

Treatment

B1

B2

B3