EFFECTS OF DIFFERENT COMPOSTS ON THE PEFORMANCE OF GREEN BEANS

By

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DECLARATION

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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DEDICATION

This thesis is dedicated to my parents, Dr and Mrs Emmanuel Asamoah. God richly bless for your prayers, advice, encouragement and financial support. I am eternally grateful.

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ABSTRACT

Composting of Municipal Solid Waste (MSW) has received renewed attention as a result of increasing waste disposal cost and the environmental concerns associated with using landfills. A targeted end use of the compost is for horticultural crop production. Currently, quality standards for MSW compost are lacking and there is the need to establish them. Elevated heavy metal concentrations in MSW compost have been reported; however, through proper sorting and recycling prior to composting, contamination by heavy metals can be reduced Compost has been shown to be useful in horticultural crop production as it improves soil physical properties, such as lowering bulk density and increasing water-holding capacity. Compost enhances supply of essential nutrients to some extent. However, supplemental fertilizer, particularly N, is usually required. A pilot dry digestion composting plant was thus established on the campus of the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi by The Swiss Federal Institute of Aquatic Science and Technology (EAWAG) supported by the Zurich University of Applied Science. The setup was to assess the effectiveness of processing of organic municipal waste to obtain biogas for domestic use and digestate for the purposes of composting. The different composts obtained were then used in planting green beans (*Phaseolus vulgaris*). The aim of this work was to assess the effects of the different composts on the performance of green beans. Results of this work identified and highlighted the superiority of fertilized crops over non-fertilized ones in terms of growth and dry matter accumulation. A long term research should be carried out on the effects of prolonged use of composts produced by vermicomposting, co-composting and windrow composting on crop and soil. Public awareness on the effects of compost on soil, crop yield and environment should be intensified.

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1.0 INTRODUCTION

1.1 General background

Rapid population growth and urbanization worldwide, have led to an enormous increase in solid waste generation per unit area (Kassim & Ali, 2006). The management of specific waste streams such as biodegradable waste represents an important element of the strategy to help reduce the impact of waste on the environment. Considering the fact that the largest fraction of waste in developing countries is organic in nature and therefore amendable to anaerobic digestion, it makes environmental and economic sense to survey this option (Mbuligwe & Kassenga, 2004).

Biological treatment of biodegradable waste such as composting and anaerobic digestion (AD), has several advantages. It contributes to the reduction of greenhouse effect, as it diverts biodegradable waste from landfills where methane is produced and emitted in an uncontrolled manner to the atmosphere (Burri & Martius, 2011). When used as soil amendment in agriculture it maintains or restores soil productivity. Its humified organic matter provides a unique property of compost itself. Another promising treatment option is anaerobic digestion which produces an energy-rich biogas and digestate. The latter one can be used as a soil amendment or fertilizer for arable land.

Anaerobic digestion is a biological process where a diverse group of micro-organism convert the complex organic matter into a simple and stable end product in the absence of oxygen. This process is very attractive because it yields biogas, i.e. a mixture of methane (CH_4) and carbon dioxide (CO_2) which can be used as renewable energy source. The dry anaerobic digestion (AD) process is an innovative waste-recycling method to treat high-solid content bio-wastes. It is done at a solid concentration higher than 10%

and enables a higher volumetric organic loading rate, minimal material handling, lower energy requirements for heating, limited environmental consequences and energetically effective performance. Dry anaerobic digestion [>15% total solid (TS)] has an advantage over wet digestion (<10% TS) because it allows for the use of a smaller volume of reactor and because it reduces waste water production. Additionally, it produces a fertilizer that is easier to transport.

Soil fertility is a limiting factor to agricultural productivity in many parts of the developing world. Among the problems of tropical soils, soil acidity, characterized by low pH, excessive aluminium, deficient calcium and low organic matter are most prominent (Hue, 1992). Tropical soils are often prone to strong phosphate fixation which renders phosphorus unavailable to plant. Such soils require extremely high phosphate application in order to alleviate the effect of phosphate fixation. Soil acidity and mineral deficiencies can be corrected by applying lime and fertilizers to the soil. Unfortunately, lime and fertilizers are not always easy options available to resource-poor farmers (Hue, 1992). However it is reported that green manures and composted organic material increase soil organic matter (SOM), provides nutrients for plant growth, alleviate aluminium toxicity and render phosphorus more available to crops (Beltran *et al.*, 2002). This increased availability of phosphorus is probably caused by the reaction of organic matter-derived molecules with soil minerals (Hue, 1992).

Kumasi is a metropolis in Ghana. With an area of about 245km^2, it has been estimated to have a population of about 2 million inhabitants (Kumasi Metropolitan Assembly, 2010). The bulk of household waste was found by Salifu (1995) to be organic with an average of 55% from three residential classes, i.e. 1st, 2nd and 3rd class areas (1st class refers to the affluent households or residential areas, the 2nd class refers to middle income households and the 3rd class refers to low income households or residences). As most part of household waste from the metropolis is biodegradable organic waste, the management option which could be considered is composting or anaerobic digestion. The interests of urban waste recycling go well with the promotion of urban agriculture since urban and peri-urban farmers are in need of organic matter as soil conditioner. In a region of abundant rainfall, Kumasi possesses great potential for implementing planned organic waste collection and processing for local food production.

1.2 Problem statement

According to UNEP (2005) the rate of waste generation generally increases in direct proportion to that of a nation's advancement in development, and failure to provide a management system could result in greater environmental degradation with increase health risk to the urban population (UNEP, 2005).

In Ghana, all district, municipal and metropolitan assemblies give urban sanitation and waste management a priority in their development objectives. However, their ability to contain the problems of waste management is declining, because of rising capital cost for plant and equipment, increasing operation and maintenance cost, the rapid spatial and population growth of most urban areas with decreasing coverage levels, and increase in levels of waste generated, confronted by increasing public demand for improved services (Salifu, 1995).

Due to Kumasi's inability to handle SWM adequately, it has been supported largely in the delivery of environmental sanitation services over the past decade by central government/external donor interventions. However, as with other infrastructure and service sectors, the overuse of equipment and facilities to terminal ruin is the practice (Salifu, 1995). A pilot dry digestion composting plant was thus established on the campus of the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi by The Swiss Federal Institute of Aquatic Science and Technology (EAWAG) supported by the Zurich University of Applied Science. The aim of this setup was to assess the effectiveness of processing of organic municipal waste. The primary purpose was to obtain biogas for domestic use. One of the potential benefits of the produced digestate is its potential to be used for the purpose of composting. The produced digestate thus had to be evaluated in terms of its agronomic potential and benefits. This is what necessitated this study which seeks to evaluate and compare the effects of using the fresh and post-treated (composted) digestates for crop production.

1.3 Justification

Agricultural systems produce organic wastes for which the soil has the capacity to assimilate as well as waste from different sources (Soliva, 1994, Soliva & Felipo, 2003). The proper management of organic waste through soil management could lead to economic and environmental benefits which contribute to sustainable development. It is therefore necessary to take into account conservation and crop nutritional needs when dealing with agro-waste.

1.4 Objectives

The main objective of the study was to assess the impact of unprocessed and composted digestate from dry fermentation as an alternative to synthetic fertilizers on green beans yield.

The specific objectives of the study were to:

1. Compare the effects of different unprocessed and composted digestates on growth parameters of green beans.

2. Compare the effects of different unprocessed and composted digestates on biomass and nutrient levels of green beans.

1.5 Research questions

1. What are the effects of different unprocessed and composted digestates on growth parameters of green beans?

2. What are the effects of different unprocessed and composted digestates on biomass and nutrient levels of green beans?

1.6 Significance

The project offers a sustainable approach to management of municipal organic waste. Large scale recycling of waste will largely reduce waste sent to the landfills by a significant percentage.

It also offers the most successful example for which the concept of peri-urban agriculture can be used as a response to food shortage, not only by individual residents but also as a government-supported strategy.

If an integrated approach is adopted it will help to avoid many of the problems associated with urban farming in other cities. For example, the use of the digestate instead of toxic agricultural chemicals which results in environmental degradation, especially groundwater pollution, can be limited and this can become an important component in urban development.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter presents a preview of literature significant in answering the research questions. The review is carried out in a systematic manner with references made to empirical research carried out on the subject matter. Evidence presented in the review includes information in research articles in journals, online journals, abstracts, books as well as relevant publications.

2.2 Origins and definitions

Any substance which constitutes a scrap material or an effluent or other surplus substance arising from the application of any process is defined as waste. Any substance or article which requires to be disposed of as being broken, worn out contaminated or otherwise spoiled, but does not include a substance which is explosive is defined as waste (Environmental Protection Agency Act of UK, 1990). Municipal solid waste (MSW) management issues have become core on the public agenda. Concerns and activity by citizens and governments worldwide have reached unprecedented levels. New waste management techniques are being developed in response to this situation, but many are in their infant stages of which several are not proving to be economic (Shen, 1998). The Journal of Environmental Management defines solid waste to encompass the heterogeneous mass throwaways from the urban community as well as the homogeneous accumulations of agricultural, industrial and mineral wastes. The Concise Oxford Dictionary also defines waste as a by-product of human activity. Waste differs from useful production only by its lack of value.

2.3 Waste management

Rapid increase in population all over the world, coupled with the increasing growth of commerce and trades has increased solid waste generation at rapid rates. Solid waste management is defined as the application of techniques to ensure orderly execution of the various functions of collection, transport, processing, treatment and disposal of solid waste (Robinson, 1986). There are agricultural, industrial, civic amenity, household, commercial and sewage wastes, but for this work only municipal solid waste (MSW) will be discussed, where household and commercial wastes are grouped together.

In much of the developed world, municipal solid waste management has evolved from primitive origins through the development of open dumps to the sophisticated collection and disposal systems that are in use today. In England the Public Health Act of 1875 made it a law that all domestic refuse should be kept within a dustbin which would be emptied by the relevant local authority at least once per week.

In India, solid waste management (SWM) is a function obligatory on the urban local body (ULB). The services of this body have however been found to be largely unsatisfactory due to the financial constraints, institutional weakness, improper technology and lack of infrastructure (Barman *et al.*, 1999). In recent years municipal bodies in India are gradually divesting themselves of their direct roles in provision of solid waste management, moving towards public private partnership as a new solution to their inability to handle conservancy operation effectively.

Cairo is a city of eight to eleven million people with an infrastructure capacity for two million people. Issues of air pollution, dirty streets, crumbling buildings, inadequate water and waste-water services are common. The city has no publicly organized domestic solid waste disposal system. The solid household waste is almost entirely 'digested' within the city in a manner contrary to the one-way flow of materials.

The Republic of Ghana is home to 22 million residents. Accra, the nation's capital serves as the economic, administrative, and cultural centre of the country. Its geographical position has allowed it to function as a natural port to the Atlantic Ocean, which has in turn made it an important destination point for a number of Ghanaian trading industries. It covers an area of approximately 65 square miles. It houses a full 18% of the total Ghanaian population and 30% of the country's urban population (Carboo & Fobil, 2004). Unlike the towns and villages spread throughout the majority of the countryside, Accra is a veritable urban Mecca for labor-seeking residents from all over Ghana. Half of Accra lives below the World Bank's absolute poverty threshold of little less than a dollar a day (Thompson, 2010). Still, for the past two decades this city of roughly 4 million inhabitants has had an annual growth rate of 4% making it one of the fastest growing metropolises in Africa. This phenomenal growth has contributed to municipal waste production that far outstrips the city's capacity for containment and processing.

Ghana has waste management difficulties that extend from the cities to the villages, and refuse of all shapes and sizes is a common site in both urban and rural areas. These difficulties are concentrated and complicated by population pressures in the few heavily populated cities of which Accra is the most prominent. Inequality features heavily in the capital. Eighty percent of the city population lives in low income, high density population areas. The middle class is occupied by 17% of the population. Only 3% of Accra lives in high income, low density residential areas. The sanitary infrastructure of Accra is reflective of the income divisions. Only 30% of all houses have toilets that actually flush. Only one in every five houses has functioning indoor plumbing. The public latrines that have been built to accommodate these disparities are overused and often shared by 10 or more people (Boadi & Kuitunene, 2003).

The confluence of poor governance and human factors, such as indiscriminate dumping, has resulted in a city environment characterized by choked drains, clogged gutters, and garbage piles heaped in the open (Hardoy *et al.*, 1993).

All these examples cited above are a clear description of the state of solid waste management in certain major cities worldwide

2.3.1 Municipal solid waste

Municipal solid waste accounts for only a relatively small fraction of total global waste production, yet it is the most visible element of solid waste for both the waste producer and authorities charged with its safe management. MSW is predominantly comprised of post-consumer waste produced by individual households (Gandy, 1993). Municipal waste generation in the European Union amounts to more than 300kg per person per annum, whilst in the United States of America the figure is closer to 850kg per person per annum (White *et al.*, 1995). The problem of what to do with the waste generated has become an important political issue throughout Europe and the world for that matter (Read *et al.*, 1996). Burning of dumps is also common in peri-urban and rural communities in Ghana and in many other less developed countries. A study carried out in Ado-Akiti in Nigeria by Momoh and Oladebeye (2010) showed that, the methods of solid waste disposal include dumping of waste in gutters, drains, by roadside, unauthorized dumping sites and stream channels during raining season and burning of wastes on unapproved dumping sites during the dry season.

2.3.2 Waste generation and disposal

Accra, the capital city and Kumasi the second largest city in Ghana, combine to generate about 3,000 tonnes of solid waste daily (Mensa & Larbi, 2005). According to the Mayor of Kumasi Metropolitan Assembly, the city of Kumasi in 2009 generated an average of 1,500 tonnes of solid waste daily with an estimated population of about 2 million people. Out of this amount the KMA is only able to collect about 1,300 tonnes leaving the remaining 200 tonnes uncollected due to inadequate waste collection logistics (KMA, 2010).The manufacturing industry, construction and demolition, mining, quarrying and agriculture are the main sectors that contribute to waste generation in Kumasi (Sarpong, 2009).

Cities are often generators of huge quantities of waste due to larger population and higher concentration of industrial and commercial activities. As cities grow economically as well as spatially, the per capita waste generation also increases (Hornweg *et al.*, 1999). In many cities worldwide, for example Kampur in India, there are no sanitary landfills. Waste is simply dumped at the designated sites (with or without compaction) where no soil cover is used, no visual or environmental barriers and no provision for leachate checking exists.

2.3.3 Landfilling

The traditional attractions of landfilling as a means of waste disposal are that it is both inexpensive and suitable for a wide range of waste materials. In addition, landfill gas is a clean source of fuel and the restored land provides valuable space for leisure activities or habitats for wildlife (Croners, 1994). On the downside, landfill can pose significant risks, including the release of methane gas, and noise, odour and unsightliness, as well as heavy vehicles causing a nuisance. It is difficult to recover energy from landfill sites and there is a finite risk of contamination. In addition, due to the versatility of the landfill and its convenience, it is less attractive for waste producers to be innovative in their methods of dealing with their wastes.

The increasing production of bio solid wastes such as composts, sewage sludge or municipal solid wastes highlights the need for their recycling in terms of environmental and economic impacts. Amendment to soil is the main means to recycle such wastes through soil-plant systems. Compost amendment to soil is often viewed as a way to improve soil fertility and physical structure, particularly because it can contribute to the stabilization of the aggregate framework which reduces runoff and erosion processes (Bresson *et al.*, 2001; Barzegar *et al.*, 2002), and it increases the amounts of soil organic carbon and of other major nutrients such as N and P (Filcheva & Tsadilas, 2002). Compost amendment is also used to stimulate the soil micro flora, particularly in degraded and arid environments (Ouedraogo *et al.*, 2001; Ros *et al.*, 2003), and to suppress pathogens through antagonistic effects. Adverse effects of compost amendment can also occur, such as altering the microbial biomass and diversity due to the presence of organic and inorganic contaminants (Gomez, 1998; Zheljazkov & Warman, 2003). However, the response of the microbial community is generally transient, and varies greatly with the nature of the organic amendments (Pascual *et al.*, 1999; Garcia-Gil *et al.*, 2000) and the level of compost application (Albiach *et al.*, 2000).

2.4 Origin and chemical content of Digestate

2.4.1 Origins and definitions

Digestate is the by-product of methane and heat production in a biogas plant, coming from organic wastes. Depending on the biogas technology, the digestate could be a solid or a liquid material. Digestate contains a high proportion of mineral nitrogen

(N) especially in the form of ammonium which is available for plants. Moreover, it contains other macro- and microelements necessary for plant growth. Therefore the digestate can be a useful source of plant nutrients; it seems to be an effective fertilizer for crops. On the other hand, the organic fractions of digestate can contribute to soil organic matter (SOM) turnover, influencing the biological, chemical and physical soil characteristics as a soil amendment material. Besides these favourable effects of digestate, there are new researches to use it as solid fuel or in the process of methane production. In an AD process, different organic materials could be used alone or in mixture with animal slurries and stable wastes, offal from slaughterhouse, energy crops, and cover crops and other field residues, organic fraction of municipal solid wastes (OFMSW) and sewage sludge. The quality of digestate as a fertilizer or amendment depends not only on the ingestates but also on the retention time. The longer retention time results in less organic material content of the digestate because of the more effective methanogenesis (Szűcs *et al.*, 2006).

Biogas technology is known to destroy pathogens. The thermophilic AD increases the rate of elimination of pathogenic bacteria, therefore the amounts of fecal coliforms and enterococcus fulfilled the requirements of EU for hygienic indicators (Paavola & Rintala, 2008). Mesophilic digestion alone may not be adequate for correct hygienization. It needs a separate treatment (70 ºC, 60 min., particle size<12 mm) before or after digestion, especially in the case of animal by-products (Bendixen, 1999; Sahlström, 2003).

Two types of digestate are the liquid and the solid ones which are distinguished on the bases of their dry matter (DM) content. The liquid digestate contains less than 15% DM content, while the solid digestate contains more than 15% DM. Solid digestate can be used similar to the composts or could be composted with other organic residues and can be more economically transported over greater distances than the liquid material (Møller *et al.*, 2000).

2.4.2 Composition of digestate

The quality of a digestate is determined by the digestion process used and the composition of ingestates. Therefore, the agricultural use and efficacy of the nascent materials could be different. Nevertheless, some common rules can be found in the course of the digestion process which allow for evaluation of the results of a digestion process.

2.4.3 pH of digestate

Generally, the pH of digestate is alkaline (Table 1). Increases in pH values in the course of the AD may have been caused by the formation of $(NH_4)_2CO_3$ (Georgacakis *et al.*, 1992).The pH is increased under the digesting process, but its range depends on the quality of ingestate and the digestion process. The end values are irrespective of the starting value. The alkaline pH of digestate is a useful property because of the worldwide problem of soil acidification.

Table 1. Changes of the pH at different stages of the digestion system

Type of Ingestate	Type of digestion Process	pH of ingestate	pH of intermediary stage	pH of digestate	Source of data
Pharmaceutical industry sludge	Mesophilic, solid type digester	7.0	7.5	7.8	*Gómez et al., 2007*
Cattle manure	Mesophilic, liquid type digester	6.9	7.2	7.6	
Primary sludge from municipal waste water treatment plant and organic fractions of municipal solid wastes	thermophilic (co-digestion), liquid type digester	3.5	5.0	7.5	
Energy crops, cow manure slurry and agro-industrial waste	thermophilic (co-digestion), liquid type digester	4.8	7.5	8.7	*Pognani et al., 2009*
Energy crops, cow manure slurry, agro-industrial waste and OFMSW	thermophilic (co-digestion), liquid type digester	4.0	8.1	8.3	

2.4.4 Macro element content of digestate

Nitrogen (N) is a major plant nutrient and is the most common plant growth limiting factor of agricultural crops. The fertilizing effect of added N is decreased by the inadequate synchrony of crop N demand and soil N supply (Binder *et al.*, 1996; Möller & Stinner, 2009).

The advantage of digestate application is the possibility of reallocation of the nutrients within the crop rotation from autumn to spring, when crop nutrient demand arises (Möller *et al.*, 2008). The higher N content of a digestate compared to the composts is the consequence of the N concentration effect because of carbon degradation to CO_2 and CH_4 and N preservation during AD (Tambone *et al.*, 2009).

The NH_4 content of the digestate is about 60-80% of its total N content, but Furukawa and Hasegawa (2006) reported 99% of NH_4-N of the digestate originated from kitchen food wastes. Generally, the NH_4-N concentration is increased by the protein-rich feedstock (Kryvoruchko *et al.*, 2009) like diary by-products and slaughterhouse waste (Menardo *et al.*, 2011). The conversion of organic N to NH_4-N allows its immediate utilization by crops (Hobson & Wheatley, 1992). The higher amount of NH_4-N and the higher pH predominate over the factors (lower viscosity, lower dry matter content) which could reduce the ammonia volatilization from the digestate (Möller & Stinner, 2009). The emission of ammonia could be decreased by different injection techniques which lower the air velocity above the digestate and because of the bound of gaseous ammonia to soil colloids and soil water (McDowell & Smith, 1958). The application depth has a significant effect on ammonia volatilization. Surface application of a liquid bio-fertilizer caused the loss of 20-35% of the applied total ammoniacal N while disc coulter injection into 5-7 cm depth reduced the ammoniacal loss to 2-3% (Nyord *et al.*, 2008). This method should be used also in the case of digestate application to reduce ammonia volatilization. Digestate has higher phosphorus (P) and potassium (K) concentration than that of composts (Tambone *et al.*, 2010) therefore it is more suitable for supplement of these missing macronutrients in soils. Assessment of compost maturity is important for successful use of composts in agricultural and horticultural production.

2.4.5 Micro element content of digestate

Plants, animals and humans require trace amounts of some heavy metals like copper (Cu) and zinc (Zn), while others like cadmium (Cd), chromium (Cr), mercury (Hg) and lead (Pb) are toxic for them. Heavy metal content of the feedstock usually originates from anthropogenic source and is not degraded during AD. The main origins of the heavy metals are animal feed additives, food processing industry, flotation sludge, fat residues and domestic sewage.

With a N load of 150 kg ha^{-1}, the heavy metals load into the soil (Cd, Cr, Cu, Ni, Pb, Zn) were lower in the case of digestate addition as compared to the compost and sewage sludge treatments. They were however higher in concentration of some heavy metals (Cu, Ni, Pb, and Zn) compared to the mineral fertilizer (Pfundtner, 2002).

2.4.6 Organic matter content of digestate

The amounts of organic dry matter and the carbon content of digestate are decreased by the decomposition of easily degradable carbon compounds in the digesters (Stinner *et al.*, 2008). If the organic loading rate of biogas plant is high and the hydraulic retention time is short, the digestate will contain a considerable amount of undigested organic matter (OM), which is not economic and does not result in a good amendment material. However, the OM content of digestate is more recalcitrant and therefore the microbial degradation and soil oxygen consumption can be decreased by its application (Kirchmann & Bernal, 1997).

2.5 Effects of digestate on soil properties

Digestate is a very complex material therefore its use has effect on a wide range of physical, chemical and biological properties of the soil, depending on the soil types (Makádi *et al.*, 2008). The recycled organic wastes are suitable for contribution to maintain the soil nutrient levels and soil fertility (Tambone *et al.*, 2007). Among the organic amendments the ratio of liquid digestate in agriculture is known to be around 10%. It can be applied as a fertilizer, but it could be appropriate as a soil quality amendment (Schleiss & Barth, 2008).

2.5.1 Effect of digestate on soil pH

Odlare *et al*. (2008) did not find significant change in the pH after a 4-year-long biogas residue application rate. The pH of the soil was 5.6 and 5.7 in the control and biogas residue treated samples, respectively. Similar results were reported by Fuchs & Schleiss (2008), because they found an enhancement of soil pH for about ½ units after harvesting of maize.

Because of the alkaline pH of digestates, an increase of the soil pH should be supposed. However, digestate might contain various acidic compounds (e.g. gallic acid). The poly-condensation, connection to organic and inorganic colloids and transformation of these acids can have an effect also on the soil chemical properties and finally the decrease of soil pH (Tombácz *et al.*, 1998, 1999), more particularly at the soils with high organic and inorganic colloid contents. There was no significant difference in pH, OM and T-N content during the sampling periods. In case of exchangeable potassium, its content in soil after harvesting increased with the amount of co-digestate applied. For feeding stock of additive, including copper and zinc which are essential elements for co-enzyme, it was considered that the high application rate of co-digestate combined with pig manure resulted in the accumulation of copper and zinc in soil. Other heavy metals, however, were not related with the rate of co-digestate application. Therefore the regular monitoring of soil pH is necessary in case of long-term digestate application.

2.5.2 Effect of digestate on soil macro element content

One of the main problems of digestate (and other N fertilizer) application is the N leaching. However, Renger & Wessolek (1992) and Knudsen *et al*. (2006) found that the N leaching was dependent on the use of cover crops. Similar results were reported by Möller & Stinner (2009) who did not find differences in the soil mineral N content among different manuring systems in the case of winter wheat, rye and spelt in autumn, before use of cover crops. That means that the use of cover crops is an appropriate method to avoid N leaching and to compensate for higher N application. From the same experiment, Möller *et al*. (2008) reported average soil mineral N content in spring. In this case they found significant higher soil mineral N content of the digested slurry treated samples.

Digestate contains high proportion of NH_4-N; therefore it would be expected to increase NH_4-N content of treated soil. However, digestate applied in the fall could easily be nitrified by early spring (Rochette *et al.*, 2004; Loria *et al.*, 2007).

Generally, the digestate application does not cause any significant changes in the total-N and available P content, while the available K content was increased by the application of biogas residue. Vágó *et al*. (2009) found similar results and reported the significant increase of 0.01 M dm^{-3} $CaCl_2$ extractable P content even after 5 L m^{-2}digestate treatment, while the K content of soil was significantly increased by 10 L m^{-2}digestate dose only.

2.5.3 Effect of digestate on soil microelement

After the application of the digestate in 5 and 10 L ha^{-1} dosages, the Cd, Co, Cu, Ni and Sr content of soil solutions did not change. The Zn content decreased significantly, while the amount of manganese (Mn) increased by almost 40% (Vágó *et al.*, 2009). The increasing soluble P content of digestate treated soil decreased the available Zn content in the soil solution by building slightly soluble zinc-phosphate residue (Vágó *et al.*, 2009).

2.5.4 Effect of digestate on soil organic matter content

Digestate contains high amount of volatile fatty acid (C2-C5) which could be decomposed within few days in the soil (Kirchmann & Lundwall, 1993). The greatest rate of decomposition were observed in the first day after the treatment (Marcato *et al.*, 2008) but the mineralization rate were high during the first 30 days (Plaza *et al.*, 2007). Moreover, the C-mineralization values from the soil incubation assay showed that the results of raw slurry were similar to the effect of compost being in the start of composting process while the digested slurry had similar C-mineralization rate in the soil samples than that of the matured compost (Marcato *et al.*, 2008).

2.5.5 Effect of digestate on the microbiological activity of soil

Soil microbial community has an important role in the fertility of soil and its alteration after intervention to the soil (e.g. manuring, soil improving, and soil pollution) could be an indication of how sensitive these are to changes in the soil physical and chemical properties of the soil.

Among the different organic wastes like compost, biogas residue, sewage sludge and different manures with and without mineral N, the biogas residue was more efficient for promoting the soil microbiological activity. The high amount of easy-degradable carbon increased the substrate induced respiration (SIR), which was enhanced by the higher carbon content resulting from the higher litter and root exudates of higher plant growth. In accordance with these results, the largest proportion of active microorganisms was found in the digestate treated samples (Odlare *et al.*, 2008; Kirchmann, 1991). Similarly, the activity of invertase was significantly higher in the digestate treated samples than that in control ones.

Besides the macro- and micronutrient content of digestate which are important not for the crops but for soil microorganisms too, it contains growth promoters and hormones, also.

Therefore it could be used as stubble remains to facilitate their decomposing. Makádi *et al*. (2007) compared the effect of digestate and Phylazonit MC bacterial manure on the growth of silage maize (*Zea mays* L. 'Coralba') as a second crop after winter wheat and on the enzyme activities of soil. Digestate was used at the rate of 50% of the total N demand of silage maize while the Phylazonit MC was used at 5 L ha^{-1} dose.

The maximum of the degradation of disaccharides, indicated by the invertase activity, was found in the 3rd week after Phylazonit MC Treatment, while it was found only after the 9^{th} week in the digestate treated soil samples. The Phylazonit MC contains only bacteria and promoting agents of bacterial activity for degrading the soil OM. Contrarily, in the digestate treated samples the degradation of disaccharides takes place at similar rate through 9 weeks because of the OM content of digestate used. Changes in catalase activity indicate the effect of nutrient content of digestate to the increasing microbial metabolism.

2.5.6 Effects of digestate on crop yield

On the basis of the plant reaction to the digestate treatment, plants could be classified into sensitive (alfalfa, sunflower, and soybean) and non-sensitive (winter wheat, triticale, sweet corn, silage maize) groups. The sensitive plants can be treated by digestate only in certain life stages, for example, young alfalfa is very sensitive after sowing while old alfalfa is very sensitive before cutting. In the case of sensitive plants the burning effect of digestate can be observed but it follows a strong and quick recovering process. For the non-sensitive plants the digestate can be used in any developmental stage of the plant (Makádi *et al.*, 2008).

The right application rate of liquid or solid digestate depends on the plant nitrogen demand.

It should be applied when plant N demand arises. The period for non-legume species is the late winter and spring (Stinner *et al.*, 2008). Similarly, Wulf *et al.* (2006) used 70% of the digestate in spring and 30% in autumn, while Makádi *et al.* (2008) and Nyord *et al.* (2008) split into two and three the applied rate through the vegetation period.

The effectiveness of a digestate depends on the composition of co-digested material, the treated plant species and the treatment methodology. Co-digestion of different organic materials results in more effective digestate. (Möller *et al.*, 2008; Stinner *et al.*, 2008).

2.5.7 Effects of digestate on the quality of crops

Crop yield is a very important economic parameter of plant production but nowadays the quality of food is becoming more and more important. Digestate treatment seems to be very effective to increase the protein content of plants. Banik and Nandi (2004) investigated biogas residual slurry manures (solid digestate) used as supplement with rice straw for preparation of mushroom beds. The application of bio manure increased the protein content of mushroom from 38.3 to 57.0%, while the carbohydrate concentrations were decreased.

Similar results were reported by Makádi *et al.* (2008b) who found significant increase of protein content of treated soybean. They have found 30.65±1.42% protein in control plants, while these values were 34.83±1.50% and 35.67±1.81% for 5 and 10 L m^{-2} treatments, respectively. Changes in amino acid composition of test plants were also very favourable, because almost every essential and non-essential amino acid quantity increased significantly after digestate treatment. In line with these results the oil content of the treated plants decreased significantly.

Qi *et al*. (2005) examined the effect of fermented waste as organic manure on cucumber and tomato production in North China. Before the vegetables transplantation, the diluted fermented residual dreg was applied 20-30 cm below the soil surface at a rate of 37,500 kg ha^{-1}, while liquid digestate was sprinkled to the soil surface in three vegetable growing stages and on the vegetable leaves once. They found increase in yield (18.4% and 17.8% and vitamin C content 16.6% and 21.5% of treated cucumber and tomato, respectively).

As the results show, the digestate application in solid or liquid form could result in significant improvement in the quality of foods without damaging the environment, which is very important for sustainable environment and healthy life. Another way to use the digestate for the purposes of soil amendment is to process it into compost.

2.6 Composting methods

Compost is a nutrient-rich soil-like material created by the biological decomposition of organic materials such as vegetative debris and livestock manures. It is the efficient management of the biological decomposition of organic matter.

Composting is a biological process, which is the aerobic, thermophilic, self-heating, biological decomposition of biodegradable organic materials. During the composting process microorganisms convert the raw material to humus and related compounds. Proper composting generates sufficient heat to kill weed seeds, pathogenic bacteria and helminthes, and reduces the moisture content for handling or stockpiling. The process does not attract flies, rodents and birds, or cause objectionable odors.

Application of manure or composted manure can result in increased soil concentrations of nutrients and organic matter (Chang *et al.*, 1991; Eghball, 2002). Residual effects of manure or compost application can maintain crop yield level for several years after manure or compost application ceases since only a fraction of the N and other nutrients in manure or compost become available to plant in the first year after application (Motavalli *et al.*, 1989; Eghball *et al.*, 2003). Eghball and Power (1999) found that 40% of beef cattle feedlot manure N and 20% of compost N were available to plant in the first year after application, indicating that about 60% of manure N and 80% of compost N became plant available in the succeeding years, assuming little or no loss of N due to NO_3–N leaching or de-nitrification.

Increased levels of soil N, P, K, pH, and C levels in the soil can increase crop yield beyond the application years. Soil pH, organic matter, total N, NO_3–N, and P levels were still elevated 4 years after dairy manure application ceased (Mugwira, 1979; Lund & Doss, 1980). Eghball *et al.*, (2003) found that the increased plant-available P level in soil following N-based manure or compost application can contribute to crop P uptake for up to 10 years without any additional P addition. Ginting *et al*. (2003) did not find increased emission of greenhouse gasses (CO_2, CH_4, and N_2O) as a result of residual manure and compost applications that ceased 4 years earlier.

Residual effects of manure application have been reported for studies where excessive rates of manure had been applied (Wallingford *et al.*, 1975; Mugwira, 1979; Lund & Doss, 1980). Nitrogen- and Phosphorus-based manure or compost application provides rates that are agronomically and environmentally sound. Nitrogen-based manure or compost application can increase soil Phosphorus levels (Eghball & Power, 1999). However, in areas where the risk of Phosphorus transport in runoff is not a concern, Nitrogen-based applications can be made.

In this study, three methods of composting were employed, i.e. windrow composting, co-composting and vermicomposting.

2.8.1 Turned windrow composting

Windrows may be constructed by several methods; however, it is usually done by truck and front-end loaders. Windrows can be from 2 to 6 m in width at the base and 1 to 3 m in height and of any length. The most practical windrow size is 3 to 5 m at the base and 2 to 3 m in height and somewhat triangular in shape. Optimum size will vary due to weather, turning equipment utilized, and initial characteristics of the waste.

Windrows which are too small are vulnerable to weather conditions, especially rain, and require considerably more land area for an equal amount of waste compared to larger windrows. Excessively large windrows, if not aerated at the proper times, readily form anaerobic cores with the resultant release of odours when aerated. Aerobic windrow composting does not need so much energy for operating process. In the windrow composting system, wastes are stacked in piles which can be arranged in long par ailed rows or windrows. In large systems such windrows are turned at regular intervals using mechanical equipment.

The windrow system has been used successfully for composting of a wide variety of organic residue. In general, windrow composting is relatively land intensive. The importance of aerobic windrow composting is that it shortens the time required for satisfactory composting and it may be done with a minimum of additional equipment and considerably less energy requirement.

2.8.2 Vermicomposting

Vermicomposting is a simple biotechnological process of composting in which certain species of earthworms are used to enhance the process of waste conversion (Gandhi *et al.*, 1997). It is a mesophilic process using microorganisms and earthworms that are very active at 10-32ºC (not ambient temperature but temperature within the pile of moist organic material). The process is faster than composting; but the material passes through the earthworm gut whereby the resulting earthworm castings (worm manure) are rich in microbial activity and plant regulators and fortified with pest repellence attributes as well. The moisture content of castings ranges between 32 and 66% and the pH is around 7. These worm castings contain higher percentage (nearly twice) of both macro and micronutrients than garden compost.

2.8.3 Co-composting

Co-composting is the controlled aerobic degradation of organics using more than one material. Co-composting of bio solids and municipal solid wastes (MSW) is becoming an acceptable environmentally based alternative method of waste disposal. The resulting humified organic matter (OM) is a potentially suitable amendment for agricultural soils (Petruzzeli *et al.*, 1989). There are two types of Co-composting designs: open and in-vessel. In open composting, the mixed material (sludge and solid waste) is piled into long heaps called windrows and left to decompose. Windrow piles are turned periodically to provide oxygen and ensure that all parts of the pile are subjected to the same heat treatment. Co-composting can produce a clean, pleasant, beneficial product that is safe to touch and work with. It is a good way to reduce the pathogen load in sludge.

For the purpose of assessing the agronomical properties of compost or digestate it is used in planting. Figure 2 shows the flow of organic waste through different processing methods and the benefits derived when used as a soil amendment.

2.9 Cultivation of beans

Common bean (*Phaseolus vulgaris*) is known under different names (French bean, kidney bean, snap bean, runner bean, string bean). It can be grown as a vegetable crop for fresh pods or as- a pulse crop for dry seed. World production of dry beans is about 16.7 million tons from about 23 million ha and green beans 4.7 million tons from 0.7 million ha (FAO, 2013).

Common bean grows well in areas with medium rainfall, but is not suited to the humid, wet tropics. Excessive rain and hot weather cause flower and pod drop and increase the incidence of diseases. Optimum, mean daily temperatures range between 15 and 20°C. The minimum mean daily temperature for growth is l0°C, the maximum 27°C. High temperatures increase the fibre content in the pod. Germination requires a soil temperature of 15°C or more, and at 18°C germination takes about 12 days, and at 25°C about 7 days. Most bean varieties are not affected, by day length. The length of the total growing period varies with the use of the product and is 60 to 90 days for green bean and 90 to 120 days for dry bean.

The crop does not have specific soil requirements but friable, deep soils with pH of 5.5 to 6.0 are preferred. Fertilizer requirements for high production are 20 to 40 kg/ha N, 40 to 60 kg/ha P and 50 to 120 kg/ha K. Bean is capable of fixing nitrogen which can meet its requirements for high yields. However, a starter dose of N is beneficial for good early growth. The crop is sensitive to soil-borne diseases and should be grown in a rotation; in the subtropics in the USA wheat, sorghum, onion and potato are common rotation crops, whereas in tropical Africa and Asia maize, sweet potato and cotton are common.

Normal sowing depth is about 5 to 7 cm. Spacing depends on variety. Bush types (erect) normally have a plant and row spacing of 5 to 10 x 50 to 75 cm, while pole-type (climbing) are 10 to 15 x 90 to 150 cm. Pole beans are also often grown on hills spaced 90 to 120 cm apart. Other spacing is possible, and these depend on the method of harvest. Common bean is sensitive to soil salinity. The yield decreases at different levels of ECe is: 0% at ECe 1.0, 10% at 1.5, 25% at 2.3, 50% at 3.6 and 100% at ECe 6.5 mmhos/cm. (FAO, 2013).

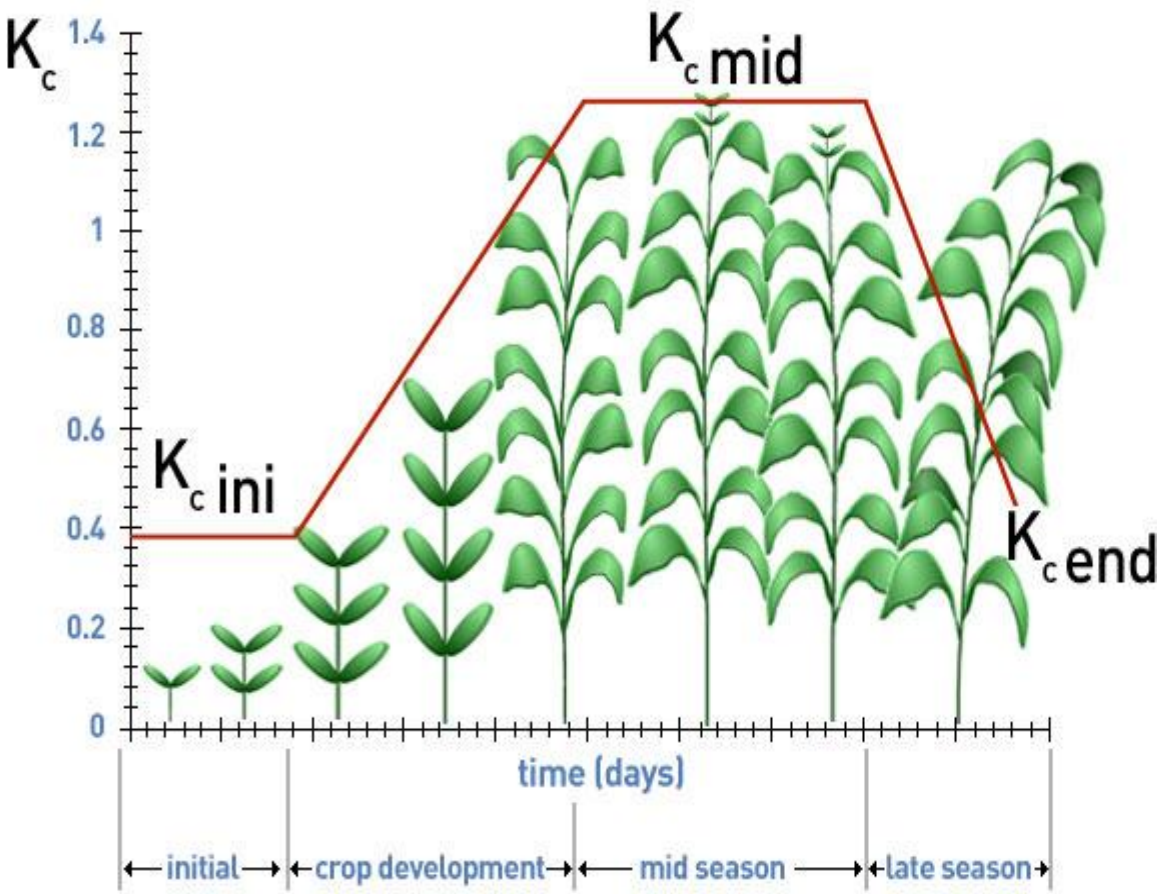

Figure 1. Developmental stages of beans

Source: FAO, (2013)

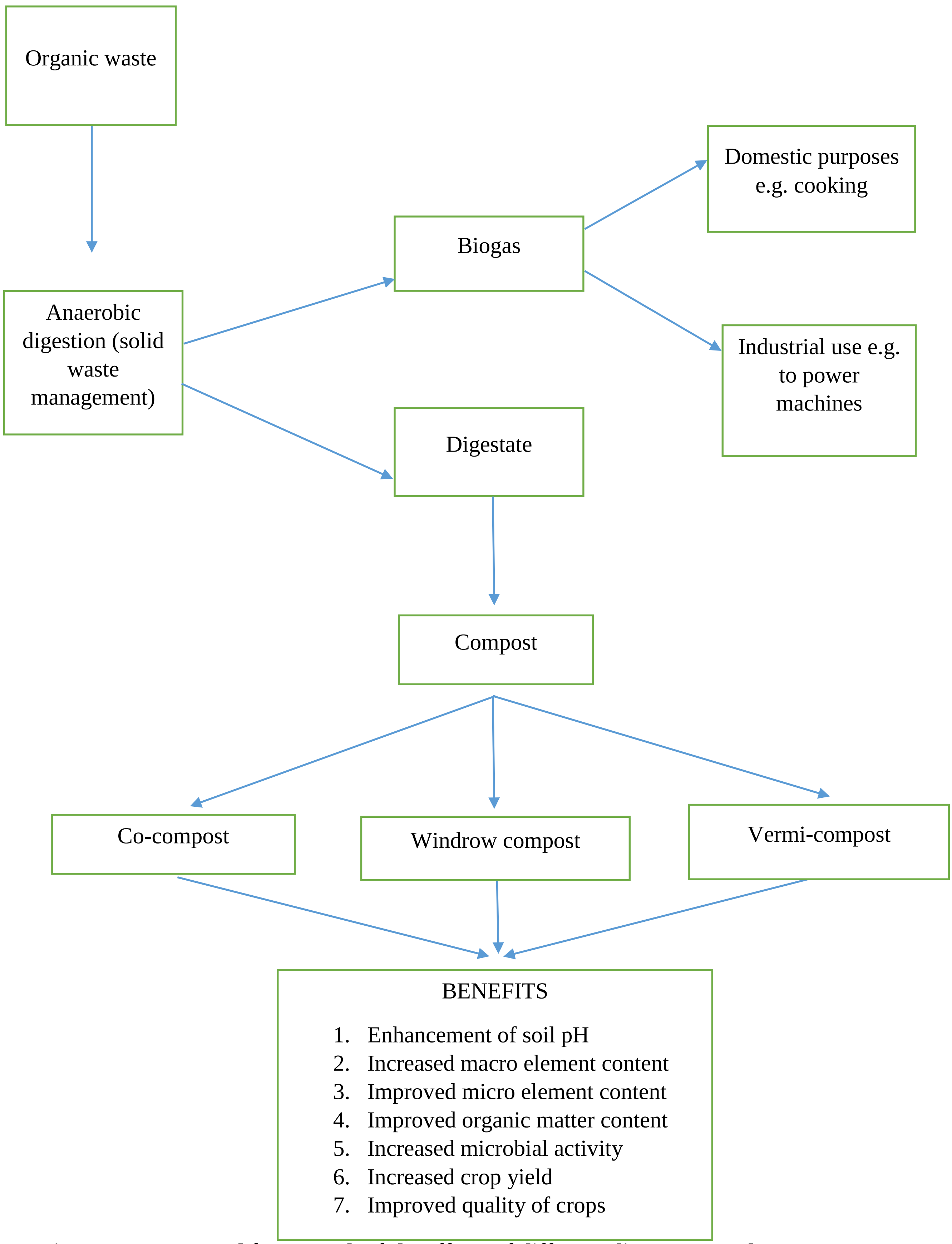

Figure 2. Conceptual framework of the effects of different digestates on the performance of green beans

Figure 2 presents the conceptual framework of the use of different composts in peri-urban cropping. It shows the flow of organic waste through different processing methods and the benefits derived when used as a soil amendment.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

3.1.1 Location of Study Area

The study was carried out in Kumasi which is the regional capital of the Ashanti region of Ghana. It is located about 270 km North- West of Accra, the capital of Ghana. Kumasi is located between latitude 6° 35' – 6° 40' and longitude 1° 30' – 1°35' (See Appendix I) with an area of about 254 sq. km and a 2010 estimated population of about 2,035,064 (Ghana Statistical Service, 2010). Kumasi functions as a nodal town as roads from the north, south, east and western parts converge on it and therefore serves as a crucial link between the northern and southern part of the country. This central function of Kumasi has given it the potential of attracting trade and commerce from all parts of the country.

3.1.2 Climate

Kumasi has a tropical wet and dry climate, with relatively constant temperatures throughout the year. Kumasi has an average rainfall of 1400 mm per annum. The city has a bimodal rainfall pattern, a major rainy season from March through July and a minor rainy season from September to November. Similar to the rest of West Africa, Kumasi experiences the harmattan from December to February.

3.1.3 Geology, Soils and Vegetation

Kumasi has an undulating topography and lies on a watershed approximately 282 meters high (Nsiah-Gyabah, 2001). The Middle Precambrian Rock is the dominant geological formation in the Kumasi Metropolitan Area with the major soil type being Forest Ochrosol. The soil associations include Kumasi-Offin Compound Association; Bomso-Offin Compound Association; Nhyanao-Yinkong Association; Bomso-Suko Simple Association and Bekwai-Akumadan-Oda Compound Association. Soils in some peri-urban areas are developed on granites or phyllites. Those developed on granites are acidic whilst those on the phyllites are less acidic. Soil classes found in the Kumasi metropolis include Haplic Acrisols, Eutric Gleysols, Gleyic Arenosols and Gleyic Cambisols. The most common soil group is Ferric Acrisols (CEDAR, 1999). Ashanti Region falls within the Moist Semi-Deciduous South East Ecological Zone. The region is characterized by several vegetation and land cover types. Predominate among them is the moderately closed tree canopy with herb and bush consisting of about 15 trees per hectare. The moist semi-deciduous forest is the most extensive closed canopy forest type in Ghana (14.1%). Other vegetation types found in the region are moderately dense herb or bush with scattered trees, open cultivated savanna woodland consisting of about 11 to 20 trees per hectare, open forest with less than 60% and closed forest with more than 60% trees (MES, 2002)

3.2 Compost preparation

Digestate from the biogas plant at the sewage plant under the Department of Agricultural Engineering KNUST was composted. Constituents of the digestate included kitchen waste, grass, sugarcane peels, and pear seeds, orange peels and coconut husks.

The test period spanned from August 2012 to April 2013, with the period of crop production beginning in January and ending in March 2013.

3.3 Experimental design

The experimental design used was Randomized Complete Block Design.

A plot of land was acquired at the Mechanization Section of the Agricultural Engineering Department of KNUST, Kumasi. This was divided into 20 plots. The plots were of size 1m × 2m with 1m path between blocks and treatments (Figure 3).

Block I	II	III	IV
A	D	C	E
B	E	A	D
C	A	E	B
D	B	B	C
E	C	D	A

Figure 3 Experimental layout

There were five treatments with four replicates. The treatments were:

A- Fresh digestate

B- Vermi-composted digestate (cast)

C- Co-composted digestate

D – Windrow compost

E - Control

3.6 Treatment application and crop management

Each bed of 2 m^2 was planted with the Dragon Tongue variety of green beans (*Phaseolus vulgaris*) at a spacing of 10cm × 75cm.

Hague *et al.* (1996) formulated that 120kg of nitrogen is required for the application of digestate or compost per hectare. Calculation of various amounts of digestate and compost for application was derived from the Equation;

For 120 kgN/ha, 22.43 t/ha Fresh Weight (17, 0470 kg/ha Dry Weight) dry digestate was applied.

Therefore for 90 kg of N = $\frac{90}{120} \times 22.43$

[1]

$$= 16{,}822.5 \ t/ha$$

Thus the amount of manure for plot size of 2 m^2 = $\left(\frac{2}{10{,}000}\right) \times 16{,}822.5$kg

[2]

$$= 3.3645 \ kg$$

Seeds of beans (*Phaseolus vulgaris*) were purchased from an agro-chemical shop. Digestate was obtained from the biogas digester at KNUST. The various forms of the treatments were mixed with soil for planting of the seedlings.

Planting was done six weeks after application of compost. During this period turning of the soil was done weekly. Soil around the plants was turned to prevent compaction of the soil and allow easy drainage of water to the roots of the seedlings. Seeds of green beans were planted $10cmx75cm$ (distance between plants by distance between rows). Watering was done with a watering can twice daily, that is morning and evening, at the stages prior to and during germination. Twenty five litres of water was supplied to each plot each time of watering. Three weeks after germination, watering was done once a day, in the evening.

Eight weeks after planting, sampling of crops was carried out randomly from all blocks. Dry matter was determined and analyzed for nutrient contents.

3.4 Data collection

Sampling was done randomly. Three crops were randomly selected from each plot for analysis. This represents 33.33% of the sample space.

3.4.1 Types and sources of data

Data for the research include composition and treatment process (es) of the organic waste used. Data on the nutrient content of the digestate was also collected. Information on soil, post-planting treatment of the crop was also obtained from literature.

Primary data was sourced from the waste separation unit of Zoomlion Ghana Limited (Kumasi branch). In addition, personal observation and interviews were used. Data was sourced from literature, the Ghana Statistical Service, the Food and Agriculture Organization of the United Nations and the Ministry of Food and Agriculture in Ghana.

The digestate which was obtained from the anaerobic digestion process was then analyzed to assess its effect on the cultivation of green beans. A detailed description of the analysis is presented in Section 3.4.3.

3.4.2 Determination of dry matter

The wet weight of fresh samples of each treatment was measured using the Mettler Toledo weighing balance. The dry weights were also determined by oven-drying at 80^{0}C for a period of 12 hours in grams. The period of drying was to ensure a constant dry weight of samples. The percentage dry matter was calculated as follows:

$$\% \text{ Dry matter} = \frac{Dry\ weight \times 100\%}{Fresh\ weight} \quad [1]$$

3.4.3 Determination of plant nutrients by analytical methods

In determining the quantity of plant nutrient, the Modified Truog procedure was used (Ayres & Hagihara, 1952).

Dry-ashing was used to determine the total ash content as well as the concentration of the individual nutrient elements in plant materials. This procedure involved ashing of the material to destroy the organic matter component leaving the various elements in the ash. The amount of Potassium (K) and Sodium (Na) were determined using flame photometry by comparing the intensities of radiation emitted by K and Na atoms with respect to a series of standard solutions. Phosphorus (P) was determined by colorimetric method using vanadium phosphomolybdate method (Henry, 1974).

Calcium was determined by titrating Calcium solution (Ca) to a 10ml aliquot of the sample solution extracted and filtered above. A 10ml of 10% KOH solution were added followed by 1 ml of 30% Triethanolamine. Three (3) drops of 10% KCN solution were added and a few crystals of Cal-red indicator and then shaken vigorously for uniform mixture. The mixture was then titrated with 0.02 N EDTA solution from a red to blue endpoint.

NB: Ca = Titre value of Ca x 0.4%

A solution of (Ca+Mg) was titrated to a 10-ml aliquot of the same sample solution in a 100ml conical flask. Five (5) ml of Ammonium Chloride-Ammonium Hydroxide buffer solution were added followed by 1ml of triethanolamine. Three (3) drops of 10% KCN solution were added as well as few drops of EBT indicator solution and then shaken vigorously to obtain a uniform mixture. The mixture was then titrated with 0.02 N EDTA solution from a red to blue endpoint.

Calculation

The value for Mg only was obtained by subtracting the value for Ca from that of Ca +Mg.

3.4.4 Growth and yield

Rate of growth was monitored by taking plant height and number of leaves. The N, P, K, Ca and Mg content were analyzed to ascertain the nutritional content of crops treated with each type of digestate.

Dry matter yield was also determined. Each parameter was measured at least three times.

3.5 Data analysis

Analysis of variance (ANOVA) was carried out to compare means of the physico-chemical and biological parameters for the different treatments. The chemical analyses done was compared to the American Public Health Organisation (1992) standards for the examination of water and wastewater. Data obtained from the analysis were presented in the form of graphs and charts where appropriate.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Introduction

During the developmental stages of a crop, several factors can be used to assess its growth. Some of these were analysed and determined for the different treatments. These are plant height, number of leaves, dry weight, and N, P, K, Mg and Ca.

4.2 Effects of treatments on plant growth

4.2.1 Treatment effect on plant height

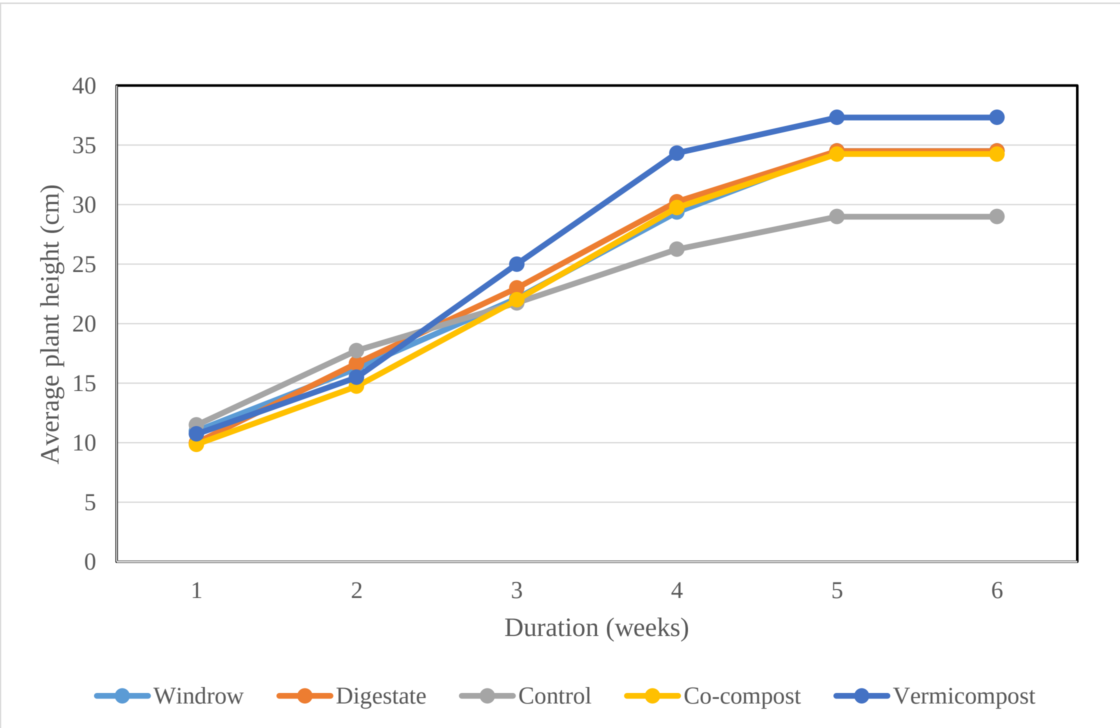

Figure 4. Changes in plant height due to treatments over the growing period

Figure 4 shows the trend in plant height throughout the growth period. It was observed that there was a general increase in plant height from the first week of cultivation to the fifth week after which plants ceased to increase in height till harvest. From the graph, the control in comparison with those treated with compost and digestate, had no significant difference plant height from the first and second weeks. Although the average plant height for the control was 12 cm, higher than that of the other treatments which were between 10 and 11 cm. From the third to sixth weeks plant heights for the control increased from 22 to 29 cm while crops treated with digestate, vermicompost, co-compost and windrow composts increased from 23 to 35, 25 to 35, 22 to 34 and 22 to 35 cm respectively. Treatments with vermicompost had the highest plant height even though the initial stages of development were quite slow in comparison to the control and other treatments.

Studies have shown that fresh digestate contains high content of nitrogen which accounts for growth in organisms. Banik and Nandi (2004) investigated this by testing biogas residual slurry on beds for the cultivation of rice. The plant heights were not significantly different at 5 % significance level over the growth period (See Appendix II) as F statistics of 1.78 were less than the F critical values of 3.48 at 5 % level of significance for the treatment.

4.2.2 Treatment effect on number of leaves

The number of leaves of green beans over the growing period is shown in Figure 5. Number of leaves of plants increased from the first week after germination with average number of leaves of 2 for all treatments. The digestate treatment gave the highest number of leaves of 51 at five weeks after planting. The windrow, co-compost, vermicompost and control had 37, 46, 42 and 34 respectively five weeks after planting. The number of leaves was not significantly different after all the weeks.

The treatments did not have any significant effect on the average number of leaves as the F statistic value of 1.96 is less than the critical value of 3.59 at 5% significance level (See Appendix II).

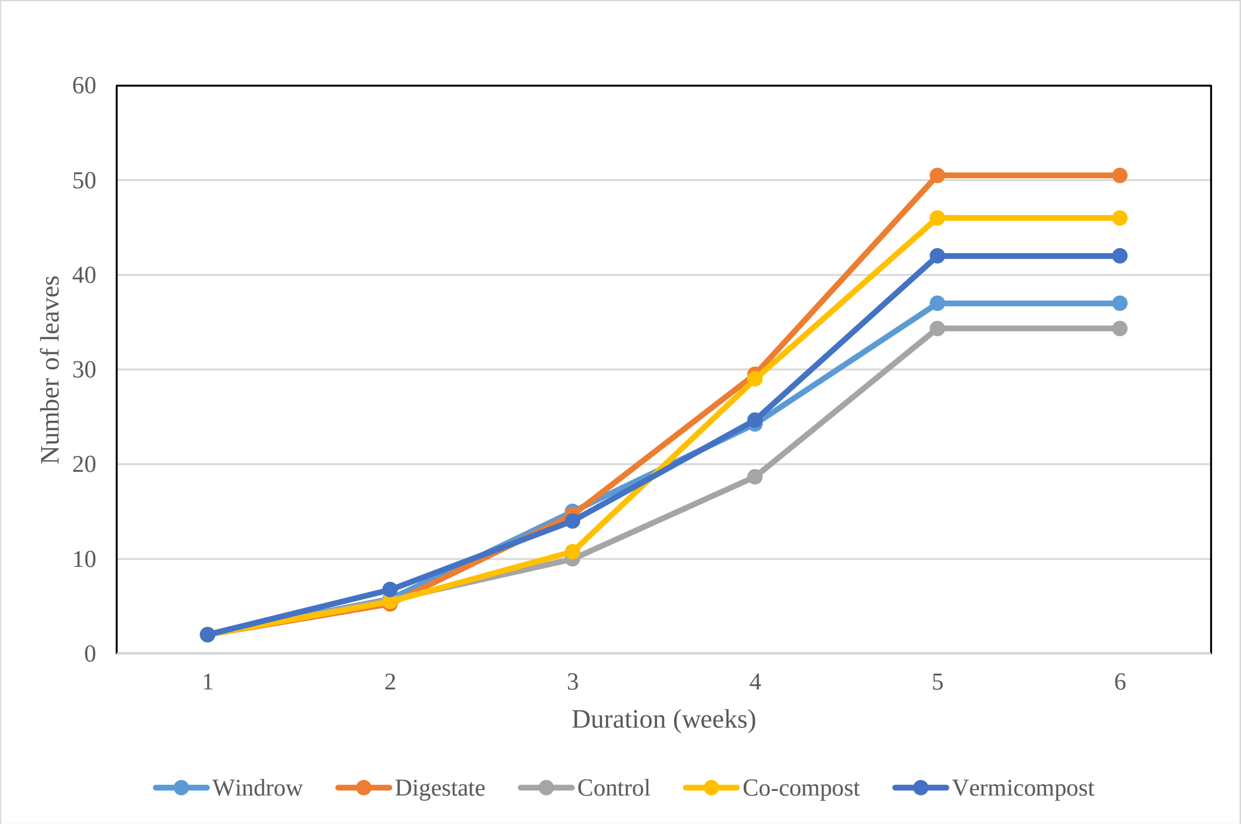

Figure 5. Average number of leaves per treatment over the growing period

4.2.3 Treatment effect on biomass dry matter

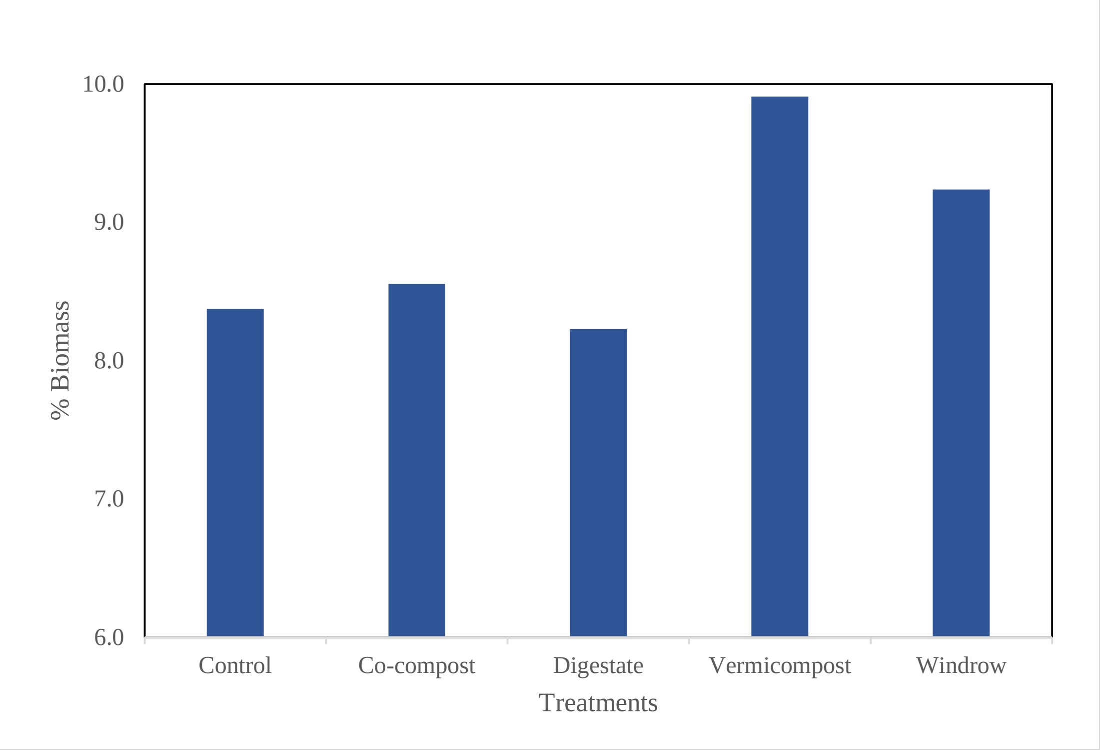

Figure 6. Effects of various treatments on % biomass of plants

The biomass results from various treatments is shown in Figure 6. Biomass yield for control treatments of co-compost, digestate, vermicompost, and windrow compost are 8.37, 8.55, 10.65, 10.81 and 10.03 respectively. Dry matter content for control and co-compost treatments were much lower than those treated with digestate, vermicompost and windrow compost. Samples treated with vermi-compost gave the highest biomass.

From the dependent-samples *t*-test carried out on the biomass, a t-value of -16.156 was found not to fall within the critical region defined by the critical value of 2.776, and the p-value less than the critical value of 0.05. Therefore the null hypothesis was rejected. From these results treatments had a significant effect on the biomass.

Knowing the moisture content of a feed ingredient is important because the moisture content affects the weight of the feed, but does not provide nutrient value to the animal. Studies on the effects of organic production on the quality of produce by Bourn and Prescott (2002), Lester (2006) and Zhao *et al.,* (2006) showed higher levels of dry matter content. Lower soil Nitrogen (N) and Potassium (K) availability in organic systems than conventional systems could be the reason for higher dry matter content in organic produce (Woese *et al.*, 1997) and this could account for why the dry matter content of crops treated with digestate and/or compost recorded a percentage dry matter weight higher than the control. Under low nitrogen supply, as in the case of organic green beans, plants tend to synthesize N-poor molecules such as amino acids, proteins, which results in an increase in the dry matter content of such produce (Herencia *et al.*, 2011).

The results indicate a consistency of plants treated with compost performing better than crops which are not treated with any compost. The results of this experiment show that compost application significantly influenced the growth parameters and dry matter production. Application of compost to soil improved the growth attributes of the green beans in the field.

4.3 Treatment effect on nutrient content of plants

Nitrogen, Phosphorus, Calcium, Potassium and Magnesium are considered essential nutrients for plant growth. If there is a deficiency of any of these element, plants cannot complete their vegetative or reproductive cycles.

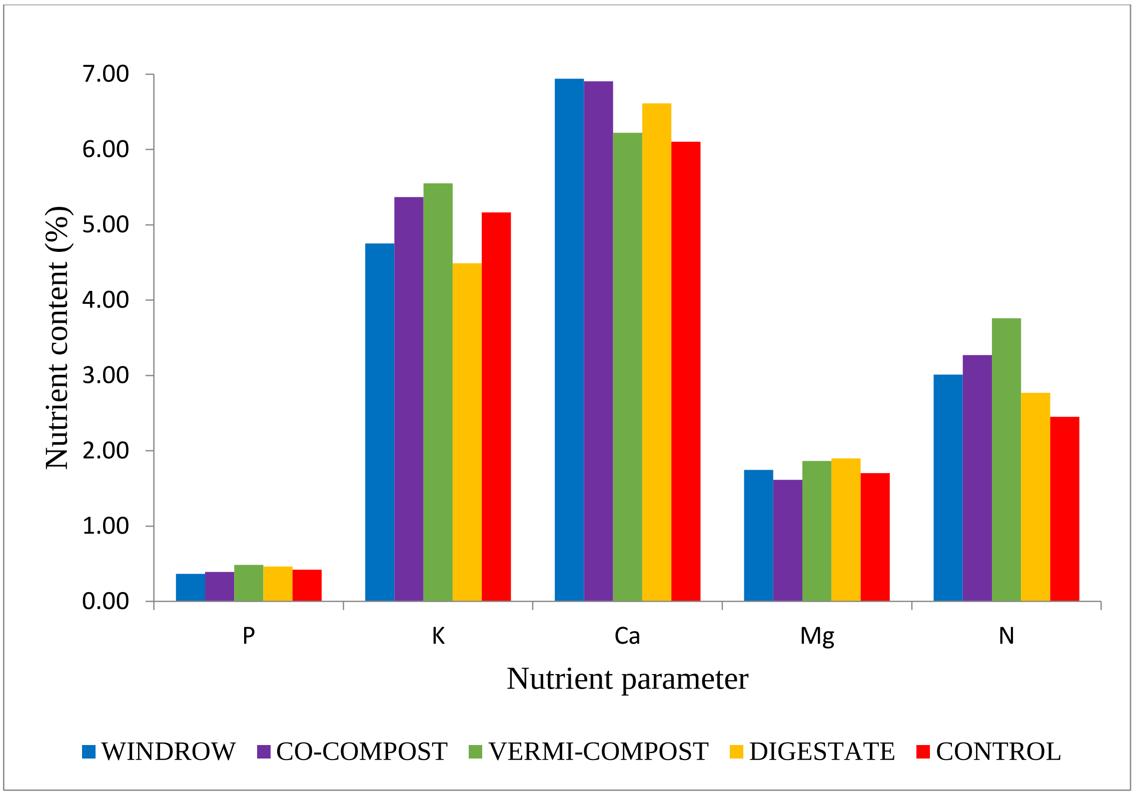

Figure 7. Effects of various treatments on nutrient content of plants at harvest

Phosphorus (P) contents were 0.37 for crops treated with windrow compost, 0.39% for co-compost, 0.49% for vermi-compost and 0.46 for digestate-treated crops and 0.42% for the control (Figure 7 and Appendix II). The values for Potassium (K), were 4.75%, 5.37%, 5.55%, 4.49% and 5.17% for crops treated with windrow compost, co-compost, vermi-compost, and digestate and control samples respectively. Values for Calcium (Ca) were 6.94% for windrow compost, 6.91% for co-compost, 6.22% for vermi-compost, 6.61% for digestate and 6.1% for control samples. Data recorded for Magnesium were 1.75% for windrow compost, 1.62% for co-compost, 1.87% for vermicompost, 1.90% for digestate and 1.71% for control. Values of Nitrogen (N) obtained were 3.01%, 3.27%, 3.76%, 2.77% and 2.45% for crops treated with windrow compost, co-compost and vermicompost as well as digestate and crops not treated with any compost or digestate respectively. The differences as a result of treatments were significant. The overall F ratio value for various treatments exceeded the threshold which is the F- critical value at $p>0.05$ (level of significance). The p value 0.03 was less than the level of significance.

The various treatments significantly affected the data obtained at $p>0.05$. The F value obtained was 4.75. This is greater than the F critical value of 3.41. The p value 0.02 was also less than the level of significance.

Values of N for all crops were generally low and this is expected since organic green beans is a nitrogen fixing crop. Low soil nitrogen could also have accounted for the low values recorded in crop yield. F ratios show that the treatments did not significantly affect results.

For values of Ca and Mg the F values were less than the F critical values and the p values obtained were greater than the level of significance. In all these the treatments did not significantly affect the values of Ca and Mg that were obtained.

A pairwise comparison of treatments for P showed that the differences between windrow and vermicompost and between windrow and digestate were significant. The P values of 0.01 and 0.04 were less than the level of significance ($p<0.05$). Differences between co-compost and control were not significant as values of p were 0.52 and 0.24 respectively. A comparison between co-compost and vermicompost also showed significant difference. The value for P was 0.03 which is less than the critical value of 0.05.

A pairwise comparison of the means was carried out using the Least Significant Difference (LSD) method. For K, a pairwise comparison of windrow compost with co-compost showed a significant difference in the effect of treatments. Values of significant difference 0.03 and 0.009 respectively. These were less than 0.05, thus the null hypothesis that the effects of treatments on nutrients values are the same was rejected. A comparison between the digestate and control however showed no significant difference as the values of significant difference were greater than 0.05. A pairwise comparison between co-compost and the digestate showed a significant difference with P = 0.008 which is less than the p value. The difference was significant. A comparison between co-compost and control gave P values of 0.46 and 0.51 respectively. These are greater than the p value of 0.05. There were no significant differences in the effect of these treatments on values of K.

Optimum crop performance is usually limited by inadequate essential nutrients. The results of this work have highlighted the superiority of fertilized plants over non-fertilized ones in terms of growth and dry matter accumulation. The consistently poor performance of non-fertilized plants shows that when nutrients are available in adequate amount there is a potential for plants to produce at their optimum.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

- In comparing the effects of different digestates on growth parameters of green beans, results showed that crops treated with vermicompost generally performed much better. This is in terms of plant height and number of leaves as compared to crops treated with co-compost, windrow compost and digestate.
- The study has shown that crops treated with vermicompost generally performed much better in terms of biomass and nutrient content of green beans.
- The treatment of vermicompost resulted in higher P and K in the plants.

5.2 Recommendations

- A long term research should be carried out on the effects of prolonged use of composts produced by vermicomposting, co-composting and windrow composting on the soil and crop yield.
- A comparative study of other methods of composting such as trench, in-vessel and sheet should be carried out to assess how they compare with the methods studied.
- Research on other characteristics of compost such as adaptation in different conditions should be carried out under the same and controlled conditions to ascertain their effects on crop yield.
- Public awareness on the effects of vermicompost on soil, green beans growth and biomass should be carried out.

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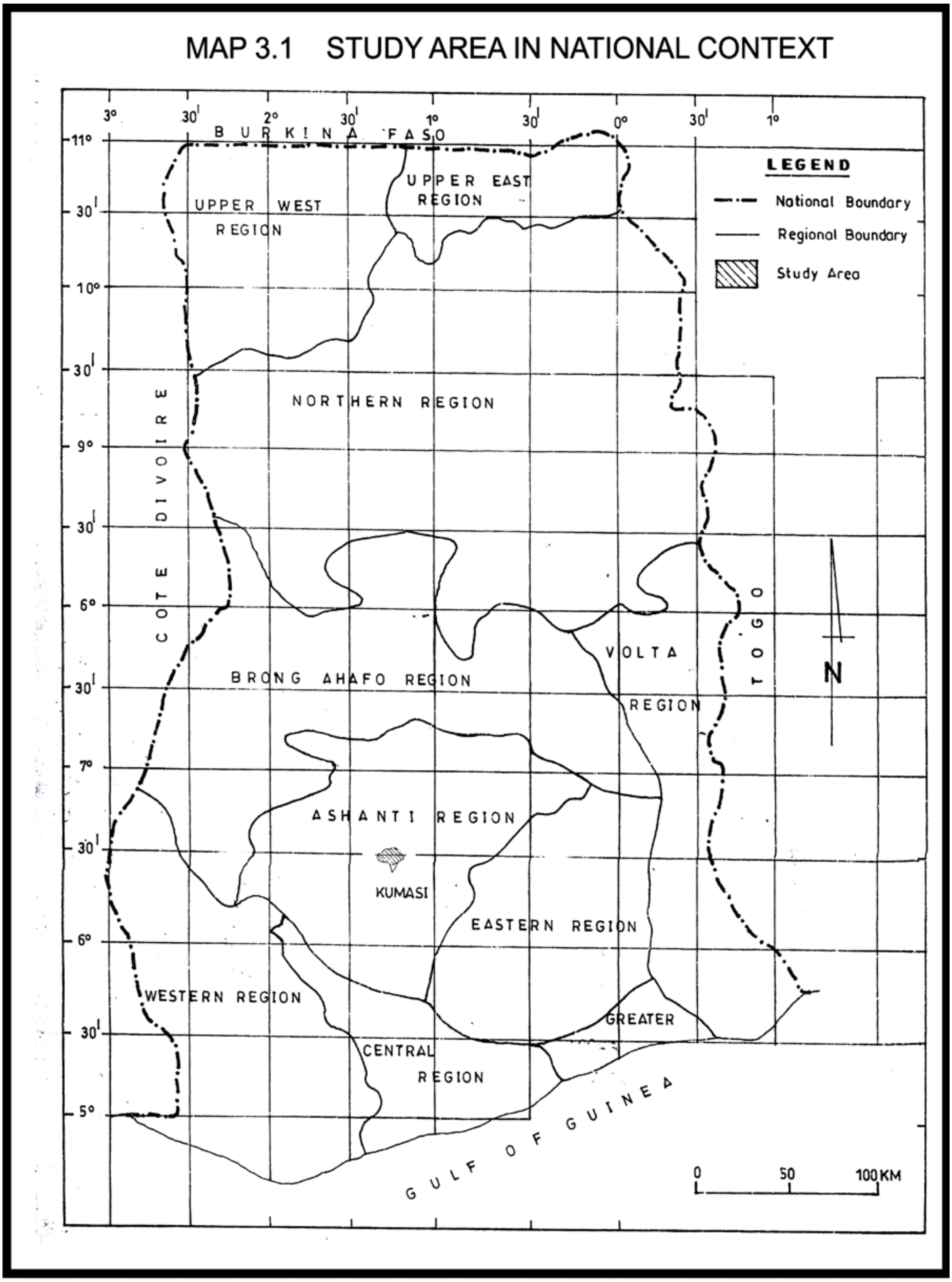
Appendix I



SOURCE: Department of Geography, KNUST 2009

Figure 8.Map of study area

Appendix II

Table 2.Effects of various treatments on plant heights

Treatment	Average plant height per week					
	Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6
Windrow	11	16	22	29	35	35
Digestate	10	17	23	30	35	35
Control	12	18	22	26	29	29
Co-compost	10	15	22	30	34	34
Vermicompost	11	16	25	34	37	37

Table 3. F statistics of number of average plant height

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	106.2667	4	26.56667	1.779018	0.209583	3.47805
Within Groups	149.3333	10	14.93333			
Total	255.6	14				

Table 4. Average number of leaves per treatment

Treatment	Average plant height per week					
	1wk	2wks	3wks	4wks	5wks	6wks
Windrow	2	6	15	24	37	37
Digestate	2	5	15	30	51	51
Control	2	6	10	19	34	34
Co-compost	2	6	11	29	46	46
Vermicompost	2	7	14	25	42	42

Table 5. F statistics of average number of leaves

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	701.9333	3	233.9778	1.96021	0.178524	3.587434
Within Groups	1313	11	119.3636			
Total	2014.933	14				

Table 6. Average% Dry weight of samples with various treatments

	Treatment				
	Control	**Co-compost**	**Digestate**	**Vermicompost**	**Windrow**
Wet weight	111.11	145.02	108.97	111	110.17
Dry weight (g)	9.3	12.4	11.6	12	11.05
% Dry weight	8.37	8.55	10.65	10.81	10.03
% Moisture	91.63	91.45	89.35	89.19	89.97

Table 7. Dependent-samples *t*-test for biomass

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	Upper			
Pair 1 dweight - wweight	-1.06384E2	14.72442	6.58496	-124.66679	-88.10121	-16.156	4	.000

Appendix III

Table 8. LSD analysis for Potassium

Multiple Comparisons

Values
LSD -
POTASSIUM

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.6150*	.23876	.030	-1.1551	-.0749
	3	-.7975*	.23876	.009	-1.3376	-.2574
	4	.2625	.25789	.335	-.3209	.8459
	5	-.4125	.29242	.192	-1.0740	.2490
2	1	.6150*	.23876	.030	.0749	1.1551
	3	-.1825	.23876	.464	-.7226	.3576
	4	.8775*	.25789	.008	.2941	1.4609
	5	.2025	.29242	.506	-.4590	.8640
3	1	.7975*	.23876	.009	.2574	1.3376
	2	.1825	.23876	.464	-.3576	.7226
	4	1.0600*	.25789	.003	.4766	1.6434
	5	.3850	.29242	.221	-.2765	1.0465
4	1	-.2625	.25789	.335	-.8459	.3209
	2	-.8775*	.25789	.008	-1.4609	-.2941
	3	-1.0600*	.25789	.003	-1.6434	-.4766
	5	-.6750	.30824	.056	-1.3723	.0223
5	1	.4125	.29242	.192	-.2490	1.0740
	2	-.2025	.29242	.506	-.8640	.4590
	3	-.3850	.29242	.221	-1.0465	.2765
	4	.6750	.30824	.056	-.0223	1.3723

Based on observed means.

The error term is Mean Square(Error) = .114.

*. The mean difference is significant at the .05 level.

Table 9. LSD analysis for Calcium

Values

LSD - CALCIUM

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	1.3000	1.70321	.465	-2.5529	5.1529
	3	.7200	1.70321	.682	-3.1329	4.5729
	4	.3267	1.83968	.863	-3.8350	4.4883
	5	1.0000	2.08600	.643	-3.7189	5.7189
2	1	-1.3000	1.70321	.465	-5.1529	2.5529
	3	-.5800	1.70321	.741	-4.4329	3.2729
	4	-.9733	1.83968	.610	-5.1350	3.1883
	5	-.3000	2.08600	.889	-5.0189	4.4189
3	1	-.7200	1.70321	.682	-4.5729	3.1329
	2	.5800	1.70321	.741	-3.2729	4.4329
	4	-.3933	1.83968	.835	-4.5550	3.7683
	5	.2800	2.08600	.896	-4.4389	4.9989
4	1	-.3267	1.83968	.863	-4.4883	3.8350
	2	.9733	1.83968	.610	-3.1883	5.1350
	3	.3933	1.83968	.835	-3.7683	4.5550
	5	.6733	2.19884	.766	-4.3008	5.6475
5	1	-1.0000	2.08600	.643	-5.7189	3.7189
	2	.3000	2.08600	.889	-4.4189	5.0189
	3	-.2800	2.08600	.896	-4.9989	4.4389
	4	-.6733	2.19884	.766	-5.6475	4.3008

Values

LSD - CALCIUM

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	1.3000	1.70321	.465	-2.5529	5.1529
	3	.7200	1.70321	.682	-3.1329	4.5729
	4	.3267	1.83968	.863	-3.8350	4.4883
	5	1.0000	2.08600	.643	-3.7189	5.7189
2	1	-1.3000	1.70321	.465	-5.1529	2.5529
	3	-.5800	1.70321	.741	-4.4329	3.2729
	4	-.9733	1.83968	.610	-5.1350	3.1883
	5	-.3000	2.08600	.889	-5.0189	4.4189
3	1	-.7200	1.70321	.682	-4.5729	3.1329
	2	.5800	1.70321	.741	-3.2729	4.4329
	4	-.3933	1.83968	.835	-4.5550	3.7683
	5	.2800	2.08600	.896	-4.4389	4.9989
4	1	-.3267	1.83968	.863	-4.4883	3.8350
	2	.9733	1.83968	.610	-3.1883	5.1350
	3	.3933	1.83968	.835	-3.7683	4.5550
	5	.6733	2.19884	.766	-4.3008	5.6475
5	1	-1.0000	2.08600	.643	-5.7189	3.7189
	2	.3000	2.08600	.889	-4.4189	5.0189
	3	-.2800	2.08600	.896	-4.9989	4.4389
	4	-.6733	2.19884	.766	-5.6475	4.3008

Based on observed means.

The error term is Mean Square (Error) = 5.802.

Table 10. LSD analysis for Magnesium

Values

LSD -

MAGNESIUM

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	.1300	.19901	.530	-.3202	.5802
	3	-.1200	.19901	.561	-.5702	.3302
	4	-.1517	.21495	.498	-.6379	.3346
	5	.0400	.24373	.873	-.5114	.5914
2	1	-.1300	.19901	.530	-.5802	.3202
	3	-.2500	.19901	.241	-.7002	.2002
	4	-.2817	.21495	.223	-.7679	.2046
	5	-.0900	.24373	.720	-.6414	.4614
3	1	.1200	.19901	.561	-.3302	.5702
	2	.2500	.19901	.241	-.2002	.7002
	4	-.0317	.21495	.886	-.5179	.4546
	5	.1600	.24373	.528	-.3914	.7114
4	1	.1517	.21495	.498	-.3346	.6379
	2	.2817	.21495	.223	-.2046	.7679
	3	.0317	.21495	.886	-.4546	.5179
	5	.1917	.25692	.475	-.3895	.7729
5	1	-.0400	.24373	.873	-.5914	.5114
	2	.0900	.24373	.720	-.4614	.6414
	3	-.1600	.24373	.528	-.7114	.3914
	4	-.1917	.25692	.475	-.7729	.3895

Values

LSD -

MAGNESIUM

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	.1300	.19901	.530	-.3202	.5802
	3	-.1200	.19901	.561	-.5702	.3302
	4	-.1517	.21495	.498	-.6379	.3346
	5	.0400	.24373	.873	-.5114	.5914
2	1	-.1300	.19901	.530	-.5802	.3202
	3	-.2500	.19901	.241	-.7002	.2002
	4	-.2817	.21495	.223	-.7679	.2046
	5	-.0900	.24373	.720	-.6414	.4614
3	1	.1200	.19901	.561	-.3302	.5702
	2	.2500	.19901	.241	-.2002	.7002
	4	-.0317	.21495	.886	-.5179	.4546
	5	.1600	.24373	.528	-.3914	.7114
4	1	.1517	.21495	.498	-.3346	.6379
	2	.2817	.21495	.223	-.2046	.7679
	3	.0317	.21495	.886	-.4546	.5179
	5	.1917	.25692	.475	-.3895	.7729
5	1	-.0400	.24373	.873	-.5914	.5114
	2	.0900	.24373	.720	-.4614	.6414
	3	-.1600	.24373	.528	-.7114	.3914
	4	-.1917	.25692	.475	-.7729	.3895

Based on observed means.

The error term is Mean Square (Error) = .079.

Table 11. LSD analysis for Nitrogen

Values

LSD -

NITROGEN

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.0150	.42478	.973	-.9759	.9459
	3	-.4325	.42478	.335	-1.3934	.5284
	4	.2450	.42478	.578	-.7159	1.2059
	5	.5600	.50771	.299	-.5885	1.7085
2	1	.0150	.42478	.973	-.9459	.9759
	3	-.4175	.39327	.316	-1.3071	.4721
	4	.2600	.39327	.525	-.6296	1.1496
	5	.5750	.48166	.263	-.5146	1.6646
3	1	.4325	.42478	.335	-.5284	1.3934
	2	.4175	.39327	.316	-.4721	1.3071
	4	.6775	.39327	.119	-.2121	1.5671
	5	.9925	.48166	.069	-.0971	2.0821
4	1	-.2450	.42478	.578	-1.2059	.7159
	2	-.2600	.39327	.525	-1.1496	.6296
	3	-.6775	.39327	.119	-1.5671	.2121
	5	.3150	.48166	.529	-.7746	1.4046
5	1	-.5600	.50771	.299	-1.7085	.5885
	2	-.5750	.48166	.263	-1.6646	.5146
	3	-.9925	.48166	.069	-2.0821	.0971
	4	-.3150	.48166	.529	-1.4046	.7746

Values

LSD -

NITROGEN

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.0150	.42478	.973	-.9759	.9459
	3	-.4325	.42478	.335	-1.3934	.5284
	4	.2450	.42478	.578	-.7159	1.2059
	5	.5600	.50771	.299	-.5885	1.7085
2	1	.0150	.42478	.973	-.9459	.9759
	3	-.4175	.39327	.316	-1.3071	.4721
	4	.2600	.39327	.525	-.6296	1.1496
	5	.5750	.48166	.263	-.5146	1.6646
3	1	.4325	.42478	.335	-.5284	1.3934
	2	.4175	.39327	.316	-.4721	1.3071
	4	.6775	.39327	.119	-.2121	1.5671
	5	.9925	.48166	.069	-.0971	2.0821
4	1	-.2450	.42478	.578	-1.2059	.7159
	2	-.2600	.39327	.525	-1.1496	.6296
	3	-.6775	.39327	.119	-1.5671	.2121
	5	.3150	.48166	.529	-.7746	1.4046
5	1	-.5600	.50771	.299	-1.7085	.5885
	2	-.5750	.48166	.263	-1.6646	.5146
	3	-.9925	.48166	.069	-2.0821	.0971
	4	-.3150	.48166	.529	-1.4046	.7746

Based on observed means.

The error term is Mean Square (Error) = .309.

Table 12. LSD analysis for Phosphorus

values

LSD -

PHOSPHORUS

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.0250	.03714	.518	-.1090	.0590
	3	-.1175*	.03714	.011	-.2015	-.0335
	4	-.0958*	.04011	.041	-.1866	-.0051
	5	-.0575	.04548	.238	-.1604	.0454
2	1	.0250	.03714	.518	-.0590	.1090
	3	-.0925*	.03714	.034	-.1765	-.0085
	4	-.0708	.04011	.111	-.1616	.0199
	5	-.0325	.04548	.493	-.1354	.0704
3	1	.1175*	.03714	.011	.0335	.2015
	2	.0925*	.03714	.034	.0085	.1765
	4	.0217	.04011	.602	-.0691	.1124
	5	.0600	.04548	.220	-.0429	.1629
4	1	.0958*	.04011	.041	.0051	.1866
	2	.0708	.04011	.111	-.0199	.1616
	3	-.0217	.04011	.602	-.1124	.0691
	5	.0383	.04794	.445	-.0701	.1468
5	1	.0575	.04548	.238	-.0454	.1604
	2	.0325	.04548	.493	-.0704	.1354
	3	-.0600	.04548	.220	-.1629	.0429
	4	-.0383	.04794	.445	-.1468	.0701

values

LSD -

PHOSPHORUS

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	2	-.0250	.03714	.518	-.1090	.0590
	3	-.1175*	.03714	.011	-.2015	-.0335
	4	-.0958*	.04011	.041	-.1866	-.0051
	5	-.0575	.04548	.238	-.1604	.0454
2	1	.0250	.03714	.518	-.0590	.1090
	3	-.0925*	.03714	.034	-.1765	-.0085
	4	-.0708	.04011	.111	-.1616	.0199
	5	-.0325	.04548	.493	-.1354	.0704
3	1	.1175*	.03714	.011	.0335	.2015
	2	.0925*	.03714	.034	.0085	.1765
	4	.0217	.04011	.602	-.0691	.1124
	5	.0600	.04548	.220	-.0429	.1629
4	1	.0958*	.04011	.041	.0051	.1866
	2	.0708	.04011	.111	-.0199	.1616
	3	-.0217	.04011	.602	-.1124	.0691
	5	.0383	.04794	.445	-.0701	.1468
5	1	.0575	.04548	.238	-.0454	.1604
	2	.0325	.04548	.493	-.0704	.1354
	3	-.0600	.04548	.220	-.1629	.0429
	4	-.0383	.04794	.445	-.1468	.0701

Based on observed means.

The error term is Mean Square (Error) = .003.

values

LSD -

PHOSPHORUS

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.0250	.03714	.518	-.1090	.0590
	3	-.1175*	.03714	.011	-.2015	-.0335
	4	-.0958*	.04011	.041	-.1866	-.0051
	5	-.0575	.04548	.238	-.1604	.0454
2	1	.0250	.03714	.518	-.0590	.1090
	3	-.0925*	.03714	.034	-.1765	-.0085
	4	-.0708	.04011	.111	-.1616	.0199
	5	-.0325	.04548	.493	-.1354	.0704
3	1	.1175*	.03714	.011	.0335	.2015
	2	.0925*	.03714	.034	.0085	.1765
	4	.0217	.04011	.602	-.0691	.1124
	5	.0600	.04548	.220	-.0429	.1629
4	1	.0958*	.04011	.041	.0051	.1866
	2	.0708	.04011	.111	-.0199	.1616
	3	-.0217	.04011	.602	-.1124	.0691
	5	.0383	.04794	.445	-.0701	.1468
5	1	.0575	.04548	.238	-.0454	.1604
	2	.0325	.04548	.493	-.0704	.1354
	3	-.0600	.04548	.220	-.1629	.0429
	4	-.0383	.04794	.445	-.1468	.0701

*. The mean difference is significant at the .05 level.

Appendix IV

Figure 9. Plants shaded with palm fronds, two weeks after cultivation.

Figure 10. Plants at the time of harvest