EFFECTS OF DIFFERENT APPLICATION RATES OF VERMICOMPOST AND BIOFERTILIZER ON GROWTH, YIELD AND QUALITY OF BEETROOT (*Beta vulgaris* var. *crassa* L.)

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A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Master of Science Degree in Horticulture of Egerton University

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DECLARATION AND RECOMMENDATION

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

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RECOMMENDATION

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DEDICATION

This work is dedicated to God who gave me strength, endurance and its successful accomplishment.

ACKNOWLEDGEMENTS

I acknowledge the goodness of the Almighty God for granting me life; good health and understanding that enabled me undertake this work. I sincerely thank the management of Egerton University for granting me the opportunity to study a Master of Science degree in Horticulture at the institution. It could not have been easy to prepare this work without the keen supervision of Prof. Mwanarusi Saidi and Prof. Mariam Mwangi. I would like to sincerely thank them for their commitment, patience, support, guidance and encouragement throughout this research work. I am also grateful to the Department of Crops Horticulture and Soils for providing the necessary support. My heartfelt gratitude to my parents and all my family members whose affection, concern, patience, dedication, sacrifice and blessing have always been my source of inspiration thus enabling me to complete the work successfully. May God bless you all.

ABSTRACT

Beetroot (*Beta vulgaris* var. *crassa* L.) is gaining prominence in Kenya because of its high nutritive and medicinal value. In order to obtain high yields and good quality beetroot, it is essential to provide soils with high organic matter and nutrients supply throughout the growing season. In trying to address some of these challenges, a study was conducted in the Horticulture Research and Teaching Field, Egerton University to determine the effects of different application rates of vermicompost and biofertilizer on growth, yield and quality of beetroot. The research was conducted over a span of two growing seasons as an unbalanced factorial experiment in a Randomized Complete Block Design (RCBD) with four replications. Two organic fertilizer types (vermicompost and biofertilizer) were studied each at four different application rates (5, 10, 20 and 30t/ha) and two controls; one with no fertilizer applied (negative control) and the other with inorganic fertilizer NPK (17:17:17) applied at the recommended rate of 60kg/ha (positive control).The variables studied were plant height, number of leaves, Leaf Area Index (LAI), fresh and dry root weight, fresh and dry leaf weight, total plant biomass, harvest index, brix content, titratable acidity, sugar/acid ratio, soil pH, leaf and root N, P, K, Ca and Fe content. The data were analyzed using SAS version 9 and means separated using Tukey's Honest Significant difference test at $P \leq 0.05$. Results showed that the use of vermicompost and biofertilizer at 30tonnes/hectare improved beetroot growth measured in leaf number, leaf area index and plant height; yield measured in root and leaf weight, total plant biomass and harvest index and quality measured in brix content compared with no fertilizer application and were comparable with the recommended inorganic fertilizer rate. Findings of this study indicate potential of using of vermicompost and biofertilizer to improve beetroot production, methods that principally provide for the use of sustainable and environmentally sound waste management systems to recycle crop nutrients.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
Ca	Calcium
CAN	Calcium Ammonium Nitrate
Fe	Iron
FYM	Farm Yard Manure
HCD	Horticultural Crops Development
HCL	Hydrochloric acid
HNO_3	Nitric Acid
NH_3	Aqueous ammonia
NPK-	Nitrogen, Phosphorus and Potassium
PSB	Phosphate Solubilizing Bacteria
RCBD-	Randomized Complete Block Design
SAS	Statistical Analysis System
t/ha	Tonnes per hectare
VAM	Vesicular Arbuscular Mycorrhiza

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Beetroot (*Beta vulgaris* var. *crassa* L.), a member of Chenopodiaceae family is an edible root vegetable consumed throughout the world. Beetroot is indigenous to Asia Minor and Europe and was first used for food about the third century although the crop had been grown for thousands of years for medicinal purposes (Hadfield *et al.*, 1996). Currently, it is widely grown in Germany and France and in lesser amounts in other European countries, Asia, South America and Africa.

In Kenya, beetroot is mainly grown for the domestic market. Beetroot juice is gaining importance for its nutritional and medicinal value especially for HIV infected persons (HCD, 2016). Despite the medicinal and nutritional attributes associated with the crop, the area under cultivation has increased over the years. According to HCD (2017) low yields per unit area of 7.5t/ha have been recorded as compared to 34 t/ha as the recommended optimal yield. Improved agronomic practices adopted through experimental learning by growers, however increased production from 634 MT in 2016 to 707 MT in 2017translating to a11% increase in yields in 2017 compared to 2016 (HCD, 2017).

Beetroot is a true biennial though grown as an annual, producing thickened root and a rosette of leaves during the first season and flowers and seeds during the second season. As a vegetable, the crop is mainly grown for its swollen roots but the leaves can also be eaten as spinach (Tesfaye *et al.*, 2015). It is a cool-season crop and a popular choice for cultivation as it is fairly easy to grow, is rapid maturing; reaching maturity within 60 days and has many varieties. The seeds germinate under a wide range of soil temperatures from as low as 4.5 °C to as high as 30 °C, with the optimum between 18 to 24 °C. It needs plenty of water for fast growth and does best on deep and well-drained, loose soils with high organic matter content (Pietermaritzburg *et al.*, 2009).

The most popular consumed part of beetroot is the tuberous root although the tops can be used as a leafy vegetable. Beetroot contains anthocyanidins; pigments that give the sweet, earthy-tasting vegetable its deep indigo colour. Beetroot also provides antioxidants and vitamins A and C. It contains the compounds, betaine and methionine, that support liver detoxification. Eating either the roots or leaves of beetroot can help combat anaemia (Lu *et al.*, 2003; Winkler *et al.*, 2005). Both parts of the plant are high in iron and can be steamed or eaten raw in salads. The high concentration of folate (a B vitamin) in beetroot helps prevent high blood pressure, dementia and birth defects such as Spina Bifida in unborn babies while

the presence of magnesium may ease muscle tension, stress and anxiety. Studies on mice have even shown that betacyanin (one of beetroot's key antioxidants and the element behind its deep red colour) may inhibit the formation of cancer-forming compounds called nitrosamines. Beetroot is high in macro and micronutrients and has a good quality and quantity of amino acids. In Africa, beetroot is used as an antidote to cyanide poisoning (Wettasinghe *et al.*, 2002). Beetroot helps normalize the pH balance of the body and has also been reported to increase the uptake of oxygen by as much as 400 percent (Jackman *et al.*, 1996).

In order to obtain high yields and good quality beetroot, it is essential to ensure friable soils and a continuous supply of nitrogen, phosphorus and potassium among other nutrients throughout the growing season (Pietermaritzburg *et al.*, 2009). Intensive cultivation by many smallholder farmers using inorganic fertilizers has led to increased yield at the expense of product quality and environmental degradation. The use of organic amendments on soil as nutrient inputs is increasing as an alternative agricultural practice for sustaining economically viable crop production with minimal environmental pollution (Padel *et al.*, 2009). Organic fertilizers have been reported to improve growth and yield of crops grown on dilapidated soils through enhancing physical, chemical and biological properties of the soils (Nair *et al.*, 2006; Saha *et al.*, 2008). Other reports have also shown that organic matter is an excellent source of plant–available nutrients and its addition to the soil could maintain high microbial populations and activities (Joshi *et al.*, 2010).

Vermicompost is a product of a non-thermophilic biodegradation of organic materials through interactions between earthworms and microorganisms (Atiyeh *et al.*, 2002). It is characterized by high porosity, aeration, drainage, water holding capacity and microbial activity (Atiyeh *et al.*, 1999). Vermicompost has greatly increased microbial activity and nutrient availability. In addition, it contains most nutrients in plant available forms such as nitrates, phosphates, and exchangeable calcium and soluble potassium which are responsible for increased plant growth and crop yield (Edwards & Arancon, 2004). Vermicompost has also large particulate surface area that provides many microsites for microbial activity and strong retention of nutrients. It is rich in microbial population and diversity, particularly fungi, bacteria and actinomycetes which can aid in biodegradation of waste and subsequently releasing nutrients as well as aerating the soil thereby enhancing growth of crops (Edwards & Bohlen, 1996). Vermicomposthas also been documented to contain plant growth regulators and other growth-influencing materials produced by the microorganisms which can contribute positively towards better crop yields (Atyieh *et al.*, 2002).

Similar to vermicompost, biofertilizers are ready to use organic formulations that are inoculated with live effective and beneficial microorganism(s) (EM) that are added to a soil to directly or indirectly make certain essential elements available to plants for their nutrition. On application to seed, roots or soil, biofertilizers mobilize the availability of nutrients through their biological activity and help to build up the micro-flora for good soil health and sound environment. Some EM can illicit systemic resistance in plants against a variety of pathogens Mghalu *et al.* (2010) and/or increase the supply or availability of primary nutrients to the host plant thereby promoting good growth (Gaur, 2010). They are cost effective, eco-friendly and renewable source of plant nutrients to supplement chemical fertilizers in sustainable agricultural system.

One of the most important factors that impact the physiology of beetroot plant growth and development is the availability of nutrients which can be taken up by plants from the soil. Phosphate and nitrogen are important for plant growth, but most plants have a limited ability to extract them from the environment. Such plants may need microbes involved in "nutrient recycling," to help them uptake and absorb these nutrients at optimal concentration, as plants donate waste by-products to the microbes as food. Various sources of biofertilizers include nitrogen fixers, Phyto stimulators, phosphate solubilizing bacteria, plant growth promoting rhizobacteria, among others Shekh (2006), application of which may enable growers to get a yield of high quality and to minimize environmental pollution (Das *et al.,* 2008). Many researchers have shown that growth, yield and quality parameters of certain plants are significantly increased by biofertilizers containing bacterial nitrogen fixers, phosphate and potassium solubilizing bacteria and microbial strains of some bacteria. Biofertilizers are considered as one of the most important factors in reducing the application of chemical nitrogen fertilizers, minimizing environmental pollution (Canbolat *et al.*, 2006; El-Sirafy *et al.*, 2006) and improving soil fertility status to sustain crop yield (Mostafa *et al.*, 2010).

1.2 Statement of the Problem

Beetroot is an important root vegetable with medicinal and nutritional value essentially needed in the human diet. Its' production in Kenya is, however, characterized by low yields per unit area standing at 7.5 t/ha compared to 34 t/ha recorded as the optimal yield. Most beetroot growers use conventional fertilizers to replenish soil nutrients. Repeated use of inorganic fertilizers has, however, been associated with degradation of soil fertility and environmental pollution with time apart from increasing the cost of production due to escalating prices of the fertilizers. On the other hand, most farms generate substantial amounts

of organic wastes annually through weeding, pruning, crop residues and kitchen waste. These wastes are high in nutrients like Nitrogen, phosphorus, potassium, calcium, iron, magnesium but end up in landfills, hence polluting the environment. Through composting these materials can be recycled into a useful form 'vermicompost' or 'biofertilizer' for reuse in crop production. Limited information is, however, available on the application rates of vermicompost and biofertilizer and their potential benefits in beetroot production in Kenya.

1.3 Justification of the Study

Beetroot is among the crops with an increasing demand in Kenya due to increasing awareness of the nutritional and medicinal value of the crop. Farmers in the country mostly grow the crop with low rates or no fertilizer application at all due to the high costs and/or inaccessibility of inorganic fertilizers resulting in reduced yields and quality. On the other hand, vermicompost and biofertilizer have been documented to be rich and sustainable sources of plant nutrients. It is anticipated that the use of vermicompost and biofertilizer in beetroot production will not only provide an affordable source of nutrient to farmers for high yield and better-quality beetroot production but also enhance biological and physical properties of the soil where used. Moreover, application of the findings of this study would also contribute towards reducing environmental pollution through reduction in waste accumulation, hence a healthy environment. Findings of this study will also contribute to the existing pool of scientific knowledge on beetroot culture.

1.4 Objectives of the Study

1.4.1 General Objective

To contribute towards increased beetroot production through the use of sustainable and environmentally sound waste management systems to recycle crop nutrients.

1.4.2 Specific Objectives

To determine the;

i. Effects of different application rates of vermicompost and biofertilizer on the growth of beetroot.
ii. Effects of different application rates of vermicompost and biofertilizer on the yield of beetroot.
iii. Effects of different application rates of vermicompost and biofertilizer on the quality of beetroot.

1.5 Hypotheses

i. Different application rates of vermicompost and biofertilizer have no significant effect on the growth of beetroot.

ii. Different application rates of vermicompost and biofertilizer have no significant effect on the yield of beetroot.

iii. Different application rates of vermicompost and biofertilizer have no significant effect on the quality of beetroot.

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CHAPTER TWO

LITERATURE REVIEW

2.1 Inorganic Fertilizer Use in Crop Production

Use of chemical fertilizers has been the kingpin of modern agriculture over the past 100 years. Consumption of NPK fertilizers rose to six-fold from 18070 (1999-2000) to108420 (2013-2014) thousand tons despite a tremendous increase in the cost of chemical fertilizer. The rampant use of chemical fertilizers contributes largely to the deterioration of the environment through depletion of fossil fuels, generation of carbon dioxide (CO_2), and contamination of water resources and loss of soil fertility (Wani *et al.*, 2002).

Although, inorganic fertilizers have been used as a way of sustaining soil productivity, the extent to which farmers can depend on this input is constrained by unavailability of the right type of inorganic fertilizers at the right time, high cost, lack of technical know-how and lack of access to credit (Chude, 1999). In addition, as indicated by Ansari and Ismail (2001), the application of chemical fertilizers over long period results in poor soil health, reduction in produce, and increase in incidences of pest and disease and environmental pollution. This concern has led to diversion of the attention of scientists towards making use of organic materials (both organic manures as well as organic wastes) for improving the physical properties of soils that allow profitable crop production (Somani & Totawat, 1996).

Organic inputs are often proposed as alternatives to mineral fertilizers. However, the traditional organic inputs such as crop residues, and animal manures cannot meet crop nutrient demand over large areas because of the limited quantities available, the low nutrient content of the materials, and the high labour demands for processing and application (Palm *et al.*, 1997).On the other hand, the application of bio-fertilizers and vermicompost have been recognized as an effective means for improving soil aggregation, structure and fertility, increasing microbial diversity and populations, improving the moisture-holding capacity of soils and increasing the soil Cation Exchange Capacity (CEC) and crop yields (Hargreaves *et al.*, 2008).

2.2 Organic Fertilizer Use in Crop Production

The use of organic fertilizers in crop production has gained much interest following increased use of chemicals under intensive cultivation that has not only contaminated the ground and surface water but also disturbed the harmony existing among the soil, plant and microbial population (Bahadur *et al.*, 2006). There has been a growing public concern about adverse impacts of chemical fertilizers on the environment and on the safety and quality of

food. Organic fertilizers can be used to promote a healthy population of beneficial organisms in the soil (Babalad *et al.*, 2009). A judicious use of organic fertilizers may be effective not only in sustaining crop productivity and in maintaining soil health, but also in supplementing chemical fertilizers in crop production (Mal *et al.*, 2003; Worthington, 2001). Intensive cultivation in many areas has led to a rapid decline in organic matter and nutrient levels besides affecting the physical properties of soil.

Several reports show that the combined and/or sole application of organic fertilizers can increase yield and influence quality attributes of vegetables (Mal & Chatterjee 2014). Vermicompost and biofertilizer are types of organic fertilizers which can improve the beneficial utilization of organic wastes. Organic amendments like vermicompost increase the organic matter content necessary for the maintenance of soil properties, which is beneficial for long-term sustainability and crop productivity. It has been argued that large-scale production of vermicompost through vermitech to recycle organic waste could effectively help in managing solid waste, and farmers could apply vermicompost thus produced for crop productivity; leading to a suitable environment-friendly effort towards a balanced ecosystem(Ansari *et al.*, 2001; 2001).Biofertilizer, on the other hand has been termed a cost-effective and renewable source of plant nutrients to supplement the parts of chemical fertilizers(Gaur, 2010).

2.2.1 Advantages of Organic Fertilizer

Use of organic matter such as animal manures, human waste, food wastes, yard wastes, sewage sludges and composts has long been recognized in agriculture as beneficial for plant growth and yield and the maintenance of soil fertility (Ramesh *et al.*, 2005). The new approaches to the use of organic amendments in farming such as the use of vermicompost and biofertilizers have proven to be effective means of improving soil structure, enhancing soil fertility and increasing crop yields. Organic matter is an excellent source of plant-available nutrients in addition maintaining high soil microbial populations and activities (Joshi & Pal Vig, 2010). Other than releasing nutrients as they break down, organic fertilizers develop the structure of the soil and raise its capacity to hold nutrients and water (Okalebo *et al.*, 2002). With time, organic fertilizers have the capacity to make soil and plants strong and healthy with slight to no risk of toxic accumulations of salts and chemicals that can be lethal to plants associated with the use of organic fertilizers (Hussain *et al.*, 2007). Organic fertilizers are biodegradable, renewable, justifiable, and ecologically friendly (Mal & Chatterjee, *2014*). Although slightly expensive in packages, people can make their own

organic fertilizer by finding inexpensive sources such as local dairy farms that do composting and sell composted manure (*Lu et al., 2003*).

2.2.2 Disadvantages of Organic Fertilizer

Microbes are necessary to break down organic materials and discharge nutrients into the soil (Edwards *et al.*, 2006). Since they require warmth and moistness to perform their job, the efficiency of organic fertilizer is seasonally restricted. These microbes gain energy from decaying animal and plant matter (Arancon *et al.*, 2006). Organic fertilizers decompose consistent with nature's rules, thus in most cases they may not produce nutrients the moment they are needed (Thankamani *et al.*, 1996). Growers need to be persistent as progress will not be seen overnight. Rather, an insufficiency in plants may essentially be seen during the first few months until the initial application breaks down (Aalok *et al.*, 2008). Nutrient proportions are often unidentified, and the general percentage is below that of chemical fertilizers. Nevertheless, some organic products are essentially greater in certain nutrients (Edwards *et al.*, 2006).

2.3 Vermicomposting and the Role of Earthworms

Vermicomposting is a non-thermophilic process by which organic materials are converted by earthworms into rich soil amendments with greatly increased microbial activity and nutrient availability. In addition, vermicomposting leads to the release of nutrients in plant available forms such as nitrates, phosphates, and exchangeable calcium and soluble potassium which are responsible for increased plant growth and crop yield (Edwards & Arancon, 2004).

The role of earthworms in the breakdown of organic debris on soil surface and soil turn over process was first highlighted by Darwin in 1881 (Aalok *et al.*, 2008). Since then, it has taken almost a century to appreciate their important contribution in curbing organic pollution and providing topsoil to impoverished lands thus increase in crop production. This realization has awakened the global population to give a serious thought to utilize earthworms for the benefit of mankind (Hadi *et al.*, 2011). An innovative discipline of vermiculture biotechnology, comprising the breeding and propagation of earthworms and the use of its castings has become an important tool of waste recycling which can be used in crop production. Essentially, the vermiculture provides for the use of earthworms as natural bioreactors for cost-effective and environmentally sound waste management (Chaoui *et al.*, 2003). There is now an all-round recognition that adoption and exploitation of vermiculture

biotechnology besides arresting ecological degradation could go a long way towards meeting the nutrient needs of the agricultural sector in a big way. On another front, widespread use of vermicultural biotechnology could result in increased employment opportunity and rapid development of the rural areas (Wani, 2002).

2.3.1 Vermicompost and its Properties

Vermicompost is a product derived from the accelerated biological degradation of organic wastes by earthworms. Earthworms consume and fragment the organic wastes into finer particles by passing the waste through a grinding gizzard that feeds on the microorganisms found on the organic waste. The process accelerates the rates of decomposition of the organic matter and alters the physical and chemical properties of the material, leading to a humification effect in which the unstable organic matter is fully oxidized and stabilized (Orozco *et al.*, 1996). The end product, commonly referred to as vermicompost is greatly humified through the fragmentation of the parent organic materials by the earthworm and colonization by microorganisms (Edwards & Bohlen, 1996). Vermicompost has good porosity, aeration, drainage, and water-holding capacity (Arancon *et al.*, 2006). It has increased surface area which provides more microsites for microbial decomposing organisms, and strong adsorption and retention of nutrients (Shi-wei & Fu-zhen, 1991). Vermicompost tends to have pH values near neutrality which may be due to microbial metabolic processes (Albanell *et al.*, 1988). It is also reported that moisture content of vermicompost is reduced progressively during vermicomposting giving final moisture contents between 45 and 60%, the ideal moisture contents for land-applied composts (Edwards & Burrows, 1988).

Among its superior chemical attributes, Edwards and Burrows (1988) reported that vermicompost, especially from animal waste sources, usually contained more mineral elements than commercial plant growth media, with many of these elements changed to forms that could be readily taken up by the plants, such as nitrates, exchangeable phosphorus, and soluble potassium, calcium, and magnesium. Orozco *et al.* (1996) reported that coffee pulp increased the availability of nutrients such as phosphorus, calcium and magnesium, after processing by *Eisenia fetida*. Phosphorus was 64% higher in vermicompost than in the original organic material which was suggested to be due to increased phosphatase activity from the direct action of gut enzymes and indirectly by the stimulation of microorganisms. Werner and Cuevas (1996) reported that most vermicompost contained adequate amounts of macronutrients and trace elements of various kinds but exact concentration of the nutrients

depended on the sources of the earthworm feedstock. In investigations into the bioconversion of solid paper-pulp mill sludge by earthworms, it was reported that total carbohydrate content decreased while total extractable carbon, non-humified fraction and humification rates increased by the end of the experiment (Rashtbari *et al.*, 2012).

Vermicompost has many outstanding biological properties. It is rich in bacteria, actinomycetes, fungi Edwards *et al.* (2006) and cellulose-degrading bacteria (Werner and Cuevas, 1996). In addition, Tomati *et al.* (1983) reported that earthworm castings, obtained after sludge digestion were rich in microorganisms, especially bacteria. Nair *et al.* (2006) compared the microorganisms associated with vermicompost with those in traditional composts. Vermicompost had much larger populations of bacteria (5.7×10^7), fungi (22.7×10^4) and actinomycetes (17.7×10^6) compared with those in conventional composts. The outstanding physio-chemical and biological properties of vermicompost makes it an excellent material as an additive to greenhouse container media, organic fertilizers or soil amendments for various horticultural field crops.

2.3.2 Effects of Vermicompost on Growth, Yield and Quality of Crops

Many greenhouse experiments have demonstrated that vermicompost can have consistently positive effects on plant germination, growth, yield and quality. Using a wide range of test plants such as pea, lettuce, wheat, cabbage, tomato and radish, Edwards and Burrows (1988) reported that vermicompost increased seedling emergence compared with those in control commercial plant growth media. Similar trends of increased growth were also reported in greenhouse pot trials using 0% to 100% mixtures of vermicompost and sand (Buckerfield *et al.*, 1999). Although the germination of radish decreased with increasing vermicompost concentrations, radish harvest weights were increased proportionally to the application rates of vermicompost, with the yields of plants in 100% vermicompost being up to ten times greater than those in 10% vermicompost. Buckerfield and Webster (1998) reported that vermicompost applications inhibited germination initially, but subsequent weekly applications of the diluted extracts improved plant growth and significantly increased radish yields by up to 20%.

The growth of tomato, lettuce, and pepper were reported to be best at substitution into soils at rates of 8-10%, 8%, and 6% using duck waste vermicompost and peat mixture (Wilson & Carlile, 1989). Subler *et al.* (1998) reported increased plant growth in commercial media, Metro-Mix (MM360), composts from biosolids and yard waste traditional composts using

tomato and marigold as test plants. Metro-Mix 360 is prepared from vermiculite, Canadian sphagnum peat moss, bark ash and sand, and contains a starter nutrient fertilizer in its formulation. In their experiment, increase in chlorophyll contents in response to vermicompost was observed at early stages of marigold growth. Later, increase in leaf areas and significant increase in the total plant weights were reported in 10% vermicompost and 90% MM360 combinations compared with 100% MM360. Significant increases in tomato seedling weights after substitution of 10 % and 20% vermicompost into MM360 were also reported (Arancon *et al.*, 2004). Raspberries grown in commercial media substituted with 20% pig manure vermicompost had much larger shoot dry weights compared with plants that received a complete inorganic fertilizer. In investigations in the U.K. by Scott (1988), using hardy nursery stocks of *Juniperus, Chamaecyparis* and *Pyracantha*, 20-50% substitution of vermicompost from cattle manure, pig manure, and duck waste into MM360, with regular application rates of nutrients, produced better growth than plants grown in a peat: sand mixture used as a control. In the second year of this experiment, there were variable responses among the test crops used but 25% of all three types of animal waste used with the addition of a controlled release fertilizer Osmocote (18:11:10), produced increased growth of *Juniperus sabinatamariscifolia*.

Chan and Griffiths (1988) reported stimulating effects of pig manure vermicompost on the growth of soybeans (*Glycine max),* particularly in terms of increased root lengths, lateral root numbers, and internode lengths of seedlings. Similar responses in growth were observed from cloves (*Syzygium aromaticum*) and black peppers (*Piper nigrum*) sown into 1:1 mixture of vermicompost and soil (Thankamani *et al.*, 1996). Black pepper cuttings raised in vermicompost were significantly taller and had more leaves than those grown in commercial potting mixtures. Plant height, number of branches, and the longest taproots were seen on cloves grown in the vermicompost mixtures.

Substitution of MM360 by 30% or 40% pig manure vermicompost produced more vegetative growth and flowers of marigolds in mixtures containing 40% pig manure vermicompost (Atiyeh *et al.*, 2002). Pig manure substitutions ranging from 20% up to 90% into MM360 produced marigold plants with significantly more roots. Peppers produced greater fruit yields when grown in mixtures containing 40% food waste vermicompost and 60% MM360 (Arancon *et al.*, 2004).

When cabbage was grown in compressed blocks made from pig waste vermicompost, they were larger and more mature at harvest compared to those grown in commercial blocking material (Edwards and Burrows, 1988). In a field experiment, applying vermicompost made

of cassava peel mixed with guava leaves and poultry droppings, Mba (1983) reported more shoot biomass and increased seed yields of cowpeas. Masciandro *et al.* (1997) investigated the effects of direct applications of vermicompost produced from sewage sludge into the soil as well as fertigation with humic extracts from vermicompost. They reported a greater growth index of garden cress (*Lepidium sativum)* treated with vermicompost than in control treatments with no vermicompost applications. Soil analyses after the vermicompost applications showed marked improvements in the overall physical and biochemical properties of the soil.

A surface application of vermicompost derived from grape material spread under grape vines covered with a straw and paper mulch increased yields of grape by 55% (Buckerfield & Webster, 1998). The increase in yields included large increase in both bunch-weights and bunch numbers and no losses in flavor. In a second site, applications of vermicompost from animal manures under straw mulch increased grape yields by up to 35% with vermicompost applications tending to have greater effects on yields when applied under mulches than when applied directly to the soil surface; possibly due to degradation of vermicompost on exposure to sun and air. In later experiments Webster (1998) reported that a single application of vermicompost to grapes still had positive effects on yields for 5 years. Moradi *et al.* (2014) reported that yields of Thompson Seedless grapes were significantly greater when vermicompost was applied. Vadiraj *et al.* (1998) compared vermicompost application rates of 5 t/ha up to 25 t/ha in increments on growth of three varieties of coriander. The responses to the vermicompost applications differed for all three varieties tested. The varieties RCr-41, Bulgarian, and Sakalespur Local attained largest yields at vermicompost applications rates of 15 t/ha, 10-25 t/ha, and 20 t/ha, respectively.

Some field experiments have involved amending soils with vermicompost in conjunction or combination with recommended inorganic fertilization programs. Vermicompost applied at 12 t/ha to field soils together with 100% or 75% of the recommended application rate of inorganic fertilizers significantly increased yields of okra (*Abelmoschus esculentus*) (Ushakumari *et al.*, 1999). Tuberlets from a true potato seed line, produced the greatest marketable yields after amending the soils with 75% of the recommended inorganic fertilizers and 2.5 t/ha vermicompost (Mrinal *et al.*, 1998). Sunflower (*Helianthus annuus*) yielded most after soil treatments with 50% of the recommended application rates of inorganic fertilizer and 5 t/ha or 10 t/ha of vermicompost (Dayal *et al.*, 1998). Pea (*Pisum sativum*) increased yields and production after amending soils with 100% of the recommended application rate of inorganic fertilizers, in combination

with vermicompost produced from farm manures applied at rates of 10 t/ha to soils (Ramachandra *et al.*, 1998). Zende *et al.* (1998) reported increased yields of sugarcane after amending soils with vermicompost at rates of 5 t/ha together with 100% of the recommended application rate of inorganic fertilizers. Mulberry (*Muros sp.*) growth increased after amending soils with vermicompost applied at rates of 10 t/ha together with 100% of the recommended application rates of inorganic fertilizers to soils (Murakar *et al.*, 1998). Flowering of China aster (*Callistephus chinensis* L.) increased when it was grown in soils amended with 10 t/ha vermicompost produced from farm manures, together with 100% of the recommended application rate of inorganic fertilizers (Nenthra *et al.*, 1999).

Arancon *et al.* (2003) reported significantly increased growth and yields of field tomato (*Lycopersicon esculentum*) and peppers *(Capsicum annum grossum*) when vermicompost produced commercially from cattle manure, food waste or recycled paper were applied to field plots at rates of 20 t/ha and 10 t/ha in 1999 and at rates of 10 t/ha and 5 t/ha in 2000 compared with those receiving equivalent amounts of inorganic fertilizer. Food waste and recycled paper vermicompost were applied at rates of 10 t/ha and 5 t/ha in 2000 to strawberries (*Fragaria spp.*) (Prasetya & Talkah, 2013). All vermicompost-treated plots were supplemented with inorganic fertilizers to equalize the available N levels in all plots at transplanting. The marketable tomato yields in the vermicompost (plus fertilizers) plots were consistently and significantly greater than those from inorganic-fertilizer only treated plots (Sundararasu *et al.*, 2012). There were significant increases in shoot weights, leaf areas and marketable fruit yields of pepper plants grown in plots that were treated with vermicompost compared to those of plants grown in inorganic fertilizers. Leaf area, number of strawberry suckers, number of flowers, shoot weights, and marketable fruit yields of strawberries all increased significantly in response to supplemented vermicompost applications compared to those from strawberries that received inorganic fertilizers only (Arancon *et al.*, 2004).

2.4 Bio-fertilizer Use in Crop Production

Bio-fertilizers are natural fertilizers that are microbial inoculants of bacteria, algae, fungi alone or in combination. They are defined as a product containing carrier based (solid or liquid) living micro-organisms that are agriculturally useful in terms of nitrogen fixation, phosphorous solubilization or nutrient mobilization (The Gazette of India, 2006). Bio-fertilizers augment the availability of essential elements like nitrogen, potash, phosphorous, Sulphur by directly supplying them or transforming them into soluble form in addition to helping plants to uptake several micronutrients. So far, emphasis has been given to certain

types of bacteria such as *Rhizobium, Azotobactor, Azospirillum*, and Phosphate Solubilizing Bacteria (PSB) (Adholeya & Pant, 2007). However, in practice a large variety of other microbial inoculants are also available and are being used in making biofertilizers such as Blue Green Algae, Trichoderma, Vesicular Arbuscular Mycorriza (VAM) and *Azolla (Milani et al.*, 2008).

2.4.1 Bio-fertilizer and its Properties

Biofertilizers are ready to use live formulations of effective and beneficial microbes (EM). On application to seed, roots or soil, biofertilizers mobilize the availability of nutrients through their biological activity and help to build up the micro flora for good soil health and sound environment (Mghalu, 2010). These microbes fix and activate the nitrogen in the soil, convert the unavailable P into available P, and cause fast decomposition of organic matter. Biofertilizers are mainly constituted of selected living cells of microbes which provide the plants with nutrients through their root system (Panda, 2007). The microbes in these fertilizers use different mechanisms to provide nutrients to the plants. They are capable of nitrogen fixing, phosphate solubilizing, phosphate mobilizing, and promotion of rhizobacteria (Bhat *et al.*,2010). It includes mainly the nitrogen fixing, phosphate solubilizing and plant growth promoting microorganisms.

Biofertilizer culture consists of co-existing beneficial microorganisms, mainly species of photosynthetic bacteria (*Rhodopseudomonas plastris* and *Rhodobacter sphacrodes*), lactobacilli (*Lactobacillus plantarum, L. casei*, and *Streptococcus lactis*), yeast (*Saccharomyces* spp.), and actinomycetes (*Streptomyces* spp.), which improve crop growth and yield by increasing photosynthesis, producing bioactive substances such as hormones and enzymes, controlling soil diseases, and accelerating decomposition of lignin materials in the soil (Javaid & Bajwa, 2000). The uniqueness of microorganisms and their often-unpredictable nature and biosynthetic capabilities, given a specific set of environmental and cultural conditions, has made them likely candidates for solving particularly difficult problems in life and other fields as well (Haneef *et al.*, 2014). The various ways in which microorganisms have been used over the past 50 years to advance medical technology, human and animal health, food processing, food safety and quality, genetic engineering, environmental protection, agricultural biotechnology, and more effective treatment of agricultural and municipal wastes provide a most impressive record of achievement.

Biofertilizer is also a cost-effective and renewable source of plant nutrients to supplement the parts of chemical fertilizers. A judicious use of biofertilizer may be effective

not only in sustaining crop productivity and soil health, but also in supplementing chemical fertilizers of the crops. There are several reports, which show that the combined and/or sole application of organic manures and biofertilizer increases yield and influences quality attributes of vegetables (Bahadur *et al.*, 2006; Mal & Chatterjee, 2006; Worthington 2001). Numerous field and greenhouse trials indicate the benefits of biofertilizer in crop production, as a probiotic in poultry and livestock rations, and as a starter to improve composting and recycling of municipal/industrial wastes and effluents (Hussain *et al.*, 1999).

2.4.2 Effect of Biofertilizers on Growth, Yield and Quality of Crops

There are controversial reports about the effect of applying bio-fertilizer on crop growth and yield. Some researchers have reported an increase in crop growth and yield following application of biofertilizer Javaid *et al.* (2010) while others have revealed that the effect of bio-fertilizer on crop growth and yield was not usually evident or even negative, especially in the first test crop (Shah, 2010). Application of bio-fertilizers can play an important role in improving the supply of nutrients, organic carbon, accumulation of soil enzymes, future productivity, directly reflects on soil fertility index, economy of farmers, maintain sustainability in natural soil ecosystem and vegetables crops availability in the coming years.

Various studies in agriculture have reported remarkable improvement on yield as a result of using bio-fertilizer. Javaid and Bajwa (2011) studied the effect of biofertilizer in pea production. Results showed that statistically similar yield of peas were achieved from use of inorganic fertilizer compared to biofertilizer treatments. Similarly, Riaz *et al.* (2011) found statistically equal production of radish in fertilizer and biofertilizer treatments. Ayyub *et al.* (2019) conducted a comparative study of Nature Farming profitability and sustainable development in vegetable production. He concluded that biofertilizer-Technology for potato production resulted in higher yield than the normal doze of NPK or FYM alone. Moreover, the use of biofertilizer proved more economical, generating a profit of Rs.59640/Ha (Kshs. 95,039.17/ha) than Rs.46198/ha (Kshs. 72,068.88/ha) generated under NPK.

Chandrashekar (2003) observed that the plant growth parameters *viz.*, shoot and root length and number of leaves per plant in green gram plants at 45 days were significantly increased due to inoculation of P-solubilizing fungal strains along with rock phosphate application as compared to rock phosphate alone (control).Vasanthakumar (2003) reported that combined inoculation of *Azospirillum* (AZUS10) and PSB isolate (PSB7) produced synergistic effect, resulting in increased root length, shoot length, stem girth, number of leaves and number of branches in solanaceous crop plants. Kumar and Sharma (2006) studied

the effect of different methods of biofertilizer application in tomato seed production. They used four microorganisms, namely *Azotobacter*, *Azospirillum*, *Pseudomonas* and vesicular arbuscular mycorrhiza (VAM)and application of these microorganisms was done using three methods i.e., nursery soil treatment, seedling treatment and field soil treatment, individually and in combinations. The study revealed that *Azotobacter* when applied to nursery, seedling and field soil resulted in maximum values of number of fruits per plant (19.23), fruit yield per plant (1109 g) and per hectare (356.9 kg), 1000 seed weight (3.63 g), seed yield per plant (4.58 g) and per hectare (152.70 kg) and cost benefit ratio (1:1.45). Labeena (2001) reported that the plant height, fruit weight per plant and diameter of the fruits were higher in mycorrhiza inoculated plants of tomato compared to uninoculated control plants. Results on the effect of inoculation of gram-negative bacteria to influence plant growth and P uptake under greenhouse condition using tomato as a test plant indicated that plant growth parameters and P uptake were increased significantly following inoculation with *Burkholderia cepacia* (RS2), *P. fluorescencs* (51) and *S. marcescens* (ERZ) over single super phosphate control and reference strain *P. striata* (H27) (Mahesh (2002).

Hussain *et al.* (2007) studied the effect of organic amendments and biofertilizer on radish production and found that the maximum oven dry weight of radish in biofertilizer + PM (Poultry manure) was statistically the same as that of NPK treatment. The yield of radish was statistically equal in poultry manure fermented with biofertilizer and poultry manure. In a study done on vegetable bean and mung bean, Marambe and Sangakkara (2021) observed that the application of biofertilizer alone does not produce high yield, however, when added with organic matter, yield of both species increased significantly. In another study on the effects of biofertilizer on tomato and capsicum, Marambe and Sangakkara (2021) demonstrated that both crops produced similar responses to the addition of organic matter. Application of biofertilizer also increased yield over the control by 14 to 26% in the first season for both crops and by 38 % and 18%, respectively over the control in the second season. These results suggest a long-term benefit from the use of biofertilizer.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site Description

Two trials were conducted at the Horticulture Research and Teaching Field, Egerton University, Njoro. The field lies at a latitude of 0° 23' South, longitudes 35° 35' East in the Lower Highland III Agro Ecological Zone (LH3) at an altitude of approximately 2,238 meters above sea level (Jaetzold & Schmidt, 1983). Average maximum and minimum temperatures range from 19 °C to 22 °C and 5 °C to 8 °C, respectively, with a total annual rainfall ranging from 1200 to 1400 mm. The soils are predominantly andosols (Kinyanjui, 1979).

3.2 Construction of Vermicompost Tank

The tank used consisted of two chambers enclosed by walls (1.5m width, 2.5m length and 0.9m height) made from building stones. Inside the chambers, bricks were laid at a gradient to allow for drainage of excess water and collection of vermicompost tea. A shade net was put over the bricks on which the organic waste materials were placed. The partition wall of the tanks contained small holes to facilitate free movement of earthworms from one chamber to another. An outlet was provided at the lowest corner of each chamber for collection of vermicompost tea. The two components of the tank were filled with kitchen waste from the university's kitchen one after another. Both chambers were filled up leaving 30cm space at the top of the tank.

3.3 Vermicompost Preparation and Biofertilizer Used

Kitchen waste was introduced for vermicomposting. Each tank was filled with 50 Kg kitchen wastes (OW), 15 Kg dung slurry (DS), 2 Kg Rock Phosphate (RP), 500 to 700 earthworms (EW), 5 liters water (W) in a ratio of 5:1.5:0.2:50-70:0.5, respectively. The materials were allowed to decompose for20days. Once the heat that evolved during decomposition subsided, that is after the20 days, *Eisenia fetida* were released through the cracks that had developed. The tank was then covered with white polypropylene(pp)gunny bags to prevent birds from picking the earthworms. Water was sprinkled every three days to maintain adequate moisture and body temperature of earthworms for effective vermicompositing. The vermicompost was ready in about two months. On the other hand, the biofertilizer used in the study was sourced from Pwani University College in Kilifi County. It was made of organic municipal waste inoculated with *Lactobacillus*.



Plate 2: Multiplying worms in the crates

3.4 Beetroot Production

3.4.1 Planting Material

Beetroot cultivar'Crimson Globe' was used in the study. This red variety was chosen because of it matures early, has sugary taste and its requirement for relatively high organic matter for better yields. The seeds used were purchased from Kenya Seeds Company Ltd - Nakuru.

3.4.2 Experimental Design and Treatment Application

The study was an unbalanced factorial experiment in a randomized complete block design (RCBD) with four replications. The factors tested were organic fertilizer types at 2 levels (vermicompost and biofertilizer) and organic fertilizer rates at four levels (5, 10, 20 and 30 t/ha) with a negative control treatment where no fertilizer was applied and a positive control where the recommended inorganic fertilizer rates were used. This gave a total of 10 treatment combinations (Table 1). The rates of organic fertilizers used were chosen based on the recommended organic manure rates for most vegetables. Both vermicompost and biofertilizer were incorporated into the soil at pre-plant. Each block consisted of 10 experimental units with treatments randomly assigned. The spacing between individual block

was 1m while individual experimental units within a block was spaced 0.5m apart. The total area of each block was 15.5 X1.2 m. Each experimental unit measured 1.1X 1.2 m consisting of 4 rows of beetroot sown 30 cm apart and 10 cm intra row totaling to40 plants per experimental unit.

3.4.3 Land Preparation, Crop Establishment and Maintenance

Land was first prepared by manual digging to a depth of about 30 cm and then harrowed to a fine tilth. Vermicompost and biofertilizer was then incorporated at designated rates in the different experimental units. The positive control was, NPK (17:17:17) applied at the rate of 60kg/ha as a basal at planting and a top dress of Calcium Ammonium Nitrate (CAN) (26% N) at a rate of 60 kg N/ha thirty days later.



Plate 3: Crop establishment

Table 1: Treatment Combinations of Vermicompost and Biofertilizer

Treatment notations	Description
B_0	No fertilizer application (negative control)
B_1	Recommended inorganic fertilizer (positive control)
O_1R_1	Vermicompost at 5 t/ha
O_1R_2	Vermicompost at 10 t/ha
O_1R_3	Vermicompost at 20 t/ha
O_1R_4	Vermicompost at 30 t/ha
O_2R_1	Biofertilizer at 5 t/ha
O_2R_2	Biofertilizer at 10 t/ha
O_2R_3	Biofertilizer at 20 t/ha
O_2R_4	Biofertilizer at 30 t/ha

Beetroot seed was then drilled at a row spacing of 30 cm. When seedlings got to about 7.5cm, they were thinned to attain an intra-row spacing of 10 cm. Thereafter, all other maintenance practices including weeding, pest and disease control and irrigation were applied uniformly whenever required.

3.4.4 Data Collection

The variables studied included; growth variables, yield variables and quality variables which are described below:

a) Growth Variables

Growth variables measured in this study were plant height, number of leaves, Leaf Area (LA) and Leaf Area Index (LAI). Twelve plants were randomly selected from the inner rows of each experimental unit leaving plants in the outer rows to serve as guard rows and their height measured in centimeters (cm)using a ruler on a weekly basis. Leaf numbers were also counted from the plants and recorded as leaf number per plant (no./plant) LA was also determined from the twelve plants by measuring the length and width of each leaf using a ruler then multiplying these by the constant 0.5 used for triangular leaves such as that of beetroot (length × width × 0.5) (National Canners Association. Research Laboratories, 1968). From the computed LA, LAI was determined using the formula; LAI= Leaf area/soil area as described by National Canners Association Research Laboratories (1968).

b) Yield Variables

Upon harvest at maturity stage, twelve representative sample beetroots were taken from each experimental unit for determination of fresh and dry root weight, fresh and dry leaf weight, economic yield and total biomass. The root and shoot of each harvested sample plant were separated and cleaned. Both fresh root and shoot yield was then determined as fresh root and shoot weight by weighing the root and shoot using a weighing scale balance (XJ-4K801; Shangai Precision and Scientific Instrument Co., Shangai, China) and recorded as fresh root or shoot yield in grams per plant (g/plant) and later converted into t/ha. The total biomass was determined after separately oven drying100gmsof the detached roots and shoots at 75°C toa constant weight and the dry weight for each component measured and recorded in g/plant. The total biomass per plant was then obtained as the summation of the root and shoot dry weights of the individual plants and expressed in tonnes per hectare (t/ha) using the formula:

Total biomass (t/ha) = The dry weight of shoots + dry weight of harvestable roots.

Economic yield in this study was taken as fresh weight of the edible part, in this case the root dry weight in g/plant which was also converted to t/ha. From these data, harvesting index was then computed using the formula;

Harvest index= Economic Yield / Total Biomass

Where; economic yield is the harvestable root dry weight and total biomass is the dry weight of shoots+ dry weight of the harvestable roots.

c) Quality Variables

Quality attributes measured included iron, calcium and brix content, titratable acidity and sugar/acid ratio. Another sample of 6 beetroots were taken from each experimental unit and blended to produce juice for determination of the quality variables. Calcium and iron content was determined using Atomic absorption spectrophotometer (AAS) method as described by Okalebo *et al.* (2002). Brix content was determined using a hand held refractometer (0-30 °Brix) (RHW refractometer, Optoelectronic Technology Company Ltd. UK) while titratable acidity was on the other hand determined using the colored indicator method and percent acidity computed as;

Percent acid = Titre× acid factor × 100/10 ml of beetroot juice

NB: For the case of beetroots, the predominant acid is folic acid which is an organic acid with an acid factor of 0.064 (National Canners Association. Research Laboratories, 1968).

There after sugar: acid ratio was determined using the formula;

Sugar acid ratio = Percent brix content/ Percent acid content

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3.4.5 Analysis of Soil, Manures and Leaf and Root Tissue for N, P, K, Fe, Ca, pH

Soil (top and sub mixture), manures and mature beetroot roots and shoots were analyzed for total nitrogen (N), phosphorus (P)and potassium (K) levels. Soil pH was measured using a pH meter (AB15 Fisher Accumet ®); nitrogen level (%) was determined using the Kjeldahl method; phosphorus level (ppm) by Vanadate-Molybdate method and potassium (ppm) using Atomic Absorption Spectrophotometer (AAS) as described by Okalebo *et al.* (2002). The analysis was done by AgriQ Quest Limited, Nairobi, Kenya.

3.4.6 Data Analysis

The data collected were subjected to Analysis of Variance (ANOVA) at $P \leq 0.05$, using SAS (SAS Institute, 2005) and where F test was significant; means for significant treatments were separated using the Tukey's Honest Significant difference test at $P \leq 0.05$. The study was initially analyzed as a one factor experiment using the statistical model;

$$Y_{ijkl} = \mu + \alpha_i + P_j + \beta_k + P\beta_{jk} + \varepsilon_{ijkl}$$

where; Y_{ijkl}- beetroot response,

μ -grand mean,

α_i- i^{th} effect of the block,

P_j - j^{th} effect of season,

β_k - k^{th} effect of a treatment combination,

$P\beta_{jk}$- effect of interaction of j^{th} seasonal effect and k^{th} treatment combination,

ε_{ijkl}- random error component which is normally and independently distributed about zero mean with a common variance σ^2.

Thereafter, the main effects of fertilizer type (vermicompost and biofertilizer) and organic fertilizer rates were also separately extracted from the data and compared to no fertilizer application and application of inorganic fertilizer at the recommended rate using the statistical model;

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \varepsilon_{ijk}$$

where; Y_{ijk}- beetroot response,

μ -grand mean,

α_i- i^{th} effect of the block,

β_j - j^{th}effect of fertilizer type or fertilizer rate,

ε_{ijk}- random error component which is normally and independently distributed about zero mean with a common variance σ^2.

CHAPTER FOUR

RESULTS

In this chapter results obtained are presented in the following order; growth variables yield variables, quality variables and soil nutrients and beetroot leaf and root nutrient content.

4.1. Effects of Different Application Rates of Vermicompost and Biofertilizer on the Growth of Beetroot

Beetroot growth variables measured in this study were; leaf number per plant, plant height and leaf area index.

a) Leaf Number

The use of different rates of vermicompost and biofertilizer influenced beetroot leaf numbers. The interaction of season x treatment effect on beetroot leaf numbers was however not significant. Averaged across the two seasons, beetroot plants treated with biofertilizer at the rate of 30t/ha produced the highest leaf numbers while the least leaf numbers was obtained under the control treatment with no fertilizer applied throughout the seasons (Table 2). Leaf numbers obtained from the other rates of vermicompost and biofertilizer treatments were not statistically different from those of both the negative control and the 30t/ha biofertilizer treatment and were also comparable to those of the recommended inorganic rate of NPK (positive control). Among the two seasons, significantly more leaves were produced in season 2 than season 1 (Table 2).

The main effect of fertilizer type on beetroot leaf numbers was on the other hand not significant in all sampling dates (Figure 1). However, a general trend could be established where the number of leaves tended to be slightly higher with application of organic fertilizer as either vermicompost or biofertilizer compared to no fertilizer application or the use of NPK fertilizer. The main effect of organic fertilizer rate on leaf numbers was, however, significant with the application rate of 30t/ha resulting in higher leaf numbers compared to no fertilizer application (0t/ha) during most sampling dates (Figure 1). The number of leaves recorded for the NPK treatment was not significantly different from those recorded for all organic fertilizer rates during most sampling dates. A general trend marked by an increase in the number of leaves with an increase in the amount of organic fertilizer applied was noted throughout the study period.

Table 2: Effects of Different Rates of Vermicompost and Biofertilizer on Leaf Numbers (No./Plant) of Beetroot

	Days after planting											
	40			47			54			61		
Treatment	S1†	S2	**Treatment Mean**	S1	S2	**Treatment Mean**	S1	S2	**Treatment Mean**	S1	S2	**Treatment Mean**
0t/ha	7.54*	7.60	**7.57b****	9.54*	9.60	**9.57b****	11.50*	11.60	**11.55b****	13.50*	13.60	**13.55b****
17:17:17 (60kg/ha)	8.17	8.60	**8.38ab**	10.3	10.55	**10.34ab**	12.08	12.55	**12.32ab**	14.08	14.55	**14.32ab**
5t/havermicompost	7.59	8.05	**7.82ab**	9.59	9.95	**9.77ab**	11.54	11.95	**11.75ab**	13.54	13.95	**13.75ab**
10t/ha vermicompost	7.29	9.05	**8.17ab**	9.30	11.05	**10.17ab**	11.25	13.05	**12.15ab**	13.25	15.05	**14.15ab**
20t/ha vermicomost	8.25	8.80	**8.53ab**	10.1	10.85	**10.53ab**	12.17	12.85	**12.51ab**	14.17	14.80	**14.48ab**
30t/ha vermicompost	8.34	9.25	**8.80ab**	10.34	11.30	**10.82ab**	12.29	13.30	**12.80ab**	14.29	15.30	**14.80ab**
5t/ha biofertilizer	7.54	7.90	**7.72ab**	9.54	9.90	**9.72ab**	11.50	11.90	**11.70ab**	13.46	13.90	**13.68ab**
10t/ha biofertilizer	8.00	8.10	**8.05ab**	10.00	10.10	**10.05ab**	11.96	12.10	**12.03ab**	13.96	14.10	**14.03ab**
20t/ha biofertilizer	8.54	8.20	**8.37ab**	10.50	10.20	**10.35ab**	12.46	12.20	**12.33ab**	14.46	14.20	**14.33ab**
30t/ha biofertilizer	8.58	9.20	**8.89a**	10.58	11.20	**10.89a**	12.54	13.15	**12.85a**	14.54	15.15	**14.85a**
Mean Season	**7.9f**	**8.4e**		**9.9f**	**10.4e**		**11.9f**	**12.4e**		**13.9f**	**14.4e**	

*Season x treatment interaction is not significant according to the F-test at $P \leq 0.05$.

**Means within a sampling day followed by the same letter in a letter series are not significantly different according to Tukey's Honestly Significantly Test at $P \leq 0.05$.

†S stands for season.

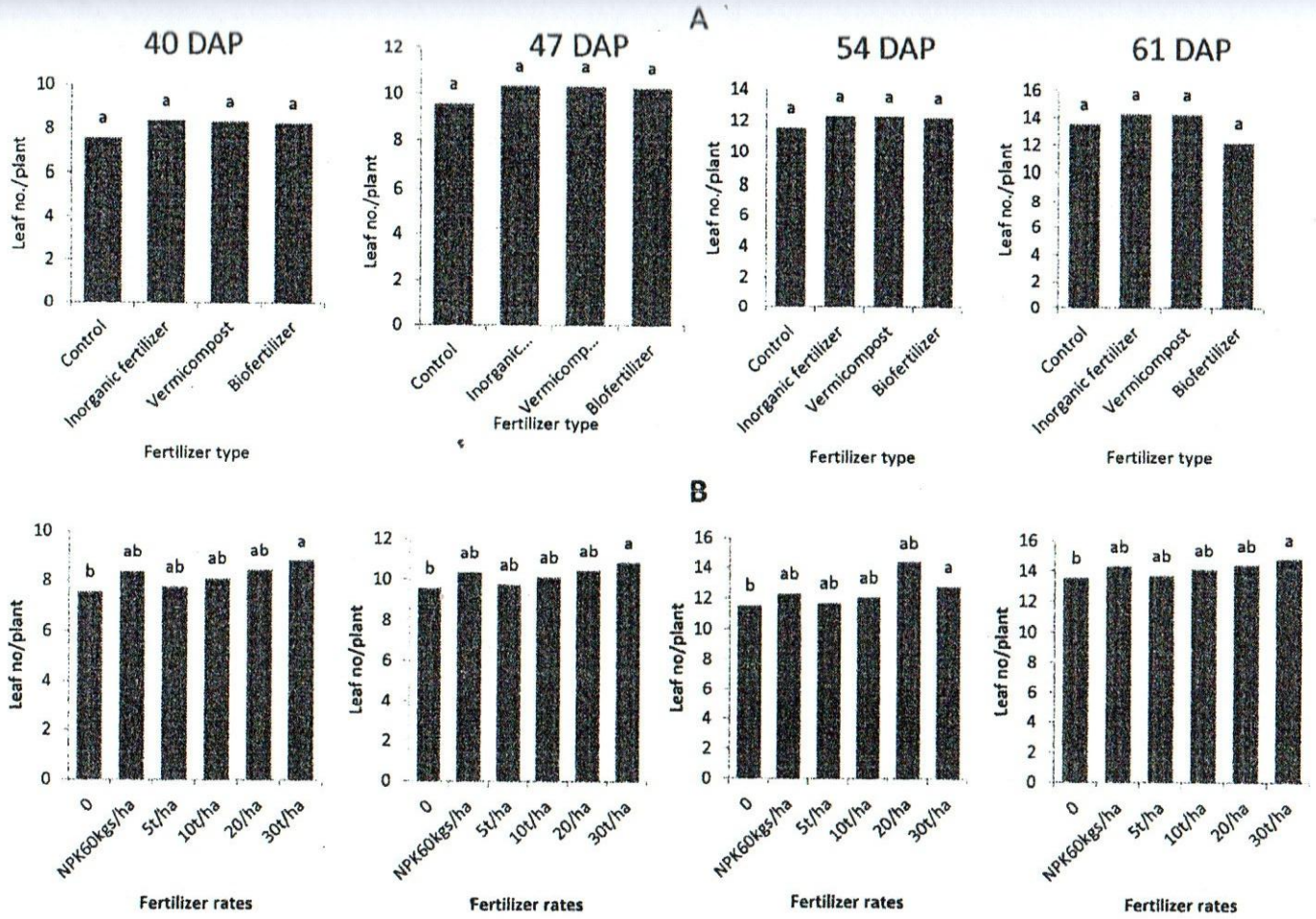


Figure 1: Main effects of fertilizer type (A) and rate (B) on Leaf numbers of Beetroot. Using contrasts, bars with the same letter in a letter series are not significantly different at $P \leq 0.05$.

b) Plant Height

Plant height was also influenced by the different application rates of vermicompost and biofertilizer (Table 3). Season x treatment interaction was not significant. Generally, plants tended to be tallest in plots applied with 30 t/ha of vermicompost and shortest in the control treatment with no fertilizer applied in most evaluation days. At the initial evaluation date (40 DAP), vermicompost applied at 10, 20 and 30 t/ha and biofertilizer applied at 20 and 30 t/ha treatments had significantly taller plants compared to the recommended inorganic fertilizer rate. During this sampling date, plants treated with the recommended inorganic fertilizer rate were statistically similar in height to those treated with 5 t/ha of vermicompost and 5 and 10 t/ha of biofertilizer. In the subsequent evaluation days (47, 54 and 61 DAP), no significant difference was observed in plant height between all the organic fertilizer rates and the recommended inorganic fertilizer rate. On overall, plants of season one were generally taller than those of season two.

The main effect of organic fertilizer type on beetroot plant height was also significant in all sampling dates (Fig. 2). Throughout the study period, significantly taller plants were obtained with fertilizer application compared to no fertilizer application regardless of the type of fertilizer applied. No statistical difference in plant height was recorded between beetroot plants treated with vermicompost and biofertilizer and those treated with NPK fertilizer. A trend could however be established where plants treated with NPK tended to be shorter early in the season (40 and 47 DAP) than those treated with vermicompost and biofertilizer but the trend was reversed later during the season (54 and 61 DAP). The Main effect of fertilizer application rates was also significant in all evaluation days (Fig. 2) with taller plants obtained with application of any rate of fertilizer compared to no fertilizer application. Among the different organic fertilizer rates, every successive increase in application rate resulted to an increase in plant height although not statistically significant. A trend similar to that displayed for main effects of fertilizer type could also be established where plants treated with inorganic fertilizer tended to be shorter early in the season (40 and 47 DAP) than those treated the different rates of organic fertilizers (5, 10, 20 and 30 t/ha) but the reverse was true later during the season (54 and 61 DAP) with plants treated with inorganic fertilizers out competing those treated with all rates of organic fertilizer.

Table 3: Effect of Different Rates of Vermicompost and Biofertilizer on the Height (cm) of Beetroot Plants

Treatment	Days after planting											
	40			47			54			61		
	S1†	S2	**Mean**	S1	S2	**Mean**	S1	S2	**Mean**	S1	S2	**Mean**
0t/ha	17.99*	10.73	**14.36d****	24.99*	13.82	**19.40c****	32.74*	17.20	**23.36b****	40.68*	21.24	**30.96b****
NPK17:17:17(60kg/)	17.05	18.85	**17.95bcd**	28.51	22.35	**25.43ab**	38.41	26.96	**32.69a**	47.61	29.61	**38.61a**
5t/ha vermicompost	19.48	16.65	**18.07bcd**	23.54	19.89	**21.72bc**	29.53	24.00	**28.37ab**	39.84	28.01	**33.93ab**
10t/havermicompost	15.46	22.67	**19.06abcd**	25.24	24.48	**24.86ab**	34.86	27.89	**31.39a**	43.63	29.00	**36.32a**
20t/havermicompost	21.82	22.20	**22.01ab**	29.82	25.14	**27.48a**	38.09	28.88	**33.48a**	43.11	30.73	**36.92a**
30t/havermicompost	21.66	24.90	**23.28a**	28.43	27.90	**28.16a**	35.68	30.44	**33.06a**	44.05	32.58	**38.31a**
5t/ha biofertilizer	18.77	15.08	**16.92cd**	28.19	18.20	**23.20abc**	37.08	22.09	**29.59a**	41.45	26.93	**31.19ab**
10t/ha biofertilizer	18.42	18.55	**18.48bcd**	27.83	21.06	**24.45ab**	36.52	26.08	**31.30a**	41.96	29.58	**35.77ab**
20t/ha biofertilizer	21.75	18.98	**20.36abc**	29.75	22.60	**26.18ab**	38.25	26.81	**32.53a**	44.45	28.60	**36.53a**
30t/ha biofertilizer	23.03	20.50	**21.77ab**	31.01	23.00	**27.01a**	38.97	27.55	**33.26a**	43.52	29.28	**36.40a**
Mean Season	**19.54g**	**18.91h**		**27.73f**	**21.84g**		**36.01e**	**25.79f**		**43.03e**	**28.55f**	

*Season × treatment interaction is not significant according to the F-test at $P \leq 0.05$.

**Means within a sampling day followed by the same letter in a letter series are not significantly different according to Tukey's Honestly Significantly Test at $P \leq 0.05$.

†S stands for season.

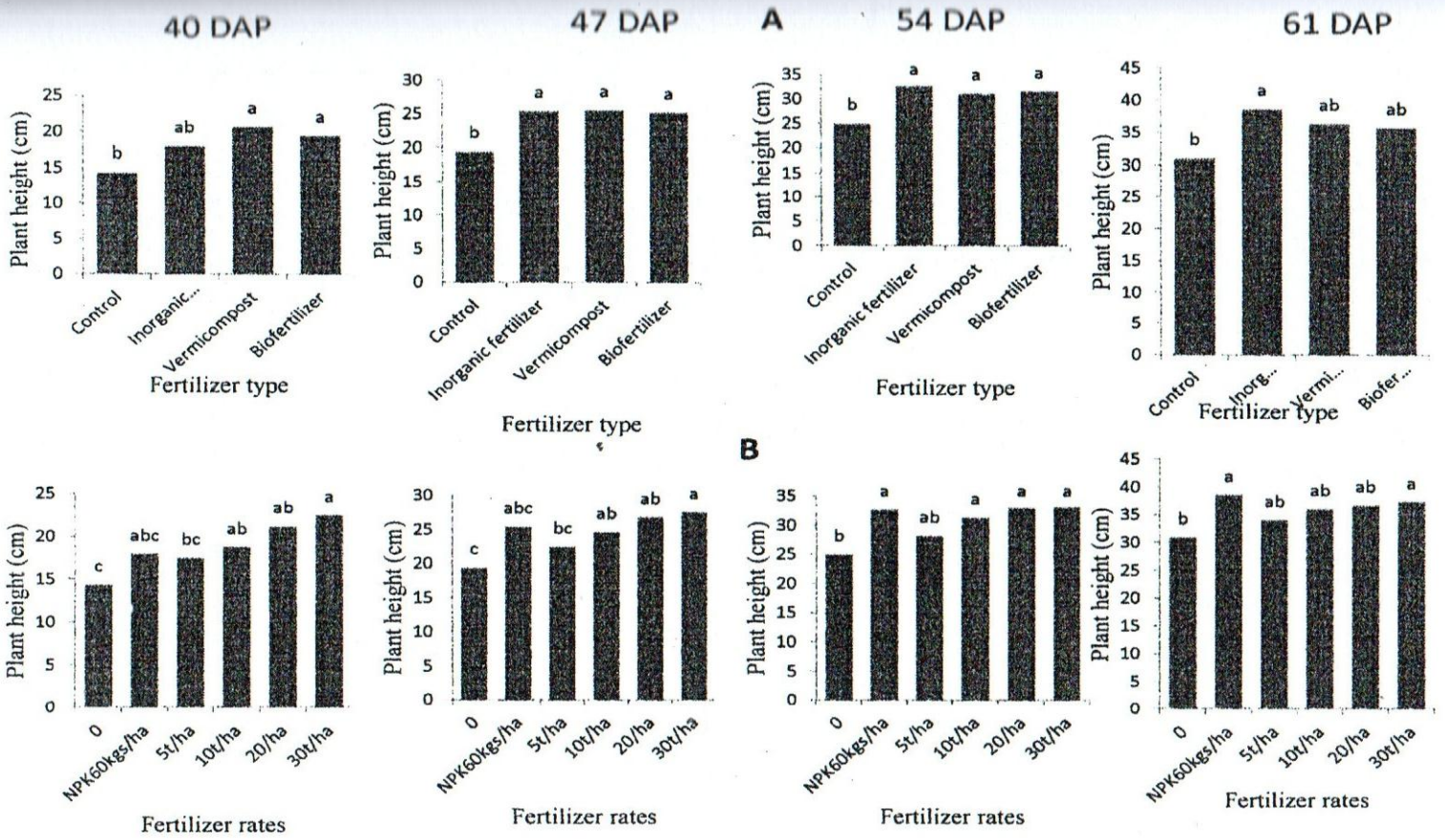


Figure 2: Main effects of fertilizer type (A) and rate (B) on Plant height of Beetroot. Using contrasts, bars with the same letter in a letter series are not significantly different at P≤0.05.

c) Leaf Area Index

Leaf area index (LAI) was taken during two growth phases; at the vegetative (47 DAP) and root bulking (61 DAP) stage. LAI was significantly influenced by the different application rates of vermicompost and biofertilizer sat both stages of beetroot plant growth. No significant interaction was observed between season and the treatments during both seasons. At vegetative phase, the highest LAI was obtained with application of 20 and 30 t/ha vermicompost as well as with application of 20 t/h biofertilizer. Application of NPK fertilizer yielded LAI that were slightly lower than those recorded for these treatments. The lowest LAI was, on the other hand obtained in the control treatment where no fertilizer was applied. Compared to the control treatments, LAI was generally higher for all other treatments although the difference was not statistically significant.

At root bulking stage, LAI was highest in the 10 t/ha vermicompost treatment and lowest under the control treatment. No significant differences in LAI were noted with application of 10 and 20 t/ha biofertilizer compared to application of NPK fertilizer. Among the organic fertilizer treatments, LAI was slightly lower for the 5 and 10 t/ha biofertilizer treatments but the LAI recorded for these treatments was still higher than for the control treatment. On average, beetroot plants produced during the first season had significantly higher LAI compared to those produced during the second season, at both vegetative and root bulking stage (Table 4).

Comparing the main effects of fertilizer type and fertilizer rate, beetroot LAI was significantly influenced by both the main effects of fertilizer type and fertilizer rates (Fig. 3). Higher LAI was obtained with application of any type or rate of fertilizer compared to no fertilizer application both at the vegetative and root bulking stages. During the vegetative stage, control plants had significantly lower LAI compared to those treated with NPK, vermicompost and biofertilizer. LAI tended to be slightly higher under the organic compared to the inorganic fertilizer treatment. At the root bulking stage, LAI was also lowest in the control treatment and highest with application of NPK fertilizer although not statistically different from that recorded for organic fertilizer treatments. Similarly, no significant LAI difference was noted between plants treated with NPK and the different rates of organic fertilizer at the vegetative stage (47DAP) of beetroot growth (Fig. 3). However, at the root bulking stage (61 DAP), a highest LAI was obtained from plants treated with 10 t/ha organic fertilizer followed by application of NPK at 60 kg/ha with slightly lower LAI recorded following application of 30 t/ha, 20 t/ha and 5 t/ha of organic fertilizer.

Table 4: Effect of Different Rates of Vermicompost and Biofertilizer on Leaf Area Index of Beetroot

Treatment	**Days after planting**					
	47			61		
	S1†	S2	**Treatment Mean**	S1	S2	**Treatment Mean**
0t/ha	0.23*	0.07	**0.15c****	1.04*	0.13	**0.58b****
NPK 17:17:17(60kg/ha)	0.27	0.17	**0.22abc**	1.21	0.30	**0.76ab**
5t/ha vermicompost	0.29	0.13	**0.21abc**	0.95	0.27	**0.61b**
10t/ha vermicompost	0.21	0.23	**0.22abc**	1.28	0.37	**0.83a**
20t/ha vermicompost	0.31	0.22	**0.27a**	1.04	0.26	**0.65ab**
30t/ha vermicompost	0.30	0.24	**0.27a**	1.04	0.35	**0.70ab**
5t/ha biofertilizer	0.23	0.12	**0.18bc**	1.00	0.21	**0.60b**
10t/ha biofertilizer	0.29	0.17	**0.23abc**	0.90	0.31	**0.60b**
20t/ha biofertilizer	0.33	0.21	**0.27a**	1.29	0.27	**0.78a**
30t/ha biofertilizer	0.32	0.19	**0.26ab**	1.06	0.28	**0.67ab**
Mean Season	**0.28f**	**0.18g**		**1.08e**	**0.27f**	

*Season × treatment interaction is not significant according to the F-test at $P \leq 0.05$.

**Means within a sampling day followed by the same letter in a letter series are not significantly different according to Tukey's Honestly Significantly Test at $P \leq 0.05$.

†S stands for season.

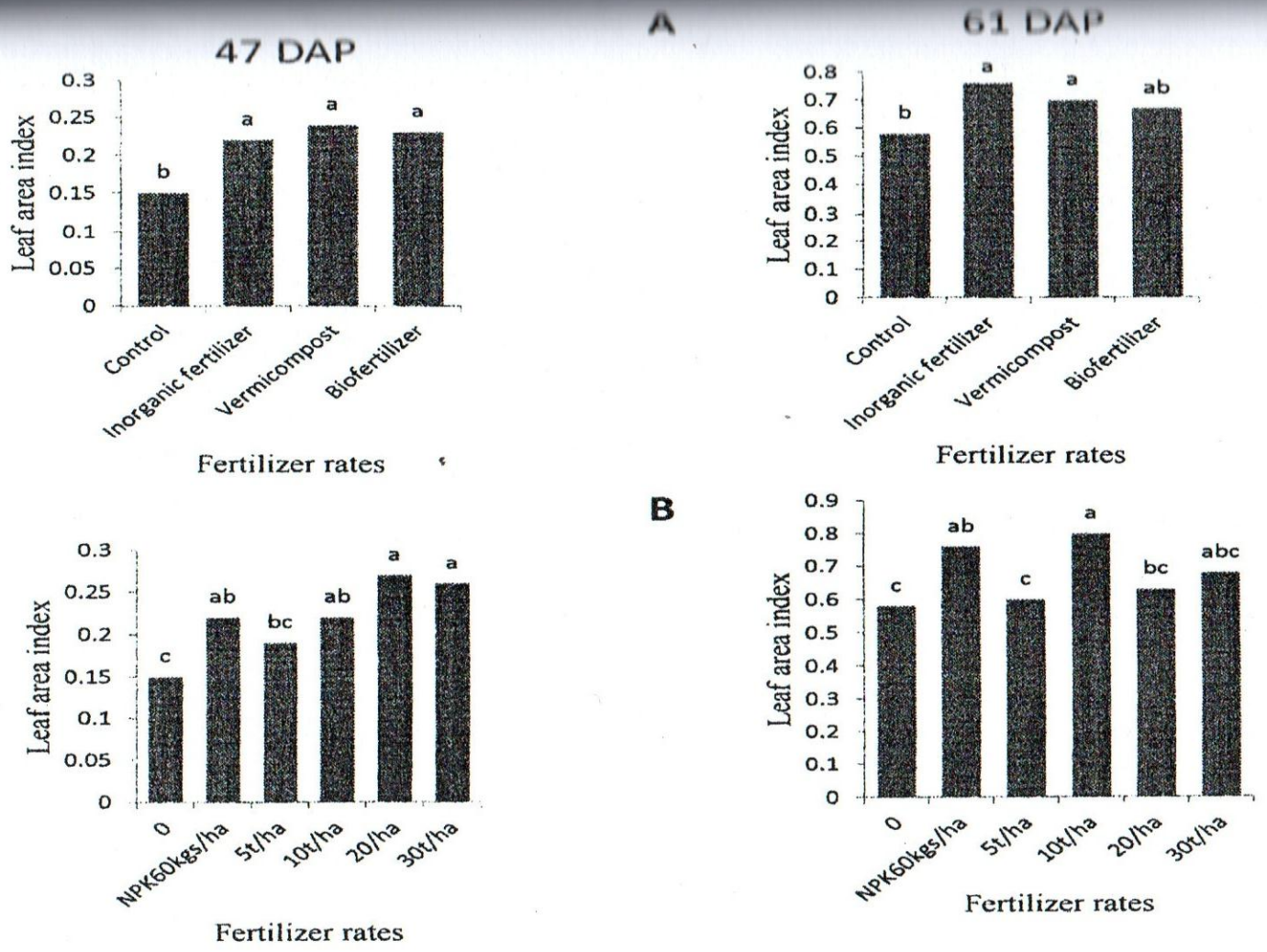


Figure 3: Main effects of fertilizer type (A) and rate (B) on Leaf Area Index of Beetroot. Using contrasts, bars with the same letter in a letter series are not significantly different at P≤0.05

4.1.1 Effects of Different Application Rates of Vermicompost and Biofertilizer on the Yield of Beetroot

Beetroot yield variables presented in this section include; i) Fresh and dry root weight ii) Fresh and dry leaf weight, iii) total plant biomass and iv) Harvest index (HI).

a) Fresh and Dry Root Weight

The use of different rates of vermicompost or biofertilizer did not significantly influence both the fresh and dry root weight of beetroot (Table 5). The interaction effect of season and the different rates of vermicompost and biofertilizer were also not significant. A trend could however be established where fresh and dry root weight generally tended to be higher for plants treated with inorganic fertilizer and the different rates of vermicompost and biofertilizer compared to no fertilizer application with the highest fresh and dry root weight obtained with application of 10 t/ha of biofertilizer followed by NPK application and application of 30 t/ha of vermicompost. The Averaged over each season, beetroot in season one produced significantly higher fresh and dry root weight compared to that of season two.

A comparison of the main effects of using inorganic fertilizer, vermicompost or bio-fertilizer and the control (no fertilizer application) revealed a significant influence of fertilizer on fresh and dry root weight of beetroot plants. Fresh root weight however tended to be highest in plants treated with 10t/ha biofertilizer followed by the 30 t/ha vermicompost treatment then the NPK fertilizer treatment. Root dry weight followed a similar pattern except that the NPK fertilizer treatment yielded slightly higher root dry weight than the 30 t/ha vermicompost treatment. The lowest root fresh and dry weight was obtained in the control treatment where no fertilizer was applied (Fig. 4). Among beetroot plants treated with the different fertilizer types, (inorganic fertilizer, vermicompost and biofertilizer), the difference in fresh and dry root weight obtained was not significantly different from each other but fresh and dry root weights tended to be highest for the NPK treatment. Fresh and dry root weight of beetroot plants was, on the other hand significantly influenced by the main effects of fertilizer rates, with higher fresh and dry root weight obtained following application of NPK fertilizer and any rate of organic fertilizer compared to the control treatment. Among the different organic fertilizer application rates, the highest fresh and dry root weight was recorded with the application of 10 t/ha with no statistical difference noted between the NPK fertilizer rate and all the organic fertilizer application rates (Fig. 4).

Table 5: Effect of Different Rates of Vermicompost and Biofertilizer on Fresh and Dry Root Weight of Beetroot

Treatment	Fresh root weight(t/ha)			Dry root weight (t/ha)		
	S1†	S2	**Treatment Mean**	S1	S2	**Treatment Mean**
0t/ha	5.60*	1.62	**3.61a****	4.70*	1.11	**2.90a****
NPK 17:17:17(60kg/ha)	7.54	2.27	**4.91a**	6.68	2.04	**4.36a**
5t/ha vermicompost	5.70	2.07	**3.88a**	4.73	1.47	**3.11a**
10t/ha vermicompost	6.88	2.73	**4.80a**	4.42	1.97	**3.20a**
20t/ha vermicompost	6.36	2.65	**4.51a**	5.55	1.89	**3.72a**
30t/ha vermicompost	6.53	3.30	**4.92a**	5.72	2.42	**4.07a**
5t/ha biofertilizer	6.11	1.86	**3.99a**	5.07	1.33	**3.20a**
10t/ha biofertilizer	8.05	2.68	**5.36a**	7.08	1.87	**4.47a**
20t/ha biofertilizer	5.87	2.72	**4.30a**	5.06	1.98	**3.52a**
30t/ha biofertilizer	6.67	2.18	**4.43a**	5.41	1.63	**3.52a**
Mean Season	**6.53d**	**2.41e**		**5.44d**	**1.77e**	

*Season × treatment interaction is not significant according to the F-test at $P \leq 0.05$.

**Means within a variable followed by the same letter in a letter series are not significantly different according to Tukey's Honestly Significantly Test at $P \leq 0.05$.

†S stands for season

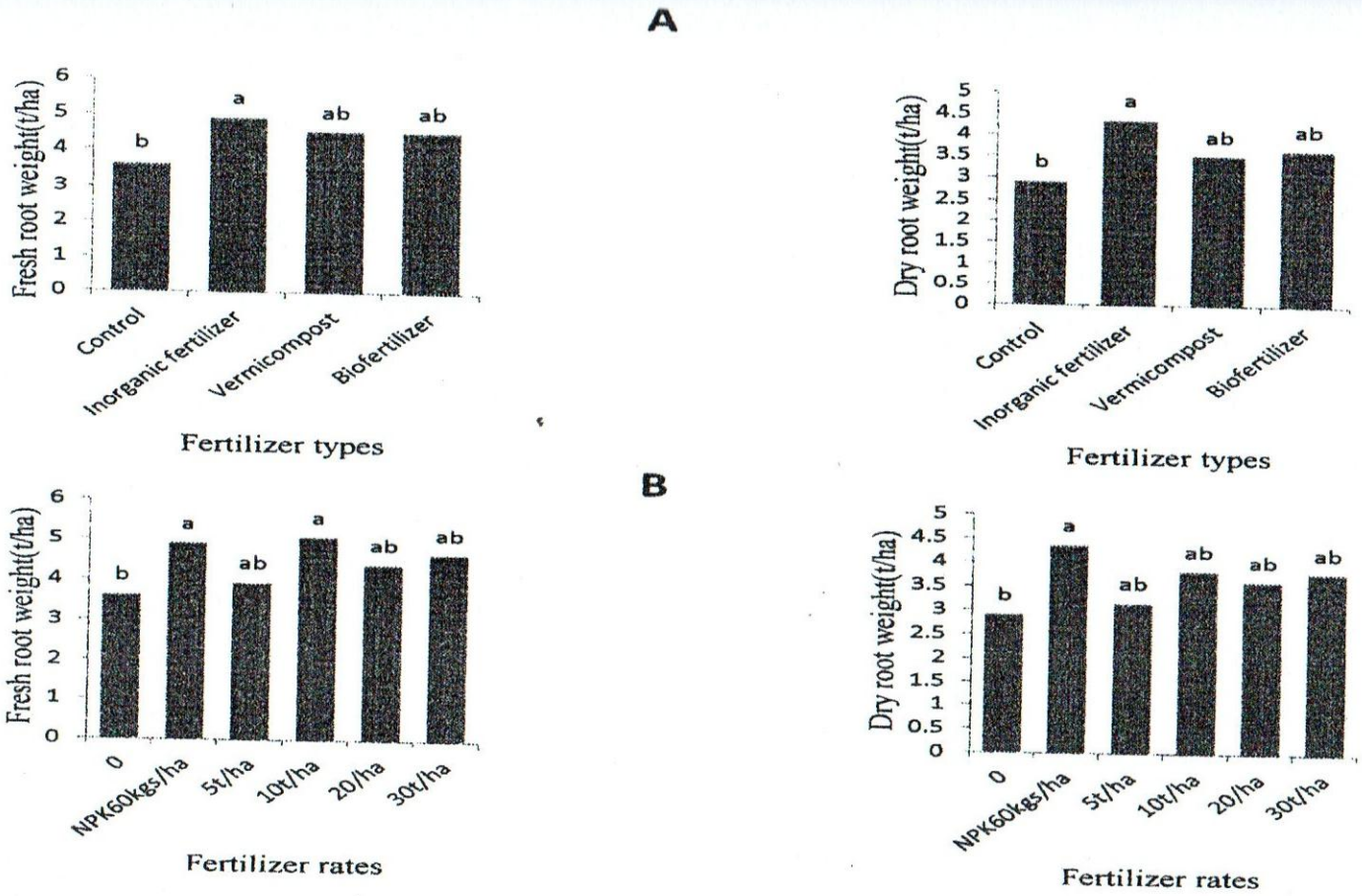


Figure 4: Main effects of fertilizer type (A) and rate (B) on Fresh &Dry Root weight of Beetroot. Using contrasts, bars with the same letter in a letter series are not significantly different at $p \leq 0.05$.

b) Fresh and Dry Leaf weight

Similar to fresh and dry root weight, the different application rates of vermicompost and biofertilizer did not significantly influence fresh and dry leaf weight of beetroot plants (Table 6). The interactive effect of season and the different rates of vermicompost and biofertilizer on beetroot fresh and dry leaf weight was also not significant. Generally fresh and dry leaf weight obtained for the NPK treatment were comparable to those obtained with application of the different rates of biofertilizer and vermicompost and the control treatment (Table 6). Averaged over each season, beetroot in season one produced signi ficantly higher fresh and dry leaf weight compared to that of season two.

A comparison of the main effects of using inorganic fertilizer, vermicompost or bio-fertilizer and the control (no fertilizer application) revealed a significant influence of fertilizer type on fresh and dry leaf weight of beetroot. The highest and lowest leaf fresh weight was obtained following application of NPK fertilizer and control treatments, respectively (Fig. 5). Yields also tended to be higher for vermicompost and biofertilizer treatments compared to those of the control treatment although the difference was not statistically different. The main effect of fertilizer rate on beetroot leaf fresh and dry weight displayed a trend similar to that of fertilizer type main effect. Leaf fresh and dry weight was slightly higher under the recommended NPK rate of 60 kg/ha and lowest for the control treatment. The differences in leaf fresh and dry weight among the different main effects of fertilizer rates were, however not statistically significant at $P< 0.05$ (Fig.5).

Table 6: Effect of Different Rates of Vermicompost and Biofertilizer on Fresh Leaf Weight and Dry Leaf Weight of Beetroot

	Fresh leaf weight (t/ha)			**Dry leaf weight (t/ha)**		
	S1†	S2	**Treatment Mean**	S1	S2	**Treatment Mean**
0t/ha	5.18*	1.15	**3.61a****	3.58*	0.67	**2.12a****
NPK 17:17:17(60kg/ha)	6.85	1.30	**4.08a**	3.98	0.85	**2.42a**
5t/ha vermicompost	5.70	0.97	**3.33a**	4.13	0.58	**2.35a**
10t/ha vermicompost	5.63	0.97	**3.30a**	3.34	0.54	**1.94a**
20t/ha vermicompost	4.82	0.93	**2.88a**	3.36	0.50	**1.93a**
30t/ha vermicompost	5.05	1.17	**3.11a**	3.28	0.70	**1.99a**
5t/ha biofertilizer	5.58	1.02	**3.30a**	4.01	0.61	**2.31a**
10t/ha biofertilizer	6.00	1.37	**3.68a**	3.85	0.80	**2.32a**
20t/ha biofertilizer	5.36	1.07	**3.21a**	3.60	0.61	**2.11a**
30t/ha biofertilizer	4.85	0.98	**2.91a**	3.05	0.57	**1.81a**
Mean Season	**5.50d**	**1.09e**		**3.62d**	**0.65e**	

*Season × treatment interaction is not significant according to the F-test at $P \leq 0.05$.

**Means within a variable followed by the same letter in a letter series are not significantly different according to Tukey's Honestly Significantly Test at $P \leq 0.05$.

†S stands for season.

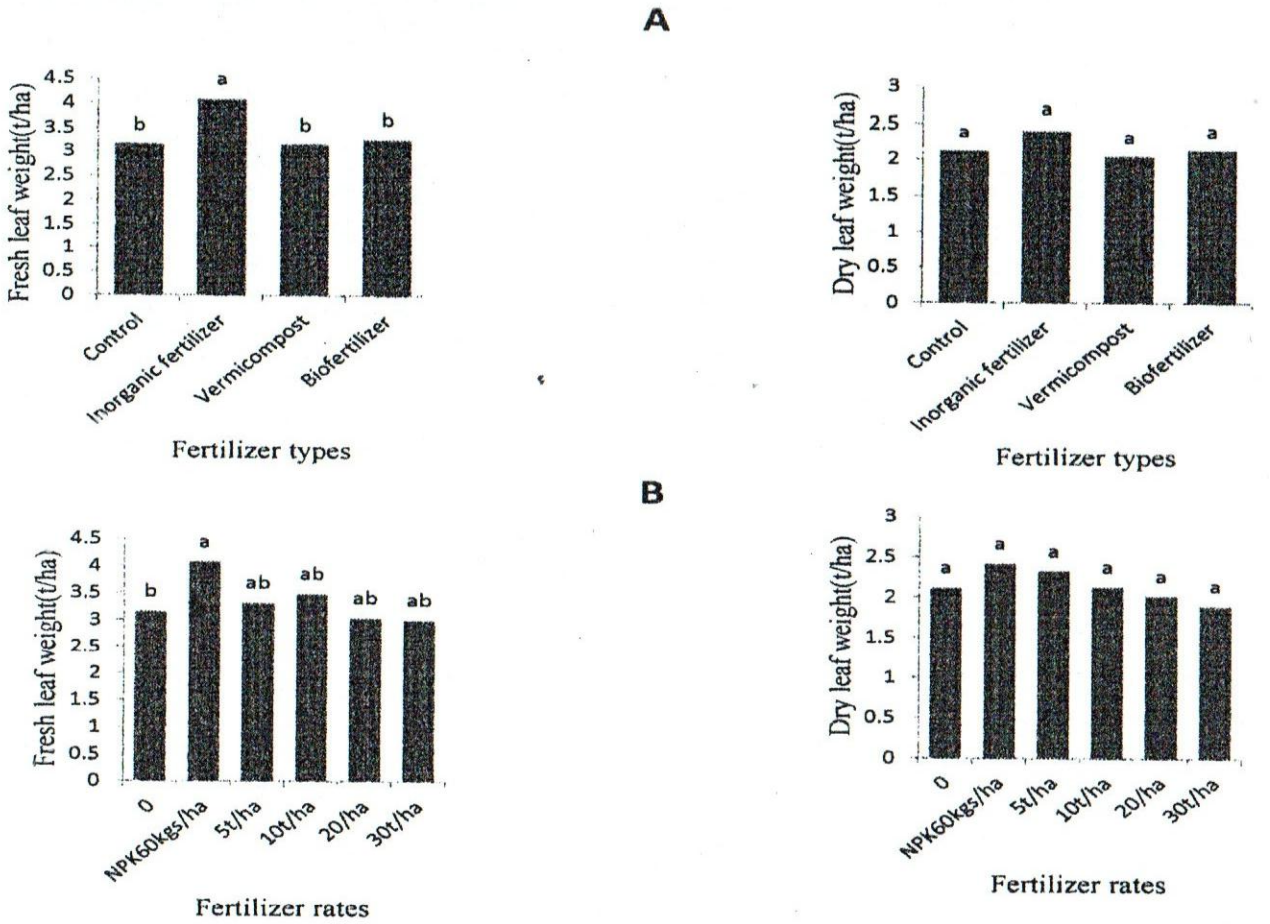


Figure 5: Main effects of fertilizer type (A) and rate (B) on Fresh &Dry leaf weight of Beetroot. Using contrasts, bars with the same letter in a letter series are not significantly different at $p \leq 0.05$.

c) Total plant biomass

The use of different rates of vermicompost or bio-fertilizer did not significantly influence biomass yield of beetroot (Table 7). The interactive effect of season and the different rates of vermicompost and biofertilizer on beetroot biomass were also not significant. A trend could however be established where biomass yield generally tended to be higher for plants treated with the different rates of vermicompost and biofertilizer similar to those treated with NPK fertilizer compared to no fertilizer application (control),with the highest biomass yield obtained with application of 10 t/ha of biofertilizer followed by NPK application and application of 30 t/ha of vermicompost. Averaged over each season, beetroot in season one produced significantly higher biomass yield compared to that of season two.

The main effect of fertilizer type as represented in Figure 8 indicates significant difference in total plant biomass between inorganic fertilizer and the control treatment. The difference in biomass between organic fertilizer and the inorganic fertilizer treatment was however not significant. The main effect of fertilizer application rate was on the other hand not significant. A trend in total plant biomass content could, however be established marked by an increment in total biomass with increase in organic fertilizer application rate.

d) Harvest index (HI)

The use of different rates of vermicompost and biofertilizer significantly influenced the harvest index of beetroot. Season x treatment interaction was however not significant. Averaged across the two seasons, beetroot plants treated with biofertilizer at the rate of 30t/ha and vermicompost at the rate of 30t/ha produced the highest harvest index while the lowest harvest index was obtained under the control treatment with no fertilizer applied (Table 7). Harvest index obtained from the other rates of vermicompost and biofertilizer treatments were not statistically different from those of both the negative control and the 30t/ha biofertilizer and vermicompost treatment and were also comparable to those of the recommended inorganic rate of NPK (positive control). Among the two seasons, a significantly higher harvest index was obtained in season 2 than season 1 (Table 7).

The main effect of fertilizer type on harvest index of beetroot was, on the other hand not significant (Figure. 6). A trend could however, be established marked by slightly higher harvest indices realized with application of NPK fertilizer and organic fertilizer as either vermicompost or biofertilizer compared to no fertilizer application. The main effect of organic fertilizer rate on harvest index was, however, significant with the application rate of 30t/ha resulting in a higher harvest index compared to no fertilizer application (0t/ha) (Figure. 6).

Harvest index recorded for the NPK treatment was not significantly different from that recorded for all organic fertilizer rates. A general trend marked by an increase in the harvest index with an increase in the amount of organic fertilizer applied was noted.

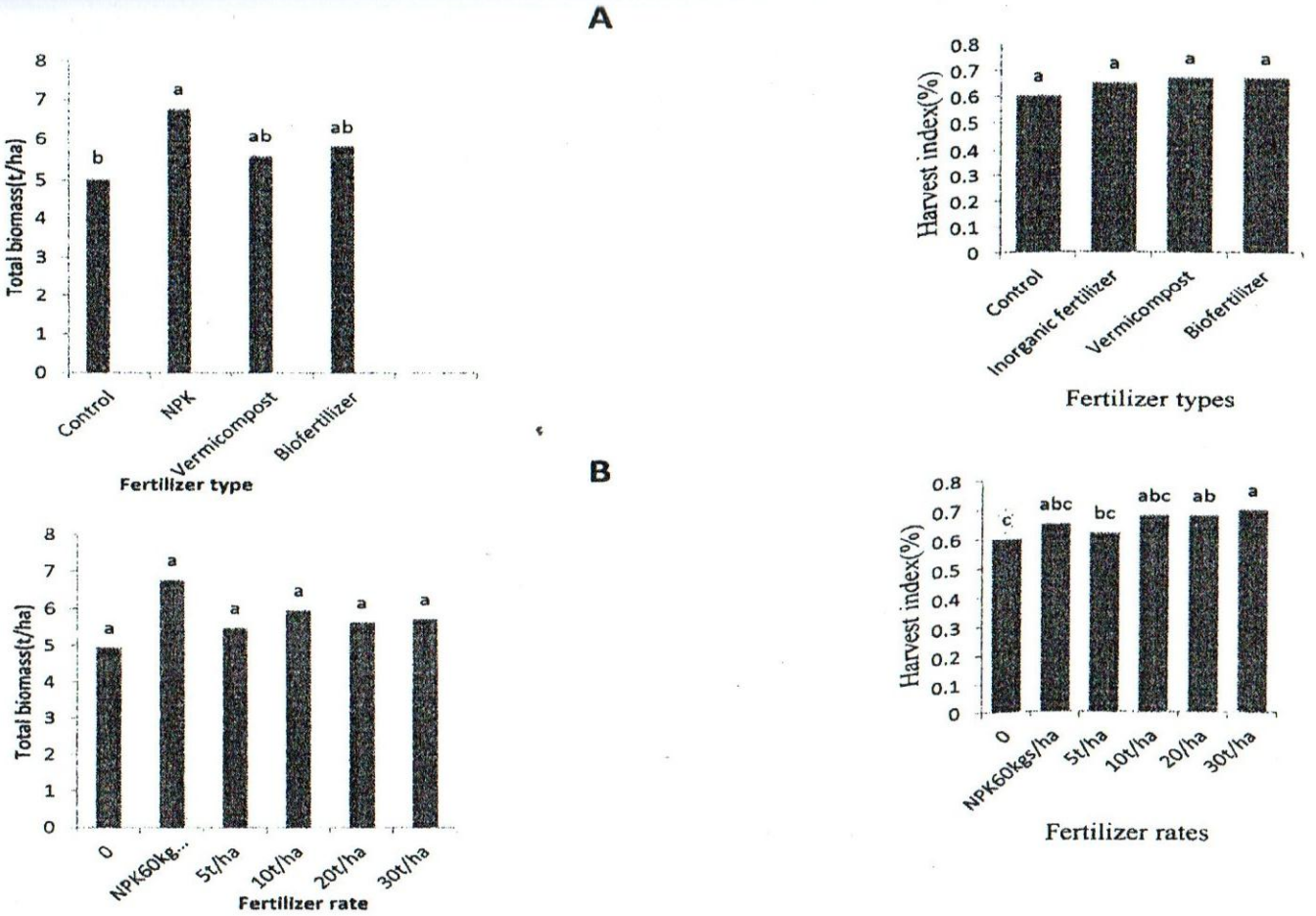


Figure 6: Main effects of fertilizer type (A) and rate (B) on Root, Leaf Yield and Harvest index of Beetroot. Using contrasts, bars with the same letter in a letter series are not significantly different at $p \leq 0.05$.

Table 7: Effect of Different Rates of Vermicompost and Biofertilizer on Harvest Index of Beetroot

Treatment	Root dry weight (t/ha)			Total Biomass yield (t/ha)			HI (%)		
	S1†	S2	**Treatment Mean**	S1	S2	**Treatment Mean**	S1	S2	**Treatment Mean**
0t/ha	4.69*	1.11	**2.90****	8.27*	1.78	**5.03****	0.57*	0.64	**0.60b*****
NPK 17:17:17(60kg/ha)	6.68	2.04	**4.36**	10.65	2.90	**6.78**	0.63	0.68	**0.65ab**
5t/ha vermicompost	4.73	1.47	**3.10**	8.86	2.05	**5.46**	0.54	0.70	**0.62ab**
10t/ha vermicompost	4.42	1.97	**3.19**	7.77	2.51	**5.14**	0.56	0.79	**0.67ab**
20t/ha vermicompost	5.55	1.89	**3.72**	8.91	2.39	**5.65**	0.62	0.75	**0.69ab**
30t/ha vermicompost	5.72	2.41	**4.07**	8.99	3.11	**6.06**	0.64	0.78	**0.71a**
5t/ha biofertilizer	5.07	1.33	**3.20**	9.08	1.94	**5.51**	0.55	0.69	**0.61ab**
10t/ha biofertilizer	7.08	1.87	**4.47**	10.92	2.67	**6.80**	0.64	0.71	**0.68ab**
20t/ha biofertilizer	5.06	1.98	**3.52**	8.65	2.59	**5.62**	0.58	0.78	**0.68ab**
30t/ha biofertilizer	5.41	1.63	**3.52**	8.46	2.21	**5.33**	0.65	0.75	**0.70a**
Mean Season	**5.44e**	**1.77f**		**9.06e**	**2.42f**		**0.60e**	**0.72f**	

*Season × treatment interaction is not significant according to the F-test at $P \leq 0.05$.

**Treatment means not followed by a letter are not significantly different according to F-test at $P \leq 0.05$

***Treatment means within a variable followed by the same letter in a letter series are not significantly different according to Tukey's Honestly Significantly Test at $P \leq 0.05$.†S stands for season.

4.1.2 Effects of Different Application Rates of Vermicompost and Biofertilizer on Quality of Beetroot

Beetroot quality attributes considered in this study were i) Brix content, ii) Titratable acidity (TA) and iii) Sugar acid ratio of the root at maturity.

a) Brix

Brix content of beetroot was influenced by the use of different rates of vermicompost and bio-fertilizer. Season x treatment interaction was however not significant. Averaged across the two seasons, beetroot plants treated with biofertilizer at the rate of 5t/ha had the highest brix content while the lowest brix content was obtained under 5t/ha of vermicompost. Among the other treatments, brix content of roots tended to be lower for NPK, 30t/ha biofertilizer and 10 t/ha of biofertilizer (Table 8). Brix content obtained for the other rates of vermicompost and biofertilizer treatments were not statistically different from those of both the negative control treatment and were also comparable to those of the recommended NPK fertilizer rate of. There was no significant difference in brix content of roots of the two seasons.

The main effect of fertilizer type showed no significant effect on brix content of beet root (Figure 7). Main effects of fertilizer application rates also did not significantly affect the brix content of beetroot (Figure 7).

b) Titratable acidity

There was no significant difference in titratable acidity of beetroot grown under the different fertilization regimes (Table 7). Similarly, the interaction between seasons and treatments was also not significant. On average, beet root of season one however tended to be more acidic than those of season two. The main effect of fertilizer type and fertilizer rates was also not statistically significant (Figure 7).

c) Sugar acid ratio

There was no significant difference in sugar acid ratio among beetroot grown under the different fertilizer application rates (Table 8). The interaction between season and treatments was also not significant. Although there was no significant difference among the treatments, increase in application rate generally resulted to increase in sugar acid ratio. When treatments effects were averaged over the seasons, beetroot grown during the second season had significantly higher sugar acid ratio compared to those of season one (Table 8).

The main effect of the fertilizer type was not statistically significant, as shown in (Figure 7) but sugar acid ratio tended to be quite low in the NPK treatment compared organic fertilizer treatments. In terms of fertilizer application rates, there was no statistically significant difference among the different fertilizer application rates, but difference between the fertilizer application rates and the control was notable (Figure 7).

Table 8: Effect of Different Rates of Vermicompost and Biofertilizer on Quality of Beetroot

Treatment	°Brix			Titratable Acidity			Sugar Acid ratio		
	S1†	S2	Treatment Mean	S1	S2	Treatment Mean	S1	S2	Treatment Mean
0t/ha	8.25*	7.50	**7.88****	0.08*	0.04	**0.06****	103.13*	187.50	**131.33*****
NPK 17:17:17(60kg/ha)	7.75	7.25	**7.50**	0.12	0.05	**0.09**	64.58	181.25	**83.33**
5t/ha vermicompost	6.75	7.50	**7.13**	0.07	0.04	**0.06**	96.43	187.50	**118.83**
10t/ha vermicompost	7.75	7.75	**7.75**	0.10	0.06	**0.08**	77.50	129.17	**96.88**
20t/ha vermicompost	8.00	8.50	**8.25**	0.06	0.06	**0.06**	133.33	141.67	**137.50**
30t/ha vermicompost	7.25	8.25	**7.75**	0.04	0.05	**0.05**	181.25	165.00	**155.00**
5t/ha biofertilizer	10.75	9.50	**10.13**	0.10	0.09	**0.10**	107.50	105.56	**101.30**
10t/ha biofertilizer	7.75	7.25	**7.50**	0.09	0.06	**0.08**	86.11	120.83	**93.75**
20t/ha biofertilizer	8.25	7.63	**7.94**	0.07	0.05	**0.06**	117.86	152.6	**132.33**
30t/ha biofertilizer	7.50	7.50	**7.50**	0.16	0.04	**0.10**	46.88	187.50	**75.00**
Mean Season	**8.00e**	**7.86e**		**0.09d**	**0.05e**		**88.89e**	**157.20d**	

*Season X treatment interaction is not significant according to the F-test at $P \leq 0.05$.

**Treatment means not followed by a letter are not significantly different according to F-test at $P \leq 0.05$

***Treatment means within a variable followed by the same letter in a letter series are not significantly different according to Tukey's Honestly Significantly Test at $P \leq 0.05$.

†S stands for season.

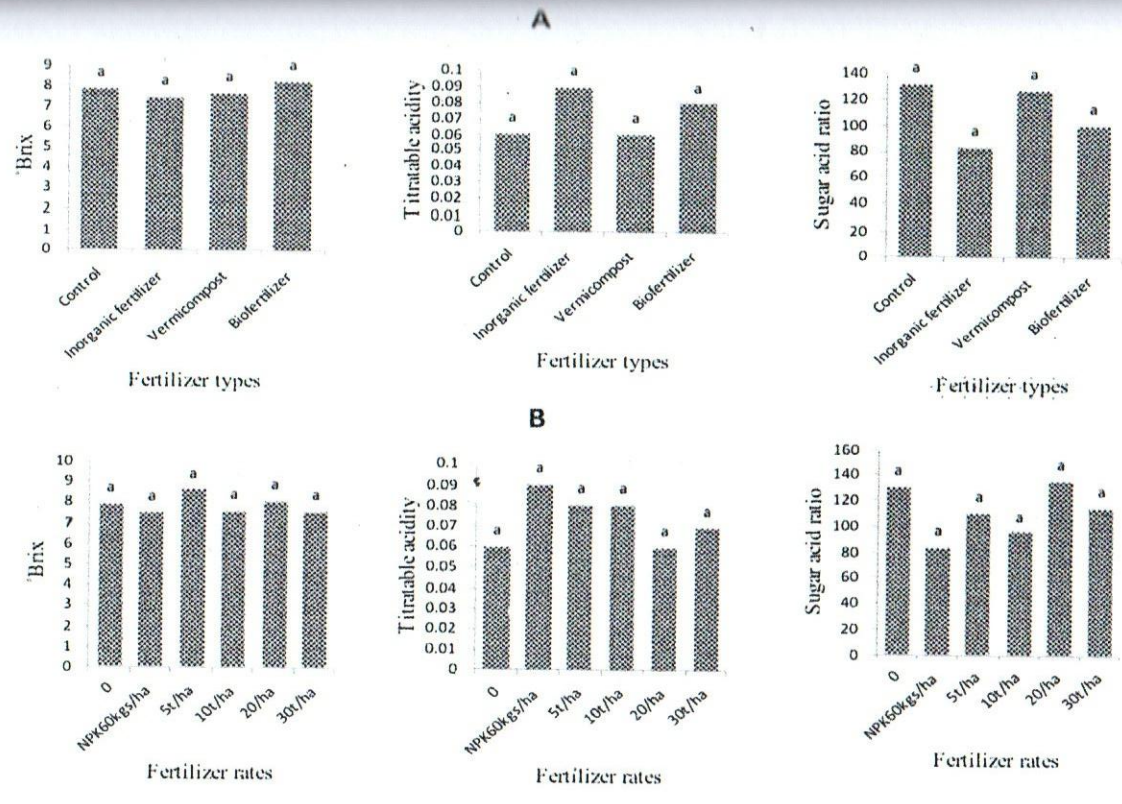


Figure 7: Main effects of fertilizer type (A) and rate (B) on Brix, Titratable acidity and Sugar acid ratio of Beetroot. Using contrasts, bars with the same letter in a letter series are not significantly different at $p \leq 0.05$.

4.1.3 Effects of Different Application Rates of Vermicompost and Biofertilizer on Soil Nutrient Status

Soil nutrient variables measured in this study were; i) soil pH, ii) Nitrogen (N), iii) Phosphorus (P), iv) Potassium (K), v) Calcium (Ca) and vi) Iron (Fe). Pre-plant soil nutrient status at the study site was as presented in table 9.

a) Soil pH

Application of different rates of vermicompost and biofertilizer did not have a significant effect on soil pH. Season x treatment interaction was also not significant. On average, plots of season one had higher soil pH than those of season two. The main effect of fertilizer type (Figure 8) and fertilizer rate (Figure 8) did not significantly affect soil pH during the production of beetroot plants.

b) Nitrogen, Phosphorus and Potassium

Similar to soil pH, soil N, P and K was were not significantly affected by application of the different rates of vermicompost and biofertilizer. A general trend could however be noted marked by an increase in soil N, P and K with increase in the rate of vermicompost and biofertilizer rate (Table 11). Interaction between season and treatments were also not significant. Averaged over the seasons, plots of season one had significantly higher soil P and K compared to those of season two while there was no significant difference in the amount of soil N amongst the plots of the two seasons.

The main effects of fertilizer type on soil N, P and K content were also not significant although soil N and K content tended to be slightly higher under vermicompost treatment. The content of soil N and K recorded under NPK treatment were comparable to those obtained under the organic fertilizer treatments (Figure 8). Soil P on the other hand, tended to be lower under NPK treatment compared to the organic fertilizer treatments although the difference was not statistically significant. Similarly, soil nitrogen, phosphorus and potassium was also not significantly influenced by the main effect of fertilizer rates during beetroot production (Figure 8) although soil nitrogen tended to be slightly higher with the application rate of 30t/ha of organic fertilizer. Soil phosphorus was on the other hand significantly high at the higher mean rate of 30t/ha of organic fertilizer Soil potassium was not also not significantly influenced by the main effect of fertilizer rates, but tended to be higher under5t/ha organic fertilizer application followed by 30t/ha, 10t/ha, 20t/ha, inorganic (NPK) fertilizer and lowest under the control treatment (Figure 8).

Table 9: Pre-Plant Soil Selected Nutrient Status

Elements	Season 1	Season 2
Ph	6.23	5.75
N%	5.74	5.42
P ppm	41.58	47.19
K ppm	66.2	42.6
C	<0.001	<0.001
Na	89	103
Ca%	262	119
Mg	70.5	63
S	44.55	46.52
Fe ppm	8.4	39.1
Mn	4.1	13.3
Zn	0.74	0.98
Pb	<0.001	<0.001

Table 10: Effect of Different Rates of Vermicompost and Biofertilizer on Soil pH

Treatment	S1†	S2	**Treatment Mean**
0t/ha	6.68*	6.16	**6.42****
NPK 17:17:17(60kg/ha)	6.77	6.18	**6.47**
5t/ha vermicompost	6.80	6.24	**6.52**
10t/ha vermicompost	6.75	6.31	**6.53**
20t/ha vermicompost	6.82	6.39	**6.61**
30t/ha vermicompost	6.91	6.07	**6.49**
5t/ha biofertilizer	6.87	6.29	**6.58**
10t/ha biofertilizer	6.75	6.18	**6.46**
20t/ha biofertilizer	6.94	6.22	**6.58**
30t/ha biofertilizer	6.97	6.34	**6.66**
Mean Season	**6.82d**	**6.24e**	

*Season X treatment interaction is not significant according to the F-test at $P \leq 0.05$.

**Treatment means within a variable not followed by a letter are not significantly different according to F-test at $P \leq 0.05$

c) Calcium and Iron

Application of the different rates of vermicompost and biofertilizer significantly influenced soil calcium (Ca) content (Table 12). Season x treatment interaction was however not significant. The highest soil Ca content was recorded under the 30 t/ha biofertilizer treatment. Soil Ca content recorded for this treatment was however not significantly different from that recorded under 30 t/ha vermicompost and 20 t/ha biofertilizer treatments. The lowest soil Ca content was recorded in plots treated with 10 t/ha biofertilizer. Soil Ca recorded for this treatment was not any different from that recorded for the control, NPK, 10 t/ha vermicompost, 20 t/ha vermicompost and 5 t/ha vermicompost treatments. The effect of biofertilizer and vermicompost rates on soil Fe content was however, not significant although a trend could be established marked by an increase in soil Fe content with increase in both biofertilizer and vermicompost rates. Averaged over the seasons, plots of season one had higher Ca content than those of season two while Fe content was significantly higher in season two compared to season one. The main effect of fertilizer type and fertilizer rates did not have a significant effect on soil Ca and Fe content (Figure 9).

Table 11: Effect of Different Rates of Vermicompost and Biofertilizer on Soil NPK

	N (%)			P (ppm)			K (ppm)		
Treatment	S1†	S2	**Treatment Mean**	S1	S2	**Treatment Mean**	S1	S2	**Treatment Mean**
0t/ha	2.17*	1.76	**1.97****	90.92*	31.27	**61.09****	71.10*	52.83	**61.96*****
NPK 17:17:17(60kg/ha)	2.02	2.48	**2.25**	59.81	30.45	**45.13**	72.68	54.80	**63.74**
5t/ha vermicompost	2.91	2.13	**2.52**	57.92	33.69	**45.80**	81.30	55.23	**68.26**
10t/ha vermicompost	2.48	1.72	**2.10**	74.50	35.69	**55.09**	73.33	58.05	**65.69**
20t/ha vermicompost	1.85	2.09	**1.97**	64.58	45.09	**54.83**	78.83	58.18	**68.50**
30t/ha vermicompost	3.74	2.34	**3.04**	84.52	39.17	**61.74**	85.20	57.83	**71.51**
5t/ha biofertilizer	1.77	1.49	**1.63**	75.41	44.35	**59.88**	83.85	56.25	**70.05**
10t/ha biofertilizer	1.89	1.72	**1.81**	63.69	30.10	**46.90**	81.78	48.55	**65.16**
20t/ha biofertilizer	1.52	2.59	**2.05**	61.46	28.03	**44.74**	73.58	50.55	**62.06**
30t/ha biofertilizer	1.93	1.48	**1.70**	64.68	29.40	**46.86**	80.18	52.60	**66.39**
Mean Season	**2.23d**	**1.98d**		**69.73d**	**34.69e**		**78.18d**	**54.49e**	

*Season x treatment interaction is not significant according to the F-test at $P \leq 0.05$.

**Treatment means not followed by a letter are not significantly different according to F-test at $P \leq 0.05$

***Treatment means within a variable followed by the same letter in a letter series are not significantly different according to Tukey's Honestly Significantly Test at $P \leq 0.05$.

†S stands for season.

Table 12: Effect of Different Rates of Vermicompost and Biofertilizer on Soil Calcium (Ca) and Iron (Fe)

Treatment	Ca (%)			Fe (ppm)		
	S1†	S2	**Treatment Means**	S1	S2	**Treatment Means**
0t/ha	237.75*	140.00	**174.50bc****	26.05*	55.23	**40.64*****
NPK 17:17:17(60kg/ha)	265.00	148.50	**184.50bc**	26.83	58.15	**42.49**
5t/ha vermicompost	192.25	138.00	**174.25bc**	29.65	54.18	**41.91**
10t/ha vermicompost	244.25	148.25	**172.00bc**	29.43	51.80	**40.61**
20t/ha vermicompost	216.00	125.75	**190.13bc**	29.68	43.78	**36.73**
30t/ha vermicompost	218.50	136.50	**217.00ab**	23.18	57.13	**40.15**
5t/ha biofertilizer	220.25	150.00	**186.75bc**	39.88	60.23	**50.05**
10t/ha biofertilizer	237.25	151.75	**161.75c**	31.53	52.88	**42.20**
20t/ha biofertilizer	232.50	152.50	**206.25abc**	31.33	54.13	**42.73**
30t/ha biofertilizer	275.25	155.00	**238.00a**	31.88	48.20	**40.04**
Mean Season	**233.90f**	**144.63g**		**29.94e**	**53.57d**	

*Season × treatment interaction is not significant according to the F-test at $P \leq 0.05$.

**Treatment means not followed by a letter are not significantly different according to F-test at $P \leq 0.05$

***Treatment means within a variable followed by the same letter in a letter series are not significantly different according to Tukey's Honestly Significantly Test at $P \leq 0.05$.

†S stands for season.

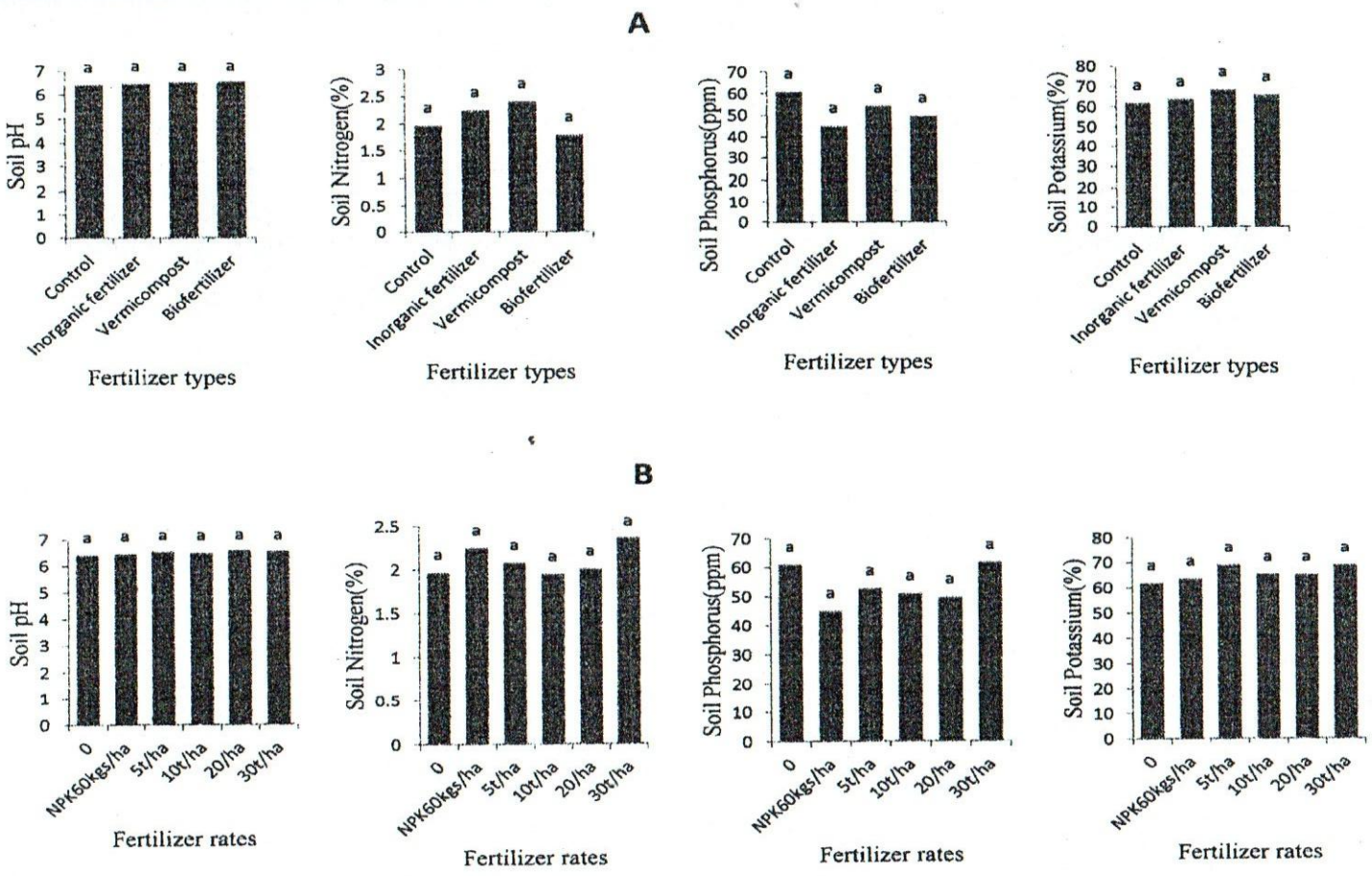


Figure 8: Main effects of fertilizer type (A) and rate (B) on Soil Nitrogen, Phosphorus, Potassium of Beetroot. Using contrasts, bars with the same letter in a letter series are not significantly different at $p \leq 0.05$.

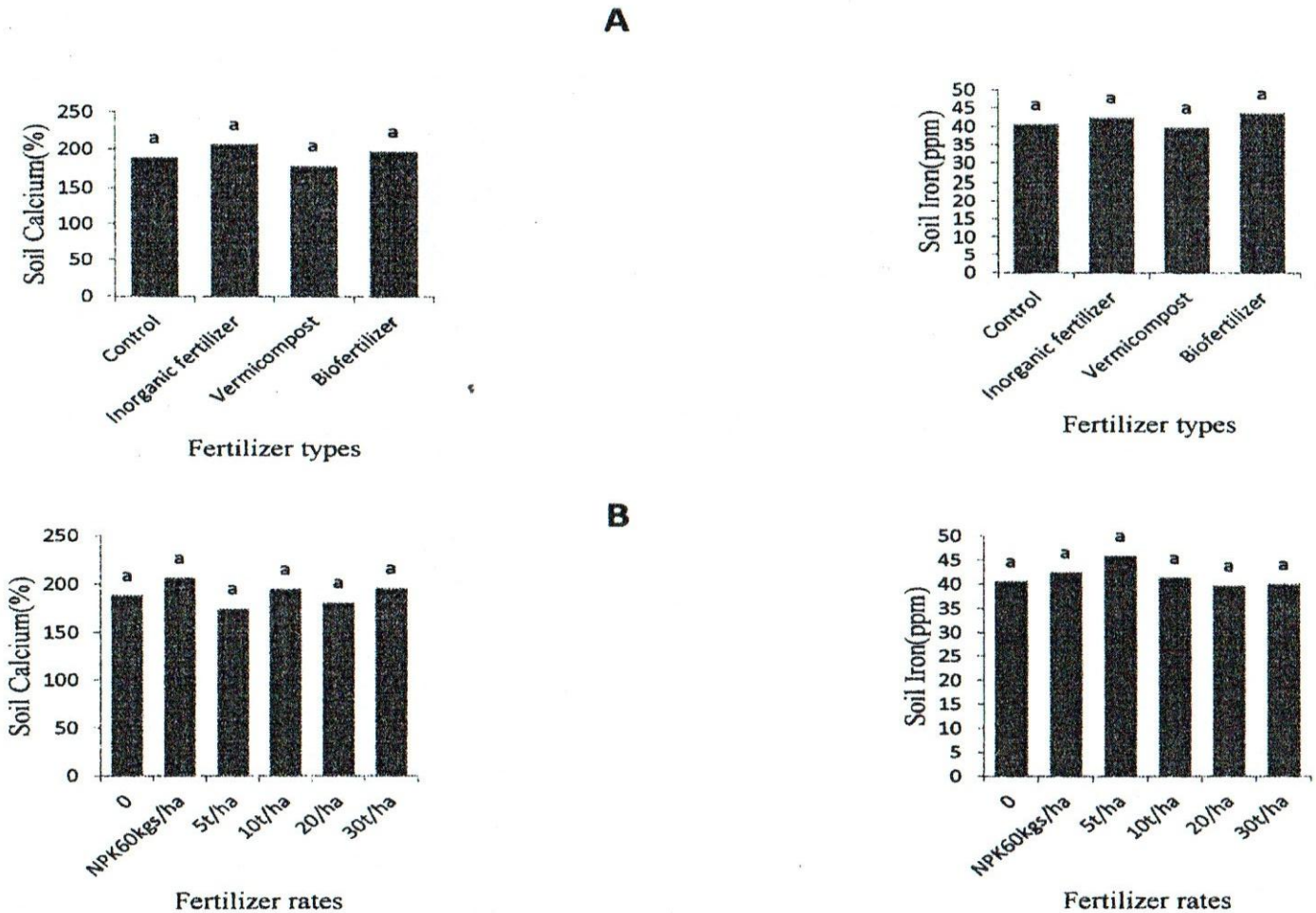


Figure 9: Main effects of fertilizer type (A) and rate (B) on Soil Calcium and Iron of Beetroot. Using contrasts, bars with the same letter in a letter series are not significantly different at $p \leq 0.05$.

4.1.4 Effects of Different Application Rates of Vermicompost and Biofertilizer on Root Nutrient Content

Root nutrient elements analyzed in this study included; i) Nitrogen (N), ii) Phosphorus (P), iii) Potassium (K), iv) Calcium (Ca) and v) Iron (Fe).

a) Root Nitrogen, Phosphorus and Potassium Content

Root N, P and K contents were not significantly influenced by application rates of vermicompost and biofertilizer (Table 13). No significant interaction was also observed between season and treatments. On average, roots of season one had significantly higher P and K compared to those of season two while there was no significant difference in root nitrogen content of beetroot of the two seasons. The main effects of fertilizer type and fertilizer rate on root N, P and K content were also not significant. Root nitrogen content tended to be slightly higher under NPK treatment but the levels of root N recorded for this treatment were comparable to those recorded for the organic fertilizer treatments (Figure 10).

b) Calcium and Iron

Root Ca and Fe content were not significantly influenced by application rates of vermicompost and biofertilizer (Table 14). There was no significant interaction effect between season and treatments on root Ca and Fe content. However, when treatments were averaged within a given season, beetroot plants of season one had higher root Ca content compared to those of season two while root Fe content was higher for season two compared to season one beetroot. The main effects of fertilizer type had no significant influence on root Ca and Fe content compared. Root Ca and Fe content remained relatively constant regardless of whether fertilizer was applied or not (Figure 11). The main effects of the different fertilizer application rates did also not have any significant influence on root calcium and iron of the beetroot (Figure 11). Root iron content was not significantly different amongst roots of beetroot plants treated with the different fertilizer application rates, but were slightly higher under the 5t/ha and 20t/ha of organic fertilizer treatments.

Table 13: Effect of Different Rates of Vermicompost and Biofertilizer on Root Nitrogen (N), Phosphorous (P) and Potassium (K) Content

	N (%)			P (%)			K (%)		
Treatment	**S1†**	**S2**	**Treatment Mean**	**S1**	**S2**	**Treatment Mean**	**S1**	**S2**	**Treatment Mean**
0t/ha	0.26*	0.24	**0.25****	0.48*	4.99	**2.73****	0.08*	0.01	**0.05*****
NPK 17:17:17(60kg/ha)	0.22	0.28	**0.25**	0.41	5.03	**2.72**	0.08	0.01	**0.05**
5t/ha vermicompost	0.23	0.21	**0.22**	0.43	4.97	**2.70**	0.08	0.01	**0.05**
10t/ha vermicompost	0.22	0.18	**0.20**	0.51	4.97	**2.72**	0.08	0.01	**0.04**
20t/ha vermicompost	0.23	0.22	**0.22**	0.48	4.58	**2.53**	0.08	0.01	**0.05**
30t/ha vermicompost	0.19	0.19	**0.19**	0.52	4.89	**2.71**	0.08	0.01	**0.05**
5t/ha biofertilizer	0.22	0.22	**0.22**	0.52	5.11	**2.81**	0.07	0.01	**0.04**
10t/ha biofertilizer	0.19	0.26	**0.22**	0.47	5.27	**2.87**	0.08	0.01	**0.05**
20t/ha biofertilizer	0.21	0.25	**0.23**	0.48	4.80	**2.63**	0.08	0.01	**0.05**
30t/ha biofertilizer	0.22	0.18	**0.20**	0.45	5.36	**2.91**	0.08	0.01	**0.04**
Mean Season	**0.22d**	**0.22d**		**0.47e**	**4.99d**		**0.08d**	**0.01e**	

*Season × treatment interaction is not significant according to the F-test at $P \leq 0.05$.

**Treatment means not followed by a letter are not significantly different according to F-test at $P \leq 0.05$

***Treatment means within a variable followed by the same letter in a letter series are not significantly different according to Tukey's Honestly Significantly Test at $P \leq 0.05$.

†S stands for season.

Table 14: Effect of Different Rates of Vermicompost and Biofertilizer on Root Calcium (Ca) and Iron (Fe)

Treatment	Ca (%)			Fe (%)		
	S1†	S2	**Treatment Mean**	S1	S2	**Treatment Mean**
0t/ha	0.01*	<0.001	**0.01****	2.34*	4.26	**3.30*****
NPK 17:17:17(60kg/ha)	0.01	<0.001	**0.01**	2.43	4.09	**3.26**
5t/ha vermicompost	0.01	<0.001	**0.01**	2.15	4.61	**3.38**
10t/ha vermicompost	0.01	<0.001	**0.01**	2.25	4.85	**3.55**
20t/ha vermicompost	0.01	<0.001	**0.01**	2.49	4.43	**3.46**
30t/ha vermicompost	0.01	<0.001	**0.01**	2.79	3.93	**3.36**
5t/ha biofertilizer	0.01	<0.001	**0.01**	2.32	4.91	**3.61**
10t/ha biofertilizer	0.01	<0.001	**0.01**	2.13	4.26	**3.20**
20t/ha biofertilizer	0.01	<0.001	**0.01**	2.04	5.05	**3.55**
30t/ha biofertilizer	0.01	<0.001	**0.01**	2.45	3.87	**3.16**
Mean Season	**0.01d**	<0.001e		**2.34e**	**4.43d**	

*Season × treatment interaction is not significant according to the F-test at $P \leq 0.05$.

**Treatment means not followed by a letter are not significantly different according to F-test at $P \leq 0.05$

***Treatment means within a variable followed by the same letter in a letter series are not significantly different according to Tukey's Honestly Significantly Test at $P \leq 0.05$.

†S stands for season.

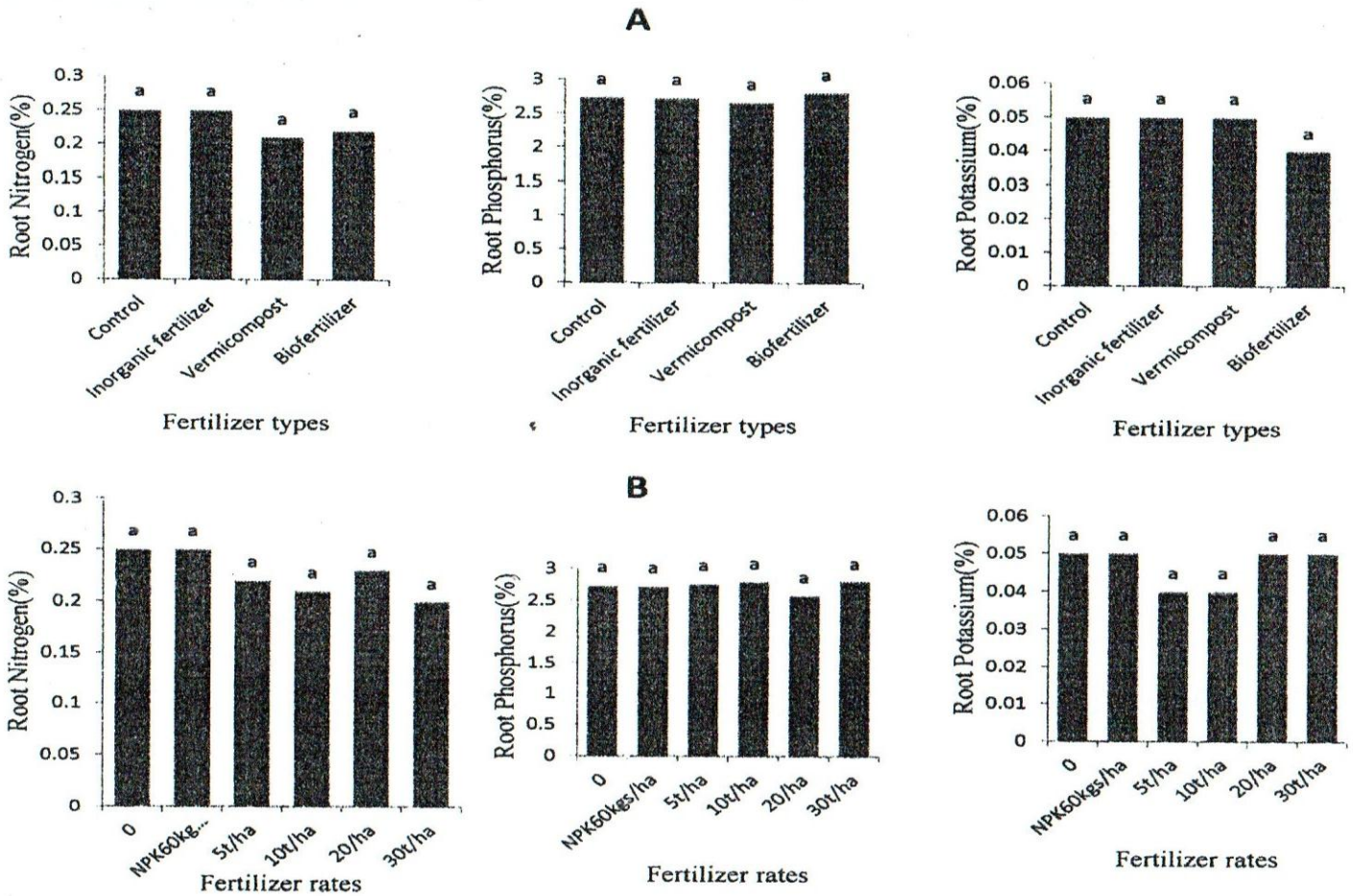


Figure 10: Main effects of fertilizer type (A) and rate (B) on Root Nitrogen, Phosphorus and Potassium of Beetroot. Using Contrasts, Bars with the same letter in a letter series are not significantly different at $P \leq 0.05$.

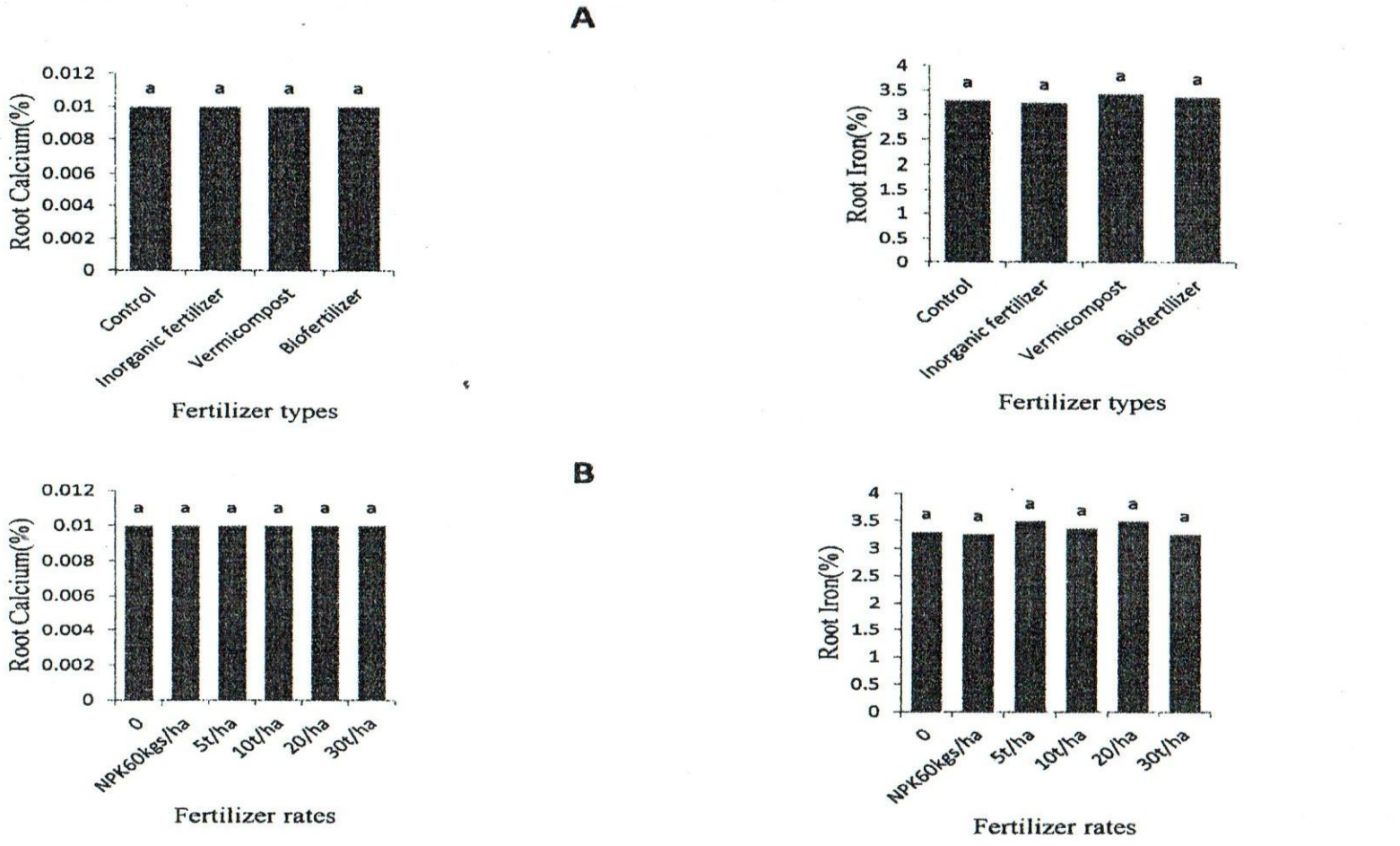


Figure 11: Main effects of fertilizer type (A) and rate (B) on Root Calcium and Iron of Beetroot. Using contrasts, bars with the same letter in a letter series are not significantly different at $p \leq 0.05$.

4.1.5 Effects of Different Application Rates of Vermicompost and Biofertilizer on Leaf Nutrient Content

Leaf nutrient content variables considered in this study were; i) Nitrogen (N), ii) Phosphorus (P), iii) Potassium (K), iv) Calcium (Ca) and v) Iron (Fe).

a) Leaf Nitrogen, Phosphorus and Potassium Content

Application of different rates of vermicompost and biofertilizer did not significantly influence leaf N, P and K content of beetroot plants (Table 15). However, increase in vermicompost and biofertilizer application rates resulted to a slight increase in leaf N, P and K content. No significant interaction was observed between seasons and treatments on leaf N, P, and K content. Averaged within each season, plants of season two had higher leaf P content compared to those of season one while more leaf K content was observed in plants of season one compared to those of season two. No significant difference was observed in leaf nitrogen content of plants of the two seasons.

Leaf N, P and K content were also not significantly influenced by the main effects of fertilizer type and fertilizer rates compared to the control treatment (Figure 12) during both seasons. In all the fertilizer types tested, leaf N, P and K content was relatively constant. However, leaf N content tended to be slightly high under NPK treatment but was not any significantly different from those of plants treated with vermicompost or biofertilizer. Leaf phosphorus and potassium on the other hand, tended to be slightly higher in plants that received the biofertilizer treatment but the content was not any significantly different from those treated with vermicompost, NPK and the control.

b) Leaf Calcium and Iron content

Beetroot leaf Ca and Fe content were not significantly influenced by application of the different rates of vermicompost and biofertilizer (Table 16). No significant interaction was observed between season and treatments on influencing beetroot leaf Ca and Fe content. Averaged within each season, leaf Ca content was significantly higher in leaves of beetroot plants

of season one compared to those of season two but the difference in leaf Fe content of plants grown during the two seasons was not significant.

The main effects of fertilizer type and fertilizer rates did not significantly influence leaf Ca and Fe content compared to the control treatment. Leaf Ca and Fe content remained relatively constant regardless of whether fertilizer was applied or not (Figure 13). Leaf Fe content however tended to be slightly higher under organic fertilizer compared to the inorganic fertilizer (NPK) and control treatment.

Table 15: Effect of Different Rates of Vermicompost and Biofertilizer on Leaf NPK

Treatment	N (%)			P (%)			K (%)		
	S1†	S2	**Treatment Mean**	S1	S2	**Treatment Mean**	S1	S2	**Treatment Mean**
0t/ha	0.20*	0.24	**0.22****	0.61*	4.99	**2.80****	0.10*	0.01	**0.05a*****
NPK17:17:17(60kg/ha)	0.22	0.28	**0.25**	0.51	5.03	**2.77**	0.10	0.01	**0.05a**
5t/ha vermicompost	0.21	0.21	**0.21**	0.56	4.97	**2.76**	0.10	0.01	**0.06a**
10t/ha vermicompost	0.18	0.18	**0.18**	0.42	4.94	**2.68**	0.10	0.01	**0.06a**
20t/ha vermicompost	0.29	0.22	**0.26**	0.59	4.58	**2.58**	0.10	0.01	**0.05a**
30t/ha vermicompost	0.19	0.19	**0.19**	0.45	4.89	**2.67**	0.10	0.01	**0.05a**
5t/ha biofertilizer	0.21	0.22	**0.21**	0.49	5.11	**2.80**	0.10	0.01	**0.06a**
10t/ha biofertilizer	0.23	0.26	**0.24**	0.48	5.27	**2.88**	0.10	0.01	**0.05a**
20t/ha biofertilizer	0.18	0.25	**0.21**	0.62	4.80	**2.71**	0.10	0.01	**0.05a**
30t/ha biofertilizer	0.24	0.18	**0.21**	0.47	5.36	**2.92**	0.10	0.01	**0.06a**
Mean Season	**0.21d**	**0.22d**		**0.52e**	**4.99d**		**0.10d**	**0.01e**	

*Season × treatment interaction is not significant according to the F-test at $P \leq 0.05$.

**Treatment means not followed by a letter are not significantly different according to F-test at $P \leq 0.05$

***Treatment means within a variable followed by the same letter in a letter series are not significantly different according to Tukey's Honestly Significantly Test at $P \leq 0.05$.

†S stands for season.

Table 16 : Effect of Different Rates of Vermicompost and Biofertilizer on Leaf Calcium (Ca) and Iron (Fe)

Treatment	**Ca (%)**			**Fe (%)**		
	S1†	S2	**Treatment Mean**	S1	S2	**Treatment Mean**
0t/ha	0.03*	<0.001	**0.03****	4.20*	4.26	**4.23*****
NPK 17:17:17(60kg/ha)	0.03	<0.001	**0.03**	4.34	4.09	**4.22**
5t/ha vermicompost	0.03	<0.001	**0.02**	3.92	4.61	**4.27**
10t/ha vermicompost	0.03	<0.001	**0.03**	4.08	4.85	**4.46**
20t/ha vermicompost	0.03	<0.001	**0.03**	6.26	4.43	**5.34**
30t/ha vermicompost	0.03	<0.001	**0.02**	4.79	3.93	**4.36**
5t/ha biofertilizer	0.03	<0.001	**0.03**	6.05	4.91	**5.48**
10t/ha biofertilizer	0.03	<0.001	**0.02**	3.52	4.26	**3.89**
20t/ha biofertilizer	0.03	<0.001	**0.03**	4.28	5.05	**4.67**
30t/ha biofertilizer	0.03	<0.001	**0.03**	4.90	3.87	**4.39**
Mean Season	**0.03d**	**<0.001e**		**4.63d**	**4.43d**	

*Season × treatment interaction is not significant according to the F-test at $P \leq 0.05$.

**Treatment means not followed by a letter are not significantly different according to F-test at $P \leq 0.05$

***Treatment means within a variable followed by the same letter in a letter series are not significantly different according to Tukey's Honestly Significantly Test at $P \leq 0.05$.

†S stands for season.

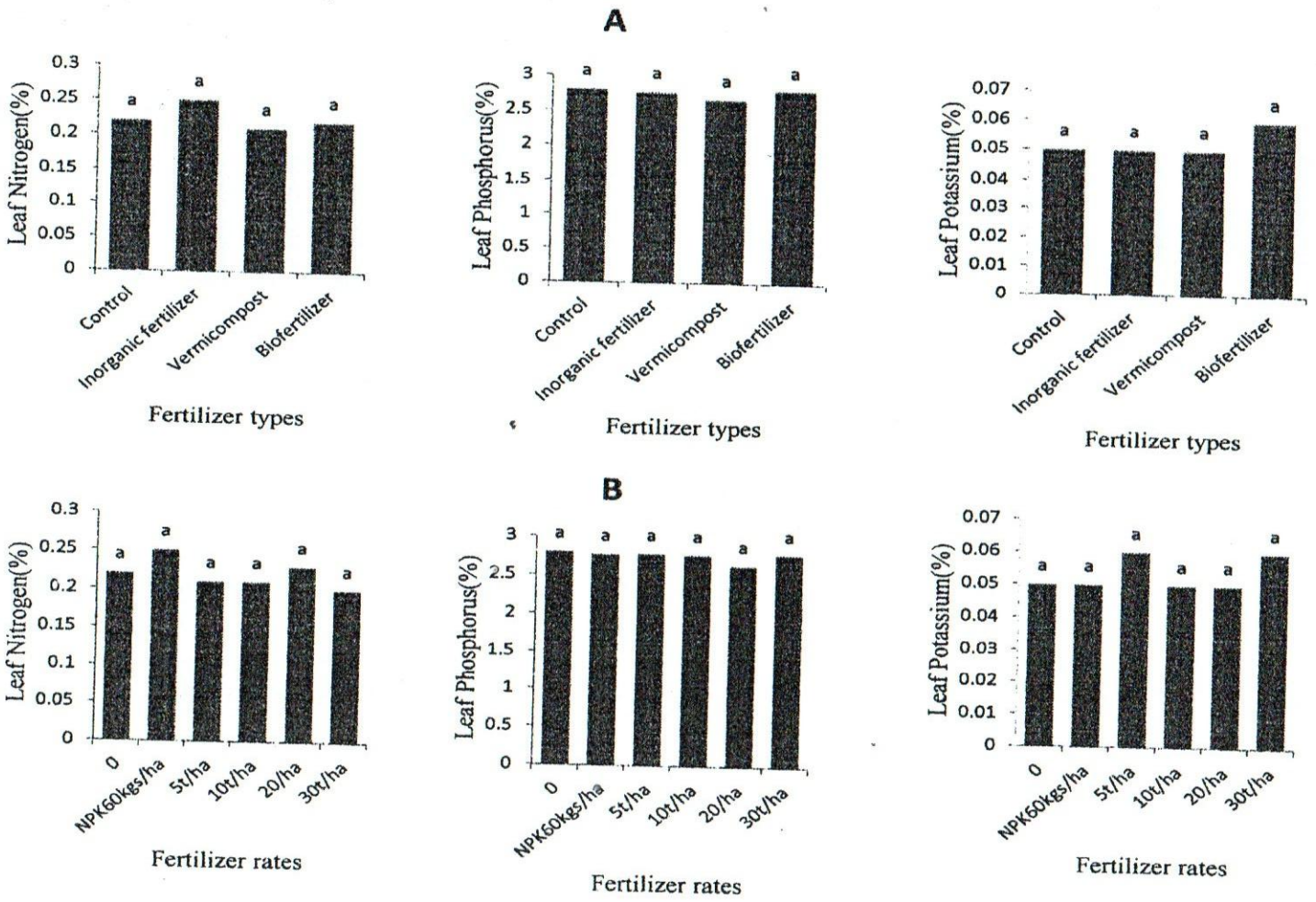


Figure 12: Main effects of fertilizer type (A) and rate (B) on Leaf Nitrogen, Phosphorus and Potassium of Beetroot. Using contrasts, bars with the same letter in a letter series are not significantly different at $p \leq 0.05$.

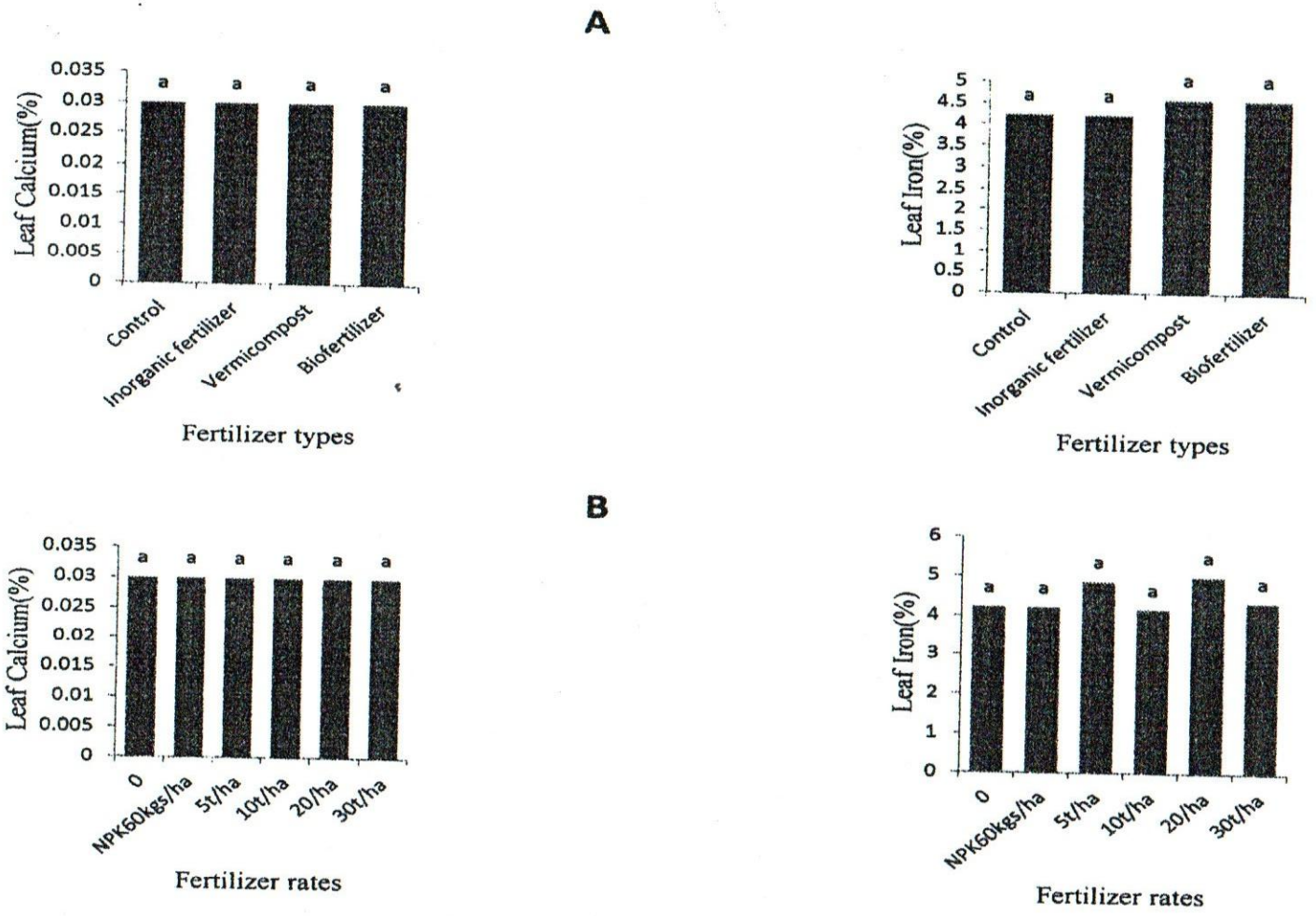


Figure 13: Main effects of fertilizer type (A) and rate (B) on Leaf Calcium and Iron of Beetroot. Using contrasts, bars with the same letter in a letter series are not significantly different at $p \leq 0.05$.

CHAPTER FIVE

DISCUSSION

Results presented in chapter four of this document have been discussed in this chapter in the order that was followed in the result section as follows:

5.1 Effects of Different Rates of Vermicompost and Biofertilizer, on Growth of Beetroot

Even though organic fertilizers have traditionally been used as sources of plant nutrients, the understanding of their importance in plant growth and soil fertility has not always been well understood (Manlay *et al.*, 2007). The present study has demonstrated that application of vermicompost and biofertilizer fertilizer rates enhance beetroot plant growth measured in leaf number, plant height and leaf area index when compared with control treatments. Plant treated with organic fertilizers, in this case vermicompost or biofertilizer yielded plant growth and Leaf Area Index that were comparable to that recorded for plants treated with the recommended rate of inorganic fertilizer. Findings of this study support Fatma *et al.* (2014) who observed that, the application of compost at two rates significantly increased vegetative growth characters measured in terms of plant height, average number of leaves, fresh and dry weight of whole plant and the different organs of onion plants compared to control treatment with other fertilizer applied. Improvement in leaf numbers and plant height following application of organic fertilizers during crop production has been attributed to increase in soil microbial biomass which creates favorable soil conditions for plant growth. Besides, Vermicompost and biofertilizer application during crop production has been associated with production of hormones or humates which acts similar to plant growth regulators such as auxins, gibberellins and cytokinins. Such products of vermicompost and biofertilizer could have resulted in increased beetroot plant height, leaf numbers and leaf area index in the current study through increased cell division and rapid cell elongation. Similar results are reported by Canellas *et al.* (2000) in maize root and Atiyeh *et al.* (2002) in tomato plants. Results of the current study also corroborates the findings of Gopinathan and Praker (2014) in Tomato.

Besides macronutrients, vermicompost and biofertilizers are also known to contain micronutrients which stimulate and boost better plant growth. Bagali *et al.* (2012) reported significantly higher plant height, number of leaves per plant, leaf area per plant and leaf area index in response to application of vermicompost at the rate of 6 t ha-1over lower levels of vermicompost. Similar to these observations, vermicompost at the rate of 30t/ha produced more leaves compared to lower application rates in the current study. According to Gupta (2005),

better performance of plants treated with vermicompost and other organic fertilizers could be as a result of plant growth promoters, enzymes, beneficial bacterial and mycorrhizae that tend to be found in such organic fertilizer sources. In the current study, 10t/ha, 20t/ha and 30t/ha of vermicompost and 20t/ha and 30t/ha of biofertilizer had significantly taller plants compared to NPK and control treatments. The increase in height due to increased rate of vermicompost or biofertilizer could be attributed to the fact that these organic fertilizers contain a good range of essential micronutrient compared to NPK fertilizers that are required for healthy plant growth; with the concentration of such nutrients increasing with increase in the amount of vermicompost of biofertilizer applied (Suthar, 2009). Vermicompost and biofertilizer also contain sufficient nitrogen which is one of the important building blocks of amino acids, where they link together and form proteins and make up metabolic processes required to support plant growth.

Reddy and Reddy (2005) similarly reported significantly taller garlic plants in response to vermicompost application and significantly increased plant height and number of leaves per plant with higher levels of farm yard manure during garlic production while Lal *et al.* (2002) observed increases leaf area per plant following application of farmyard manure during in onion production which they attributed to increased number of leaves and leaf area per plant resulting in better photosynthesis and accumulation of photosynthates leading to more vigor. Generally, plants require constant supply of mineral elements including organic matter to support their growth. Even though inorganic fertilizer quickly release mineral elements, stimulation of microbial growth due to application of biofertilizer and vermicompost could have promoted the synthesis of enzymes like phosphatase enzymes in the soil thereby increasing nutrient turnover through both increased microbial biomass and activity which could possibly explain the lack of significant difference between NPK treatment and the vermicompost and biofertilizer treatments for most growth variables measured in the current study. Similar results were also obtained by Dineshkumar (2020) and Thimmiah (1989) in green gram.

5.2 Effects of Different Rates of Vermicompost and Biofertilizer, on Yield of Beetroot

Use of vermicompost and biofertilizer in the current study influenced fresh and dry root weight of beetroot plants. Fresh and dry root weight was maximum in plants treated with 10t/ha of biofertilizer followed by 30t/ha of vermicompost then NPK at 60kg/ha and lowest under the control treatment with no form of fertilizer applied. Increase in fresh and dry root weight by

biofertilizer and vermicompost treatments may be attributed to the role of biofertilization in nitrogen fixation via free living bacteria which reduces the soil pH especially in the rhizosphere leading to increase in the availability of most essential macro and micro nutrients, consequently increasing growth and root weight. Findings of the current study support those reported by (Bassal *et al.*, 2001; Suslow *et al.*, 1979).

In the present study, use of vermicompost and biofertilizer did not significantly influence fresh and dry weight of both leaves and roots of beetroot plants. Yield from inorganic fertilizer, vermicompost and biofertilizer treated plots were comparable but tended to be higher compared to those of the control treatment. Similarly, Thanunathan *et al.* (1997) observed that the use of vermicompost on onions increased growth and yield of the crop. Gezachew *et al.* (2006), on the other hand also reported increased tuber weight in potato with application of compost.

The use of different rates of vermicompost or biofertilizer did not significantly influence biomass yield of beetroot. A trend could however be established where biomass yield generally tended to be higher for plants treated with NPK and the different rates of vermicompost and biofertilizer compared to no fertilizer application (control), with the highest biomass yield obtained with application of 10t/ha of biofertilizer. Beetroot harvest index was on the other hand significantly influenced by use of the different fertilizer rates of vermicompost and biofertilizer with the highest harvest index obtained with application of 30t/ha of vermicompost or biofertilizer and the lowest harvest index recorded under the control treatment. Findings of the current study corroborates those of Juan *et al.* (2006), who reported an increase in scorodose accumulation in garlic bulb which is directly related to the harvest index with the use of vermicompost during production. Similarly, Papathanasiou *et al.* (2012) who reported increased dry weight of lettuce and Joshi and Vig (2010) reported higher tomato total and marketable yield when soil was supplemented with vermicompost compared with the control treatment. Vermicompost and biofertilizer have high microbial activity due to presence of fungi, bacteria and actinomycetes which can produce plant growth regulators such as auxins, gibberellins, cytokinins, ethylene and abcisic acid resulting in growth stimulation and better biomass accumulation. Moreover, the supply of a fertilizer with a more varied chemical composition than the simple inorganic fertilizers of different complexity results in better growth and yield (Abdelaal & Tawfik, 2015), suggesting that a shift to more sustainable production systems, could maintain crop yields at levels comparable of those of inorganically fertilized crops.

5.3 Effects of Different Rates of Vermicompost and Biofertilizer, on Quality of Beetroot

Beetroot quality at harvest was also significantly improved by the use of vermicompost and biofertilizer rates. Brix content of beetroot was positively influenced by the use of different rates of vermicompost and highest at 5t/ha of biofertilizer. According to Arancon *et al.* (2006), growth regulators (gibberellins, cytokinin and auxin) present in vermicompost or biofertilizers play a significant role in crop quality development possibly explaining the higher brix content recorded for organic fertilizer treatments in the current study. Additionally, high humic acids in vermicompost and biofertilizer have been shown to contribute to plant health, through promotion of the synthesis of phenolic compounds such as anthocyanins and flavonoids which may improve the plant quality (Manlay *et al.*, 2007). In the current study, titratable acidity, total soluble sugars and sugar: acid ratio was not significantly different across all fertilizer treatments. These findings contradict those of earlier study where soil treated with cattle dung vermicompost was found to increase ascorbic acid, titratable acidity, soluble solids, and insoluble solids of tomato fruit compared with the control (Joshi & Pal Vig, 2010). Lack of significant influence of the different fertilizer types and rates on total sugars, acidity and sugar: acid ratio of beetroot could be attributed to high levels of nutrients in the soil.

5.4 Effects of Different Rates of Vermicompost and Biofertilizer, on Soil Nutrient Status during Beetroot Production

Results of the present study demonstrated no significant influence of vermicompost and biofertilizer on soil pH, N, P, K, Ca and Fe compared with the control and inorganic fertilizer application. Higher soil mineral element content were recorded in inorganic fertilizer treated plots compared with the organic fertilizer treated plots although the difference with the content recorded for biofertilizer and vermicompost treated plots was not significant. Similar short-term increases in mineral elements from inorganic fertilizer compared to organic fertilizer have been reported previously (Arancon *et al.*, 2006). The presence of readily available mineral elements in inorganic fertilizers appears to be responsible for the higher mineral elements tested on short-term in inorganic fertilizer treated plots whereas the effects of the more resistant mineral elements in vermicompost and biofertilizer may be more important for long-term positive effects on soil processes. Higher mineral elements content observed at higher rates of vermicompost and biofertilizer-treated soils indicates the possible increase in potential activity of the soil enzymes that degrade organic compounds compared to lower rates. In addition, it

indicates that vermicompost and biofertilizer are more stable form of organic matter and thus less likely to immobilize mineral elements when used as a growth medium amendment.

5.5 Effects of Different Rates of Vermicompost and Biofertilizer, on Nutrient content of Beetroot

The results from the study have shown that vermicompost and biofertilizer rates did not positively influence the nutrients content of (N, P, K, Ca and Fe) on both roots and leaves of beetroot plants. The observed results on vermicompost and biofertilizer were comparable with inorganic fertilizer used. Increase in organic fertilizer rates did not significantly affect nutrient content on both roots and leaves of beetroot plants. However, both root and leaf P and K tended to be higher in beetroot treated with vermicompost and biofertilizer and this agrees with Baldatto *et al.* (2009) established significant accumulation of N, P, K, Ca and Mg in the roots, shoots and leaves of pineapple as a result of the application of humic acids derived from organic fertilizer. Vermicompost and biofertilizer contains plant nutrients including N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B, the uptake of which has a positive effect on plant nutrition, photosynthesis, the chlorophyll content of the leaves. Therefore, the effect could be attributed to readily available mineral elements hence uptake by beetroot plants leading to high content in the leaves and roots as reported.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the above results, the following conclusions can be made;

i. Vermicompost and biofertilizer rates improve growth of beetroot plants. Application of vermicompost or biofertilizer at the rate of 30t/ha results in the highest plant height, Leaf Area Index during the vegetative stage and number of leaves of beetroot plants.

ii. Different application rates of vermicompost and biofertilizer influence the yield of beetroot. Application of 10t/ha of biofertilizer yielded highest fresh and dry root weight and total biomass yield while the highest harvest index was obtained with the application of 30t/ha biofertilizer or vermicompost

iii. Application of vermicompost or biofertilizer positively influence quality of beetroot with the highest brix content obtained with application of biofertilizer at 5t/ha.

6.2 Recommendations

Based on the above conclusion it is recommended that;

i. Even though there were comparable results when vermicompost, biofertilizer and inorganic fertilizer were used on beetroot plants, farmers should use vermicompost or biofertilizer in beetroot production because of the negative effects of inorganic fertilizers on the soil, plants and the environment.

ii. From the results of this study, it can be recommended that the maximum growth, yield and quality of the crop was obtained using rates as low as 5t/ha and 10t/ha of both vermicompost and/or biofertilizer, therefore I'm recommending the farmers to use at least 5t/ha.

iii. Since the experiment was done only at one location, similar experiments should be carried out in different agro – ecological regions and over several seasons to further validate the findings of this study.

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APPENDICES

Appendix I: Research publication

Effect of Different Rates of Vermicompost on Growth and Yield of Beetroot (*Beta vulgaris* L.)

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Abstract

Beetroot (*Beta vulgaris* var. *crassa* L.) is one of the vegetable that is gaining prominence in Kenya due to its high nutritive and medicinal value. While the use of organic fertilizers has been reported to improve growth and yield of crops, majority of beetroot growers mostly use inorganic fertilizers. The result of this has been an increase in cost of production, high levels of residues in soil and environmental pollution. A study was done in the Horticulture Research and Teaching Field, Egerton University to address some of these problems, with the main objective of determining the effects of different application rates of vermicompost (0, 5, 10, 20 and 30 t/ha) and a positive control (NPK 17: 17: 17) on growth and yield of beetroot. Growth variables investigated were leaf number (no. /plant), plant height (cm), and Leaf Area Index (LAI), while yield variables included root yield, leaf yield and harvest index. Based on the results, vermicompost application at the rate of 30 t/ha increased the plant growth and productivity and therefore can be recommended in the organic production of beetroot.

Key words: Beetroot, Vermicompost, Growth and Yield, Organic production

Introduction

Beetroot (*Beta vulgaris* var.*crassa L.*), is a true biennial though grown as an annual, producing thickened root and a rosette of leaves during the first season and flowers and seeds during the second season. It is mainly grown for its swollen roots but the leaves can also be eaten as spinach (Rubatzky *et al.*, 1998).In Kenya, it is consumed in salads and the beetroot juice is taken as a health drink. It contains anthocyanidins; pigments that give the sweet, earthy-tasting vegetable its deep indigo colour.It also provides antioxidant, vitamins A and C, and is an excellent source of betaine and methionine, that support liver detoxification (Lu *et al.*, 2003; Winkler *et al.*, 2005).

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