EFFECT OF ORGANIC AND INORGANIC FERTILIZER ON GROWTH, YIELD AND FRUIT QUALITY OF EGGPLANT *(Solanum melongena* L)

BY

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DECLARATION

Declaration by the candidate

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DEDICATION

To my parents and my family for their moral support to my research and thesis work. I also dedicate this work to my siblings; Collins, Kevin and Patrick, who had special interests in my work. God be with you.

ABSTRACT

Egg plant (*Solanum melongena* L) is one of the important Asian Vegetables grown in Kenya for local and export market; hence effort to improve its productivity and quality should be emphasized. Declining soil fertility due to continuous cultivation of small holder farms and escalating cost of imported fertilizers and the need to conserve and build natural resource capital and biodiversity, has renewed interest in the use of local nutrient resources for soil fertility management in Kenya. The study was conducted at Bukura Agricultural college farm during the short (SR) and long rain seasons (LR) of the year 2009 and 2010 respectively. Eggplant seedlings were raised and transplanting 42 days after sowing. During transplanting, DAP and compost was applied while CAN applied three weeks later. The experiment aimed at evaluating the effect of combination between two levels of the recommended inorganic fertilizers (50% and 100% of research recommended rates (RRR) of 220 kgha^{-1} DAP and 600 kgha^{-1}CAN)) with three types of organic manures on growth, fruit yield and quality of egg plant (*Solanum melongena* L) var. *Black beauty*. Split plot design with three replications was used, where two levels of inorganic fertilizers treatments (50%RRR and 100%RRR) were randomized in main plots while three types of organic manures; FYM, Compost (10-15tonha^{-1}) and Tithonia (6 tonha^{-1}) and control treatments were randomized within the subplots. Topsoil (0-20cm depth) and organic manures were sampled before transplanting seedlings and analyzed for chemical properties, pH, N, P, K, OC and CEC. 75 days after transplanting, determination of and plant height (cm) and fresh weight (g) of the plants was done and in the third picking the fruit length and diameter determined. Results showed that there was a significant interaction between of the two inorganic fertilizer levels and the organic manures. Increasing inorganic fertilizer from 50% to 100% of the research recommended rates (RRR) encouraged the vegetative growth of eggplants shown by plant height and fresh weight. Besides increasing the total fruit yield, fertilizer enhanced the fruit quality. The farm yard manure was considered the superior source of manure for obtaining the highest value of the parameters under study compared to compost and *Tithonia diversifolia* (tithonia). Soil fertilized with 100% recommended NPK combined with organic manures produced the superior growth of plants and the highest amount of total fruit yields. Farmers would benefit by incorporating 10-15 tonha^{-1} (1-1.5 kg/M^{2}) of FYM combined with 110 kgha^{-1} DAP and 300 kgha^{-1}CAN (83kg N ha^{-1} and 61.5kg P ha^{-1}) to improve on the growth, yield and quality of eggplants. Hence training farmers on how to increase availability and preservation of FYM is critical.

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ACRONYMS AND ABBREVIATIONS

AOAC	American Organization of Analytical Chemists
ANOVA	Analysis of Variance
AVRDC	Asian Vegetable Research and Development Center
BNF	Biological Nitrogen Fixation
CAN	Calcium Ammonium Nitrate
CEC	Cation Exchange Capacity
Cmol kg^{-1}	Centimol per kg of soil
DAP	Diammonium Phosphate
DM	Dry Matter
DNA	Deoxy-nucleic Acid
FAO	Food and Agriculture Organization of the United Nations
FORMAT	Forum for Organic Resource Mgt. and Agricultural Technologies
FYM	Farm Yard Manure
HCDA	Horticultural Crops Development Authority
I.A.E.A.	International Atomic Energy Agency
KARI	Kenya Agricultural Research Institute
LM	Lower Midland
LSD	Least Significant Difference
NPK	Nitrogen: Phosphorus: Potassium
OC	Organic Carbon
RRR	Research recommended rates
UM	Upper Midland

CHAPTER ONE

INTRODUCTION

Egg plant (*Solanum melongena* L) is one of the important Asian Vegetables grown in Kenya for export and local market. As might be expected with the crop of such promising potential, effort to improve its productivity should be emphasized. The crop nutritional requirements are among the major aspects to consider in the improvement of its growth, fruit yield and quality.

Nitrogen, phosphorus and potassium are major essential elements required for physiological mechanisms of plant growth (Rao and Subramanian, 1994). Nitrogen and phosphorus are usually the most limiting nutrients in many soils in Africa and are often simultaneously deficient (Warren, 1992). Most soils in Sub-Sahara Africa (SSA) have been used for subsistence farming resulting in low and declining fertility (Buresh *et al*, 1997). Continuous cropping with low or no fertilizer inputs, nutrient losses through harvest, soil erosion and leaching have led to decline in soil fertility (Cooper et al; 1996).

In the East African region, P deficiency is of common occurrence in the highly populated highlands (Bekele and Hofner, 1993). Estimates of P limitations in western Kenya ranged from 80-90% in the farms (Shepherd *et al*., 1995) often result in low crop yields. To a large extent, this is due to no or little phosphorus inputs. It is necessary to add fertilizer inputs to these soils in order to have good continuous crop yields. Such inputs may be either organic or inorganic in a form or forms depending on their availability. For the last two decades, there has been increasing interest in the use of plant residues in agricultural systems in the tropics where low fertilizer inputs are in use (Tian *et al*., 1992).

Organic inputs alone cannot meet the nutritional needs of crops because they contain a comparatively less quantity of nutrients compared to inorganic fertilizers, hence the need to integrate the two forms in order to achieve better crop yields. The interaction between organic matter and inorganic fertilizers may lead to either an increase or decrease in nutrients in soil depending on the nutrient and plant material in question (Frankenberger and Abdelmagid, 1985).

Low use efficiencies of inorganic fertilizers coupled with their rising costs and the need for organically produced foods have directed the attention of farmers towards organic sources. Organic manures may increase soil fertility and thus the crop production potential possibly by changes in soils physical and chemical properties including nutrient bioavailability, soil structure, water holding capacity, cation exchange capacity, soil pH, microbial community and activity etc. (Walker *et al.,*2004; Agbede *et al.*, 2008; Muhammad & Khattak, 2009). Soil pH is greatly influenced by addition of organic matter (OM) through different organic amendments and changes in pH vary with the nature of OM (Walker *et al.*, 2004).

Some organic materials can increase crop yields due to improved soil through nutrient release during decomposition and mineralization. They may also improve soil physical properties such as moisture retention, bulk density and aeration (Frankenberger and Abdelmagid, 1985). In addition, they generally have greater residual effect on subsequent crops than inorganic nutrient sources due to slow release of their nutrients over time (Szott and kass, 1993). They can also result in complexion of aluminum and iron with organic compounds from decomposition resulting in greater availability of phosphorus and reduction of aluminum toxicity.

Organic fertilization is also important for providing plant with their nutritional requirements without having an undesirable impact on the environment. (Njoroge and Manu,1999). Addition of different sources of organic manures increases the plant growth characteristics, namely plant height, number of leaves and shoots per plant, and fresh and dry weight of shoots of plants (Zhang *et al*, 1998).

It has been shown that increase in tomato yield produced by organic-mineral compounds was greater than that of plants produced by inorganic fertilizer applied at the same rate. Organic amendments especially when applied in high rates can increase the availability and use efficiency of phosphorus by plants (Iyamuremye and Dick, 1996). This has been observed to be so for farm yard manure (Tisdale *et al*, 1985).It has also been demonstrated for green leaf biomass of *Tithonia diversifolia* (Nziguheba *et al*, 1998).

Organic materials besides enhancing P availability and even supplying some P, have other major benefits such as the provision of other nutrients, especially N. This is because of their high tissue concentration of N compared to other nutrients (Palm, 1995).

1.1 Problem statement

Increasing pressures on agricultural land have resulted in much higher nutrient outflows and the subsequent breakdown of many traditional soil-fertility maintenance strategies, such as fallowing land, intercropping cereals with legume crops, mixed crop-livestock farming, and opening new lands. Such strategies have not been replaced by an effective fertilizer supply and distribution system (Sanders *et al.*, 1996).

Declining soil fertility resulting from continuous cultivation of small holder farms and the need to conserve and build natural resource capital and biodiversity has contributed to the interest in sustainable agriculture (Vukasin *et al*, 1995).

Organic proponents argue that the application of chemical inputs causes environmental pollution in the soil through acidification and altered biological activities, failure to maintain soil structure and soil organic matter (Harris *et al*, 1998).

In contrast, the application of organic inputs supplies substrate to the biological processes that in turn strengthens the resilience of soil to provide plant nutrients, maintain soil structure, retain water and detoxify agents harmful to plant roots and soil organisms (Woomer *et al*, 1994). Most smallholder farmers in Africa appreciate the value of fertilizers, but they are seldom able to apply them at the recommended rates and at the appropriate time because of high cost, lack of credit, delivery delays, and low and variable returns (Heisey & Mwangi, 1996).

The increase in prices of inputs following the liberalization of the agriculture sector in Kenya calls for promotion of organic inputs such as manures and herbal pesticides to supplement and if possible replace the inorganic fertilizers (Harris *et al*, 1998).

An issue of practical importance in this regard, therefore, is that the use of inorganic sources of fertilizer in increasing food production has been overemphasized at the expense of the organic sources of fertilizer. Although inorganic fertilizers have resulted in great increases in agricultural production, it has been realized that most of them are environmentally harmful. These materials are expensive and most of our farmers cannot afford them. Thus in Kenya, there is growing interest in finding alternative affordable, viable and sustainable technologies to replenish soil fertility with focus shifting to solutions that utilize more local resources and less external inputs.

1.2 Justification

In the past, many African countries subsidized fertilizers, however, the removal of fertilizer subsidies by most African governments as part of the Structural Adjustment Programs tripled or quadrupled fertilizer prices in relation to crop prices in many African countries (Bumb & Baanarite, 1996). Furthermore, since fertilizer recommendations are normally formulated to cover broad areas with diverse soils, farmers also lack information about the best fertilizer to use for their particular fields and cropping practices, making the crop response to fertilizers more erratic and less profitable.

The liberization of the Kenya's economy in the early 1990's was meant to empower producers while giving consumers freedom of choice. However, liberalization has been associated with price spirals for most agricultural inputs (FORMAT, 2004).

To counter the negative fall offs of liberalization there is need for integrated nutrients management whose basic concept is the maintenance and possible improvement of soil fertility for sustaining crop productivity on a long term basis (Singh and Yadav, 1992).

Organic materials enhance nutrient use efficiency and provide other nutrients, especially nitrogen because of their high tissue concentration of nitrogen compared to other nutrients (Palm, 1995). Addition of organic matter improves soil nutrient availability and uptake by plants in the sense that the increase in soil organic matter, N and P availability also increases (Ewulo *et al.*, 2008).

The observation that organic fertilizers have proved effective in increasing nutrient use efficiency and crop productivity is hypothesis which merits investigation to determine the extent to which inorganic fertilizers can be reduced and consequently reduce the cost of inputs while increasing the use of organic fertilizers.

1.3 Objectives of the study

Broad objective:

The overall objective of the study is to evaluate the effect of two inorganic sources and three sources of organic manures and their interactions on growth, yield and fruit quality of egg plant. (*Solanum melongena* L)

The specific objectives are:-

1. To study the effect of organic and inorganic nutrient sources and their interactions on plant height and fresh weight of egg plant (*Solanum melongena* L.)
2. To evaluate the effect of organic, inorganic nutrient sources and their interactions on the fruit length and diameter of eggplant (*Solanum melongena* L.)

1.4 Hypothesis

Ho: Organic, inorganic nutrient sources and their interactions have no effect on growth, yield and quality of eggplant (*solanum melongena* L).

H1: Organic, inorganic nutrient sources of fertilizer and their interactions have an effect on growth, yield and quality of eggplant (*solanum melongena* L).

CHAPTER TWO

LITERATURE REVIEW

2.1 Egg plant (*Solanum melongena* L)

Egg plant (*Solanum melongena* L) originated from India and is grown in the tropical regions. The fruit is a good source of vitamin A and C, potassium, phosphorus and calcium. It is one of the most important Asian vegetables used as cooked vegetable alone or with other vegetables as a stuffing. The fruits of white varieties have medicinal value for diabetics (HCDA *et al*, 2004).Eggplant is a perennial herb grown as an annual. It has vigorous, deep growing tap root and grows 40-150 cm tall with large coarsely lobed leaves and fruits are 5-15 cm long and 5-10 cm in diameter when mature. In Kenya, production is done throughout the year and the bulk of the crop is exported.

Eggplant grows well from the coastal lowland to lower midland zones with altitudes between 0-1600 m above sea level, temperature range of 20-30^{0}C and rainfall of 1000-1500 mm per annum. It is well adapted to both wet and dry seasons but excessive rainfall will check vegetative growth and flower formation as well as increasing incidences of soil borne diseases. The soils should be well-drained, fertile with good moisture retaining capacity and pH range 5.5-6.5 (HCDA *et al*, 2004).

To propagate the crop, seeds are sown in a well prepared raised nursery bed with friable soils in rows 30 cm apart and 10cm between seeds. Seedlings are ready for transplanting 3-6weeks after sowing when 8-10 cm in height. Plants are spaced at 75-90 cm between the rows and 60 cm within the row (HCDA *et al,* 2004). Prior to transplanting a basal dose of compost or farmyard manure at a rate of 10-15 tons/ha is recommended sources (KARI, 1994). 10gm of DAP fertilizers should be applied in each hole and mixed well with soil. Top dressing is done with CAN at 20 g/plant 3 weeks after transplanting when plants are 25 cm high. Thereafter plants are top dressed every month for four months at a rate of 40 gm/plant (HCDA *et al*, 2004).

Harvesting begins 2½- 3 months after sowing and can last up to 4 months. The surface of the fruit should be bright and glossy. The fruits are ready to harvest from the time it is one quarter grown to near ripe. Harvesting is done by cutting the fruit from the stem and leaving a short piece of stalk on the fruit when they are about two thirds maximum size The expected average yield among varieties grown in Kenya is 20-25 tons/ha, however some varieties such as ‘Ravaya’ variety can yield up to 60 tons/ha fresh fruit (HCDA *et al*, 2004).

2.2 Plant nutrition

2.2.1 General

The two most widespread limiting nutrients to food production in Africa are N and P, in that order (Bekunda et al., 1997). For example, in a series of fertilizer trials conducted throughout the Kenyan highlands, N and P deficiencies were reported in 57 and 26% of the cases, respectively. Potassium, Ca, Mg, S, and micronutrient deficiencies and Al toxicity do occur in specific circumstances in Africa, but not to the extent of N and P deficiencies. Potassium depletion rates (15 kg K ha-1 yr-1) are six times those of Phosphorus (Smaling et al., 1997), but crop responses to K fertilization are rare in Africa, except in sandy savanna soils. This is probably due to the high K capital in many parts of Africa and the low demands for K due to the current low crop yield levels. Consequently, in this chapter we focus on the two main limiting nutrients.

2.2.2 Macro and micronutrients

Plants require essential nutrients; macronutrients and micronutrients in forms that are usable by plants and in concentrations optimum for plant growth (Brady, 1984). The various nutrients must be supplied in amounts that are balanced. Macronutrients are required by plants in large quantities. These include nitrogen, potassium, phosphorus, calcium magnesium and sulfur. Nitrogen, phosphorus and potassium are commonly supplied to the soil as manure and as inorganic fertilizers. Micronutrients are required by plants in very small quantities. Some of the micronutrients needed by plants are iron, zinc, boron, copper and molybdenum. The availability of these nutrients is low in highly leached sandy soils and those that are highly alkaline and organic in nature (Brady, 1984). Organic manures and artificial fertilizers are the major sources of micronutrients.

2.2.2.1 Nitrogen

2.2.2.1.1 Role of Nitrogen in Plants

Of all nutrients, N is required in greatest quantity by crops (Giller et al., 1997). Nitrogen constitutes 1-4 g kg^{-1} of the dry weight of the plant. Nitrogen is an important component of many important structural, genetic and metabolic compounds in plant cells. It is a major component of chlorophyll, the compound by which plants carry out photosynthesis. It is also a major component of amino acids, the building blocks of proteins. Some proteins act as structural units in plant cells while others act as enzymes, making possible many of the biochemical reactions on which life is based. Nitrogen is a component of energy-transfer compounds, such as ATP (adenosine triphosphate) which allows cells to conserve and use the energy released in metabolism. Finally, nitrogen is a significant component of nucleic acids such as DNA, the genetic material that allows cells (and eventually whole plants) to grow and reproduce.

2.2.2.1.2 Soil Nitrogen

Soil nitrogen exists in three general forms - organic nitrogen compounds, ammonium ($NH4^+$) ions and nitrate ($NO3^-$) ions. At any given time, 95-99% of the potentially available nitrogen in the soil is in organic forms, either in plant and animal residues, in the relatively stable soil organic matter or in living soil organisms, mainly microbes such as bacteria. This nitrogen is not directly available to plants, but some can be converted to available forms by microorganisms. A very small amount of organic nitrogen may exist in soluble organic compounds, such as urea, that may be slightly available to plants.

The majority of plant-available nitrogen is in the inorganic (sometimes called mineral nitrogen) $NH4^+$ and $NO3^-$ forms. Ammonium ions bind to the soil's negatively-charged cation exchange complex (CEC) and behave much like other cations in the soil. Nitrate ions do not bind to the soil solids because they carry negative charges, but exist dissolved in the soil water, or precipitated as soluble salts under dry conditions. Some $NH4^+$ and $NO3^-$ may also exist in the crystal structure of certain soil minerals, and may be quite available; however, such nitrogen is important in only a few soils.

The principal sources of N for crop production are biological N fixation, mineral N fertilizers and the decomposition of organic inputs such as plant biomass and animal manures (Sanchez *et al*., 1997). Nitrogen is taken up by the plant roots mainly in form of NO_3^- and NH_4^+ ions. Nitrogen requirements vary considerably at different stages of growth and development of the plant. It is minimal in the early stages but the requirements increase as rate of growth accelerates to reach the peak in most annual crops, between onset of flowering and early grain or fruit formation .It is because of these temporal N needs that N management for crops usually involves the application of only a small fraction of the total N rate at planting time to stimulate early growth while the bulk is applied later at the period of rapid growth (Tisdale *et al.,* 1985). Sigunga (1997) identified some of the factors affecting fertilizer N uptake by crops as follows: plant genotype, N source and rate, climatic conditions, N application method and time. These factors may be in turn, influenced by such processes as N leaching, denitrification, NH_3 volatilization and soil N mineralization.

2.2.2.1.3 Nitrogen sources and inputs

Nitrogen inputs to a field consist mainly of inorganic fertilizers, biomass transfers, BNF, animal manures or composts produced outside the field, and nitrate capture from subsoil depths beyond the reach of crop roots. BNF becomes an input upon the conversion of atmospheric nitrogen gas into plant N by symbiotic plants followed by the addition of plant N to the soil.

Inorganic fertilizers accounted for about one-third of the N inputs in Africa a decade ago (Smaling, 1993), but they were used largely in mechanized agriculture and on export crops. Only three countries in sub-Saharan Africa—Nigeria, Zimbabwe, and South Africa—produce N fertilizers. Millions of smallholder farmers throughout Africa, however, use N fertilizers, most of which are imported. Heisey and Mwangi (1996) reported that only 37% of the area planted to maize in 11 African countries received N fertilizers in the early 1990s. Because of the high price of imported fertilizers at the farm gate and delays in delivery due to poor infrastructure (Donovan, 1996), smallholders often applied N fertilizer at too low rates and too late for obtaining good crop-yield responses (Heisey and Mwangi, 1996).

Most smallholder farmers apply cattle manure—usually collected from enclosures *(bomas,kraals)* where cattle spend the night—but at rates too low to meet crop requirements and prevent decreases in soil organic matter content. In the Heisey and Mwangi (1996) study, manures accounted for <10% of N inputs in Africa, or about 1 kg N ha^{-1} yr^{-1}. In intensively managed smallholder areas like the Kisii county of Kenya, applications of manure to the fields from cattle enclosures average 23 kg N ha^{-1} yr^{-1}, or about one-half of the total N inputs (Smaling *et al*, 1997). Manure was often diluted with soil when shoveled from cattle enclosures, and its quality and nutrient composition also is affected by the quality and quantity of fodder the animals eat (Probert et al., 1995). The value of manure as a source of N ranged from high-quality manure that increases crop yields to low-quality manure that depressed crop yields due to N immobilization, with a critical threshold value of 1.25% N (12.5 g N kg^{-1}) (Mugwira and Mukurumbira, 1986).

There is evidence that non-N-fixing trees and shrubs of the genus *Senna* and *Tithonia* accumulate as much N in their leaves as N-fixing legumes, presumably because of their greater root volume and ability to scavenge nutrients from the soil (Gachengo *et al*, 1998). It however, is important to note that these non-fixing trees are only cycling the N present in the soil, not adding inputs to the system, as happens via BNF in woody and herbaceous leguminous fallows. Non-N-fixing trees and shrubs can only be considered to be N inputs when biomass is transferred from one field to another.

2.2.2.2 Phosphorus

2.2.2.2.1 General

Phosphorus in most plants was found in concentration between 0.1 and 0.4% (Tisdale *et al* 1985). The P requirement for optimum growth in plants during vegetative growth is, however, within the range of 0.3- 0.5 g kg^{-1} of the plants dry matter. The roles of P in plants have been described by Brady (1984), Tisdale *et al* (1985) and Wild and Jones (1988). These include: (i) promotion of root growth, particularly of lateral and fibrous roots, (ii) conservation and transfer of energy for a wide range of biochemical processes, and (iii) promotion of flowering, crop maturation and seed formation.

Phosphorus is immobile in soil but very mobile within the plant. After it is absorbed by the plant roots, it is distributed to every living cell in the plant, but becomes more concentrated in the plants reproductive parts. Phosphorus deficiency was widely considered the main biophysical constraint to food production in large areas of farmland in sub-humid and semiarid Africa (Bationo *et al*., 1996). Phosphorus dynamics in soils are complex, because they involve both chemical and biological processes and the long-term effects of sorption (fixation) and desorption (release) processes. The low concentration and low solubility of P in soils frequently make P a limiting factor.

Phosphorus inputs to farmer fields in Africa consist primarily of inorganic fertilizers and organic sources such as biomass, manures, and composts gathered from outside the field. The P content of plant residues and manures is normally insufficient to meet crop requirements. Plant materials applied as organic inputs contain 8 to 12 kg P ha^{-1} when applied at the top realistic rate of 4 t dry matter ha^{-1} (Palm, 1995). This is about one-half the P requirements of a 4 t ha^{-1} maize grain crop, which accumulates about 18 kg P ha^{-1} in its tissues (Sanchez *et al*, 1997).

Phosphorus, unlike N, is not captured from the atmosphere by biological fixation or from deep in the soil profile, due to the very low concentrations of available P in the subsoil and low root-length densities. Consequently, P fertilizers are almost always necessary to overcome P depletion (Mclntire and Powell, 1995).

The gathering of green plant material from boundaries or adjacent fields and their addition to another field is known as biomass transfer. Most of the biomass transfers practiced by African farmers consist of leguminous plants and grasses. There is increasing evidence, however, that some non-leguminous shrubs may accumulate higher than normal concentrations of P in their biomass than legumes. Tithonia *Tithonia diversifolia* (Hemsley) A. Gray, a common farm hedge species native of Mexico and found at middle elevations throughout tropical Africa (Palm et al., 1997a) and southeast Asia (Cairns and Garrity, 1998) has unusually high concentrations of P (0.27-0.38% P or 2.7-3.8 g kg"1) in its leaf biomass (Nziguheba et al., 2000). These levels are far superior to those in commonly used legumes in agroforestry and as herbaceous cover crops, which range in the order of 0.15 to 0.20% P (1.5-2.0 g kg^{-1};) (Palm, 1995). Reasons for such high concentrations remain speculative but members of the Asteraceae (Compositae) family, to which tithonia belong, are effective nutrient scavengers (Garrity and Mercado, 1994).

2.2.2.2.2 Phosphorus fixation by soils

Phosphorus fixation has been defined as the removal of soluble phosphate from solution by a soil or soil constituent followed by its concentration in the solid phase (Sanchez and Uehara, 1980). It is influenced by soil properties such as pH, cation exchange capacity (CEC), phosphate status of the soil, aluminum (Al) and iron (Fe) oxides and type and amount of clay (Subramaniam and Sigh, 1997). The largest amounts of P are sorbed by amorphous hydrated oxides of Fe and Al and smaller amounts by crystalline and lattice minerals such as gibbsite, goethite, kaolinite and montmorrilonite (Tisdale *et al*., 1985; Wild, 1988).

The fraction of P utilizable by plant has been designated as available P. Plants obtain P by taking orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-}) from solution. Soils in which P availability is high are able to supply P in sufficient amounts so that plant growth and crop production are not limited by P deficiency. On the other hand, in soils where the P availability is low, this requirement cannot be met and plant growth and crop yields are reduced (Eijk, 1997).

Although the solution P concentration required for optimum growth varies among plants (Sanchez and Uehara, 1980), several attempts have been made to specify a solution concentration of P in soils before planting, that will ensure adequate P for near maximum yields (Lemare, 1981). A concentration of 0.2 mg P l^{-1} in solution has been suggested as the standard that would be adequate for successful growth in most plants

(LeMare, 1981). The P concentrations in most tropical soils are, however, invariably lower due to sorption and this undoubtedly is a limiting factor to crop production (Warren, 1992; Linquist *et al*., 1996).

2.2.2.2.3 Use of organic materials (OMs) to enhance P availability

Use of organic materials to increase the soil availability of P has received considerable attention (Tisdale *et al*., 1985). It has been reported by several workers that organic materials can reduce the P-sorption capacity of the soil, enhance P availability, improve P recovery or result in better utilization of P by plants (Iyamuremye *et al*., 1996).

Various mechanisms have been postulated for positive effects of organics on P availability. For example, Hundal and Biswas (1988) found that anaerobic decomposition of added green manure (cowpea, sesbania and sunnhemp) changed P sorption characteristics of the soil due to release of P during mineralization of the added plant residues. They suggested that accumulation of organic acids produced during decomposition of manure complexed metal cations which induces solubilization of native P or reduce fixation of added inorganic P.

Palm *et al*.(1997) attributed the reduction of P sorption by organic matter to be due to their blocking of adsorption sites. It has also been postulated that organic anions formed by decomposition of organic inputs can compete with P for adsorption sites and thereby increase P availability in the soil (Iyamuremye and Dick, 1996). LeMare et al.(1987) showed that application of organic mulches to a soil with high P fixing capacity and low in available P increased the desorption of P.

Organic materials are also known to be capable of supplying substantial amounts of essential nutrients (Palm *et al*., 1997) and so may improve on utilization of P by plants. They also do act as sources of P (Eijk, 1997) for the plant as some added into the soil via organic residues is converted to inorganic P during mineralization (Iyamuremye and

Dick, 1996). It is also thought that addition of decomposable organic matter also promotes activities of microorganisms which enhance solubilization of insoluble phosphates through production of chelating agents (Stevenson, 1986).

2.3 Nutrient Management

The quantity of nutrients which the farmer needs to apply depends on the yield potential of the cultivar, the level of available plant nutrients already in the soil, and growth conditions. Since vegetative and reproductive stages overlap in solanaceous vegetables, they need a continuous and steady supply of nutrients throughout their life span. It is necessary to adopt appropriate nutrient management practices which help to supply nutrients in quantities adequate to just meet crop demand and minimize losses, thereby increasing the nutrient use efficiency. Such practices will be environmentally friendly, and lead to sustainable vegetable production.

Annual application of N in four splits at 30-day intervals has been recommended by Singh *et al.* (1988) to achieve maximum yields and profits in chili production. Subhani *et al.* (1990) obtained the highest yield of chili when both N and K were applied in four splits at planting, 30, 60 and 90 DAT. Similarly, in eggplant, growth in terms of dry matter production is slow until 30 DAT.

2.3.1 Integrated Nutrient Management

Owing to the widespread use of fertilizers containing N, P and K and their effectiveness in increasing crop yields the world over, the term fertilization has become synonymous with the use of commercial NPK fertilizers. This is a rather narrow outdated concept, which does no justice to the wide field of plant nutrition or to the implications concerning undesirable environmental effects. Although inorganic fertilizers have benefited from more systematic and well-defined production and marketing, there are other effective sources of plant nutrients. These include crop residues, organic manures, various recyclable wastes and biofertilizers. Farmers all over the world have been using organic manures for a very long time. (Kaur *et al*, 2005).

There is increased concern on the impact of chemical fertilizers on environmental quality due to their continuous use. The integrated nutrient management system is an alternative to sole use of inorganic fertilizers and is characterized by reduced input of chemical fertilizers and combined use of chemical fertilizers with organic materials such as animal manure, crop residues, green manure and compost. Management systems that rely on organic inputs as plant nutrient sources have different dynamics of nutrient availability from those involving the use of chemical fertilizers. For sustainable crop production, integrated use of chemical and organic fertilizer has proved to be highly beneficial. Several researchers have demonstrated the beneficial effect of combined use of chemical and organic fertilizers to mitigate the deficiency of many secondary and micronutrients in fields that continuously received only N, P and K fertilizers for a few years, without any micronutrient or organic fertilizer. A field experiment was conducted by Chand *et al.* (2006) for seven years continuously to evaluate the influence of combined applications and organic and chemical fertility buildup and nutrient uptake in mint (*Mentha arvensis*) and mustard (*Brassica juncea*) cropping sequence. Results indicated that integrated supply of plant nutrients through FYM (farmyard manure) and fertilizer NPK, along with *Sesbania* green manuring, played a significant role in sustaining soil fertility and crop productivity.

Based on the evaluation of soil quality indicators, Dutta *et al.* (2003) reported that the use of organic fertilizers together with chemical fertilizers, compared to the addition of organic fertilizers alone, had a higher positive effect on microbial biomass and hence soil health. Application of organic manure in combination with chemical fertilizer has been reported to increase absorption of N, P and K and their levels in sugarcane leaf tissue in the plant and ratoon crop, compared to inorganic fertilizer alone (Bokhtiar and Sakurai 2005).

Kaur *et al.* (2005) compared the change of chemical and biological properties in soils receiving FYM, poultry manure and sugarcane filter cake alone or in combination with chemical fertilizers for seven years under a cropping sequence of pearl millet and wheat. Results showed that all treatments except chemical fertilizer application improved the soil organic C, total N, P, and K status which in turn increased yield. Increase in microbial biomass C and N was observed in soils receiving organic manures only or with the combined application of organic manures and inorganic fertilizers compared to soils receiving inorganic fertilizers only. This study showed that balanced fertilization using both organic and chemical fertilizers is important for maintenance of soil organic matter (OM) content and long-term soil productivity in the tropics where soil OM content is low (Kaur *et al*, 2005).

The effects of organic fertilization and combined use of chemical and organic fertilizer on crop growth and soil fertility depends on the application rates and the nature of fertilizers used. In general, the application rates of organic fertilizer mostly are based on crop N need and estimated rates of organic fertilizer N supply, but do not consider the amount of P and K provided with organic fertilizer. Diverse nutrient sources can be used in an integrated manner to meet the external nutrient supplies of any cropping system. Towards this end, scientifically, there is no conflict between mineral and organic sources of plant nutrients (FAO, 2006).

The basic concept underlying the principles of integrated nutrient management is the maintenance or adjustment of soil fertility/productivity and of optimal plant nutrient supply for sustaining the desired level of crop productivity. The objective is to accomplish this through optimization of the benefits from all possible sources of plant nutrients, including locally available ones, in an integrated manner while ensuring environmental quality. This provides a system of crop nutrition in which plant nutrient needs are met through a pre-planned integrated use of: mineral fertilizers; organic manures/fertilizers (e.g. green manures, recyclable wastes, crop residues, and FYM); and biofertilizers. The appropriate combination of different sources of nutrients varies according to the system of land use and the ecological, social and economic conditions at the local level (FAO, 2006).

Sustained productivity may be achieved through the combined use of various sources of nutrients, and by managing these scientifically for optimum growth, yield and quality of different crops, in a way adapted to local agro-ecological conditions.

In vegetable production in African countries, farmers have been using organic manures for centuries, together with inorganic fertilizers in recent decades, to meet the nutrient demands of crops. Integrated nutrient use has assumed great significance in recent years in vegetable production, for two reasons. Firstly, the need for continued increases in per hectare yields of vegetables requires that applications of nutrients increase. Many developing countries in Africa do not have enough inorganic fertilizer is available to meet crop nutrient requirements. Secondly, the results of a large number of experiments on manures and fertilizers conducted in several countries reveal that neither chemical fertilizers alone, nor organic sources used exclusively, can sustain the productivity of soils under highly intensive cropping systems (Singh and Yadav 1992).

Subbiah *et al.* (1985) obtained higher yields of tomato and eggplant with combined use of FYM and inorganic fertilizers. For eggplant, applications of 100 kg N/ha, half in urea (50%) and half in poultry manure (50%), resulted in higher yields (45.8 mt/ha) than the same level of nitrogen applied in urea alone (37.8 mt/ha). The integrated use of urea and poultry manure also resulted in a higher nutrient uptake in eggplant (Jose *et al.* 1988). Jablonska (1990) reported that the combined use of rye straw and nitrogen resulted in higher yields of tomato, eggplant and pepper than either N fertilizer or FYM used alone. Hosmani (1993) also reported higher yields of chili with integrated use of chemical and organic fertilizers than with the use of either of these separately.

2.3.2 Nutrient Requirements of Solanaceous Vegetable Crops

There are three important solanaceous vegetable crops grown for their fruits, namely, tomato, eggplant and pepper. All crops in this group are grown as annuals, and have much in common with regard to nutrient requirements (Hegde, 1987a). Tomato is a deep-rooted crop with roots growing to a depth of 120 - 150 cm or more, unless they are restricted by an impervious layer of hardpan, a rock layer or by a high water table. Eggplant and pepper are medium-rooted crop with roots which extend to a depth of 120 cm. Eggplant is a long duration crop, with high yields which remove large quantities of plant nutrients. An eggplant crop yielding about 60 mt/ha of fruit removes 190 kg N, 10.9 kg P and 128 kg K. Nutrient uptake in eggplant partly depends on the source of nutrients (Jose *et al.* 1988). Integrated use of both organic and inorganic sources results in higher uptake and increased fruit production

2.4 Organic sources of nutrients

2.4.1 General

Organic sources of nutrients are derived principally from substances of plant and animal origin. Partially humified and mineralized under the action of soil microflora, the organic sources act primarily on the physical and biophysical components of soil fertility (Marschner, 1995). These sources cover manures made from cattle dung, excreta of other animals, other animal wastes, rural and urban wastes, composts, crop residues and even green manures. The term “bulky organic manure” is used collectively for cattle dung, FYM and composts, because of their large bulk in relation to the nutrients contained in them. Concentrated organic manures, such as oilcakes, slaughterhouse wastes, fishmeal, guano and poultry manures are comparatively richer in NPK **(**Marschner, 1995).

Better management of soil forms the basis for tackling problems of food insecurity, raw materials for industries and environmental and biodiversity conservation. Meeting these challenges from a fixed land resource requires improved technologies and practices that will raise productivity of the available land by maximizing the use of local resources (FORMAT, 2004).Some of the common local resources are manure and compost, which form the most important source of soil organic matter and nutrients. The quality of manure and compost vary within and across farms depending on collection, storage and composting process (FORMAT, 2004).

The integrated use of organic inputs as external nutrient sources has been advocated as a logical alternative to expensive fertilizers in Africa (Reijntjes *et al.*, 1992). The main advantages of this approach are (i) the replacement of scarce or nonexistent capital for labor and (ii) the fact that cattle manures or green manures contain all essential nutrients plus C, the source of energy for soil biota that regulates nutrient cycling. One of the main arguments against the use of organic inputs is their low nutrient concentration in comparison with inorganic fertilizers (Shepherd *et al*, 1995). Animal manures and plant material contain from 1 to 4% N (10-40 g N kg^{-1}) on a dry weight basis, while inorganic fertilizers contain from 20 to 46% N (200—460 g N kg^{-1}) and are already dry. To haul the 100 kg N generally needed for a 4 t ha^{-1} maize crop; it would take 217 kg of urea or 201 kg of leaf biomass with 80% moisture and a 2.5% (25 g N kg^{-1}) N concentration on a dry weight basis (Shepherd *et al*, 1995). Furthermore, organic inputs are very low suppliers of P because of their low concentrations (Palm, 1995; Palm *et al*.1997b).

Organic inputs have an important advantage over inorganic fertilizers with regard to fertility replenishment—they provide a source of C for microbial use. Soil microorganisms serve as sources and sink of nutrients and their activities and turnover resulting from decomposition of organic materials are considered to be primary controlling factors in nutrient cycling and availability (Smith *et al*., 1993). According to Palm (1995), the recovery by the crop of N from the leaves of leguminous plants incorporated into the soil (10-30%) is generally lower than the recovery from N fertilizers (20-50%). This disadvantage can be overcome through consistent incorporation of leguminous plants for several seasons. Much of the remaining 70 to 90% of the applied organic N not used by crops or leached is incorporated into labile pools of soil organic N and C. Soil microorganisms require C substrate for growth and use the N from organic inputs to form soil N capital. Part of the N bound in the more recalcitrant fractions in the organic inputs will also increase soil organic N (Giller *et al*., 1997). Inorganic fertilizers do not contain such C sources, and therefore much of the fertilizer N not used by crops is subject to leaching and denitrification losses in the absence of crop residue returns.

Long-term experiments in Africa provide indirect evidence in support of the combined organic and inorganic approach to replenishing N and C capital. Kapkiyai (1996) reported a 29% loss of total soil N (1.06t N ha^{-1} in the top 15 cm) when maize and beans were grown in rotation for 18 years without nutrient inputs and with crop residues removed in Kabete, Kenya. The same loss took place in plots with the recommended fertilizer applications but no residues returned; however, when fertilizers and manures were added and the maize stover was retained, the decline in total topsoil N was reduced by one-half. Organic inputs or the recycling of crop residues apparently provided the soluble C necessary to reduce N depletion in this fertile soil.

There are some extreme situations in Kenya where research has compared mainly inorganic vs. organic sources of N with little consideration of the nutrient content of organic sources. The quantitative interaction between organic and inorganic sources of N is essentially a new subject of research in the tropics (Palm *et al*., 1997b). All organic resources are depleted or are used to meet more pressing needs such as cooking fuel. For example, much of the Western Kenyan highlands have been converted from forest to smallholder agricultural landscapes essentially devoid of trees. Crop residues are fed to livestock, while manure and even roots are used as cooking fuel. To break clear of this vicious cycle, N fertilizers must be applied along with whatever organic inputs become available from planting trees. The use of *Tithonia diversifolia* as a green manure which produces large quantities of biomass, tolerates regular pruning and easily be established, is ideal to balance fuel and nutrient demands in addition to planting agroforestry trees (Chianu and Tsujii, 2005).

2.4.2 Organic resources utilization for soil fertility improvement

The use of organic resources for soil fertility improvement in Kenya has been in practice since earliest times. However, the strategies by which these materials were applied may differ from recent conventional methods through technology development and adaptive strategies to meet peculiar modern needs. Following widespread popularity of inorganic fertilizer sources used in agriculture since the 1940's, the use of inorganic fertilizer became the natural complementary option that received the attention of agriculturists in an effort to boost soil productivity. This has achieved a considerable level of success over the years by increasing crop production at accelerated and balanced rates. However, application of inorganic fertilizers has also faced important limitations due to high costs, highly variable nature of soils and inherent low nutrient conversion efficiency (AGRA, 2007). Average fertilizer use rates for countries in SSA are considered too low and ineffective for sustaining crop and soil fertility maintenance (Gruhn *et al.*, 2000).

Alternative sources of nutrients are already being sought in several areas in Africa where soil fertility needs to be rebuilt and high costs and supply quantities limit inorganic fertilizer application. There is growing need to develop techniques for improving soil fertility without causing damage to the environment (Topliantz *et al.*, 2005). Organic resources have been identified as reliable alternatives to reduce continued large scale use of inorganic fertilizers and have great application in agricultural development due to relatively easy access and easy procurement from the local environments. However, it takes longer to reap benefits than the inorganic sources. Common organic nutrient sources in tropical SSA include plant (crop) residues, leguminous cover crops, green manures, animal manure, mulches and household wastes (Hossner and Juo, 1999). These organic materials contribute directly to the building of soil organic matter (SOM), which itself performs diverse functionary roles in improving the physical, chemical and biological composition of the soil. The maintenance and management of SOM are central to sustaining soil fertility on smallholder farms in SSA (Woomer et al, 1994). In low input agricultural systems, SOM helps to retain mineral nutrients in the soil; making them available to plants over many years in small amounts as it is mineralized (Kumwenda *et al.*, 1996). In addition, SOM improves soil structure, increases water holding capacity and cation exchange capacity (CEC) of soils and increases capacity of low activity clay soils to buffer changes in pH (Woomer *et a*l,. 1994; Hossner and Juo, 1999).The application of organic materials to soils has been shown to enhance crop yields, whereby yield increases varied with agro-ecological setting and rates of amendments applied (Schlecht *et a*l., 2006).

The success of applying organic materials in the tropics was found to be due to higher decomposition rates (3 - 5 times) that of plant residues and soil organic matter in humid tropical environments than under temperate conditions (Mueller-Harvey *et al.*, 1985). Organic materials have also been observed to increase microbial biomass and activity in soils (Vinten *et al.*, 2002); which suggesting a more responsive microbial community in such soils. The use of organic manures generally ensures effective and efficient management of soil by providing nutrients in correct quantity and proportion in environmentally beneficial forms (Gruhn *et al.*, 2000). Farmyard manure can also improve nutrient and water use efficiency as well as yields of common crops in the humid/sub humid transition zones of SSA (Juo and Kang, 1989).

2.4.3 Factors affecting decomposition and release of nutrients from organic materials

2.4.3.1 Physical and environmental factors

Soil temperatures, moisture and texture are among the environmental factors that influence decomposition of organic materials and subsequent release of nutrients into the soil through their effects on the activity of soil microbes. Optimum conditions for decomposition are high temperatures and continuous water supply (Budelman, 1988). Bumaya and Naylor (1988) found that dry soil conditions reduced decomposition of plant residues. When the soil moisture content falls below a certain minimum, the microbes though still surviving do not function (Scholes and Singer., 1994).

When the temperatures are too high, only the thermophilic microorganisms remain active. When temperatures are too low, most microorganisms likewise change into spore form and become inactive. Typically, the rate of mineralization of phosphorus is higher at higher temperatures. Soil texture affects the rate of organic material decomposition in that it affects soil properties such as moisture retention and aeration, which in turn affect microbial activity (Stark *et al*, 2005).

2.4.3.2 Quality of organic materials

Although the rate of decomposition is generally influenced mainly by climatic factors and the material's chemical composition, the influence of the latter is more important in the tropics (Bumaya and Naylor (1988). Nutrients are released to the soil from organic materials when decomposition and mineralization occur. Organic phosphorus mineralization was shown to take place independent of carbon mineralization through the process of hydrolysis of phosphate esters which supplement carbon oxidation and was catalyzed by enzyme phosphohydrase produced by plant roots (Smeck, 1985). Synthesis of this enzyme was however suppressed by supply of labile phosphorus in the soil (Smeck, 1985). The amount of phosphorous released from decomposition of organic residues depends on phosphorous content of the material and the quantity of the material applied. For instance, Bumaya and Naylor (1988) showed that the higher the concentration of phosphorous in the plant residue, the higher was the amount of phosphorus extracted from the soil.

2.4.3.3 Microbial biomass carbon and phosphorus

Soil microorganisms serve as sources and sink of nutrients and their activities and turnover resulting from decomposition of organic materials are considered to be primary controlling factors in nutrient cycling and availability (Smith *et al.*, 1993).Addition of organic residues have been found increase microbial pool sizes and activity, C and N mineralization rates and enzyme activity (Smith *et al.*, 1993), all factors that affect nutrient cycling. Since C is often the element most limiting to microbial growth and activity in the soils, the amount or C quality of organic additions will influence rates of nutrient cycling (Reinersten *et al.*, 1984).

Organic additions into the soil can also cause a shift in the distribution of nutrients in the organic and inorganic soil fractions caused by microbial activity. This redistribution might affect nutrient availability patterns and nutrient use efficiency, the net effect depending on the quality of organic resource addition. As an example, Hedley *et al.* (1982) measured soil P fractions following addition of cellulose and N, plus or minus P. They concluded that for long term build of soil P, it was necessary to add C and P sources. Carbon provides substrate for microbial growth whose turn over results in the long term accumulation of organic P especially in more available P fractions.

The soil microbial organisms is relatively a labile constituent of soil organic matter (Jenkinson and Ladd, 1981) and is the key site for mineralization of organic P in the soil. Soil microorganisms play a critical role in the mineralization of organic inputs and partitioning of P into various organic fractions and likely provide continuous inputs of orthophosphate into the soil solution during the growing season. The addition of organic residues will provide a source of C and stimulate biological activity.

Organic amendments can be a source of inorganic and organic P with the latter being subject to mineralization which releases inorganic P or forms other organic P fractions.

Biomass P is an important dynamic pool that forms 1 to 2% of the total soil P. This has been found to be directly correlated with biomass C (Brookes *et al.,* 1984), inputs to the soil which release inorganic phosphate or forms organic P fractions, immobilization of P in viable cellular biomass and solubilization of insoluble mineral P forms through release of organic acids.

2.5 Effects of organic materials on nutrient availability and acquisition

The beneficial effects of combined organic and inorganic nutrients on soil fertility are enormous. Organic materials influence nutrient availability (i) by nutrients added, (ii) through mineralization-immobilization patterns, (iii) as an energy source for microbial activities, (iv) as precursors to soil organic matter (SOM), and (v) by reducing P sorption of the soil. The challenge is to combine organics of differing quality with inorganic fertilizers to optimize nutrient availability to plants. Increased nutrient recovery and residual effects are associated with combined nutrient additions compared with inorganic fertilizers applied alone. In addition to these direct effects on nutrient availability, organic materials can affect root growth, pests, and soil physical properties that in turn influence nutrient acquisition and plant growth. The net effect of these different mechanisms on nutrient availability and plant growth differ with climatic regime, soil type, quality and quantity of organic inputs (Esilaba *et al*, 2000).

2.5.1 Sources of Nutrients

Organic inputs such as manures, cover crops, and green manures have generally been assessed in terms of their N concentration; while relatively little attention has been paid to other macronutrients and micronutrients present. Organic inputs should be considered as complete fertilizers (N-P-K), perhaps the best being those containing or releasing the nutrients in the ratios and rates required by crops (Ayuke *et al*, 2004).

The nutrient contents of organic materials, ranging from crop residues to agro-industrial wastes, vary widely. Some organic materials such as poultry manures contain sufficient nutrients in 1 to 2 t for a 2-t maize crop, while others such as crop residues can require at least 10 t to match that contained in the 2-t maize crop. Cattle manure was found to vary tremendously in its quality and fertilizer value and extremes were found in manure obtained from commercial dairy farms compared with that from the communal areas of Kenya (Mugwira & Mukurumbira, 1986). It is the latter, low-quality manures, which predominated on smallholder farms of Africa (Probert *et al*., 1995). In comparison, many leguminous trees and cover crops contain sufficient N in 2 or 3 t of leafy material (Giller *et al*., 1997). It was reported many organic materials when applied in modest amounts, i.e., <5 t dry matter ha^{-1}, contain sufficient N to match that of a 2-t crop of maize but they could not meet P requirements and needed to be supplemented by inorganic P in areas where P was deficient (Palm, 1995).

2.5.2 Regulators of Mineralization-Immobilization Patterns

Decomposition and nutrient release patterns are determined by climatic, edaphic, and resource quality factors. Of these factors, resource quality is most easily managed by farmers. Considerable research over the past century has related N release patterns to the resource quality, or chemical characteristics, of organic materials. The N concentration and the C-to-N ratio of the material still probably serve as the most robust indices when all plant materials are considered (Constantinides & Fownes, 1994).

Nitrogen concentration in tissue ranging from 18 to 22 g kg^{-1} is the critical value for the transition from net immobilization to net mineralization. Not all organic materials with high N values, however, exhibit net N mineralization. Lignin contents of >150 g kg^{-1} slow N release considerably, and polyphenol contents >30 to 40 g kg^{-1} can result in net immobilization of N (Palm, 1995). Lignin and polyphenols are particularly important modifiers of N release for the fresh, non-senescent leaves of high-quality materials (Constantinides & Fownes, 1994). The immobilization resulting from polyphenolics, particularly condensed tannins may be much longer than the temporary immobilization resulting from high C-to-N ratios in cereal crop residues (Giller et al., 1997).

Net P mineralization patterns are determined primarily by P concentration in the tissue. Materials with P content <2.5 g kg^{-1} immobilize P (Blair & Boland, 1978). Phosphorus release patterns are not necessarily correlated to N release. Some materials showing net N mineralization can result in net P immobilization and vice versa, stressing the importance of looking at more than N in organic materials.

Traditional organic resources, primarily cereal crop residues and cattle manures, fall below the critical N content and immobilize N, at least temporarily. Tanner and Mugwira (1984) found that manures with N content <10 g kg^{-1} caused a decrease in the growth of maize seedlings for 4 weeks for reasons related to immobilization. The negative effect of cereal residues on crop growth has been demonstrated in many field and pot trials (Nandwa, 1995). On an Alfisol in central Kenya, incorporation of maize stover reduced maize grain yields by 3 to 30% in the first three seasons. After the third year the reduction did not occur (Qureshi, 1987; Nandwa, 1995). Paustian *et al.*, 1992, reported that incorporation of 2.5 and 5.0 t ha^{-1} of maize stover resulted in 30 to 60% decreases in soil-available N. Furthermore, if crop residues and other low-quality organic materials can be obtained in sufficient quantities, net N and probably P immobilization will occur, exacerbating the nutrient deficiencies, at least temporarily. The negative effects can be offset by combining low-quality organic materials with inorganic N (Paustian *et al*., 1992) or high-quality organic materials with N content >20 g kg^{-1} and P >3 g kg^{-1} (Smith et al., 1993).

2.5.3 Sources of Carbon and Energy for Soil Organisms

Soil microbes can serve as sources and sinks of nutrients, and their activity and turnover resulting from the decomposition of organic materials are considered to be primary controlling factors in nutrient cycling and availability (Smith et al., 1993). Reinertsen *et al*. (1984) found that the size of the microbial biomass and rate of decomposition of wheat *(Triticum aestivum* L.) straw were determined by the size of the soluble C fraction of the organic materials.

Additions of soluble forms of C also can result in the decomposition of more recalcitrant plant components and SOM, the so-called priming effect. Collins et al. (1990) found that the decomposition of mixes of wheat residues was greater than predicted when parts with more soluble C were added. Vanlauwe et al.(2002) also confirmed that more soluble C fractions in plant materials enhanced the decomposition of the more recalcitrant fractions. Other nutrients, particularly N and P, also are probably mineralized by the priming effect of soluble C, but the topic remains controversial (Azam *et al.*, 1993).

If higher proportions of N are held in soil organic fractions, they would be less susceptible to gaseous losses and leaching. On the other hand, additions of a high-quality material, with high nutrient content and high amounts of available C may simply result in the substitution of the organic and inorganic sources of the nutrient (Jenkinson *et al*., 1985).

In summary, C inputs, particularly the soluble fractions modify the rate at which nutrients are cycled and become available and the form in which nutrients are held in the soil.

2.5.4 Precursors to Soil Organic Matter

It is through the formation of SOM that organic materials show longer term residual effects than do inorganic fertilizers. The use of inorganic fertilizers alone can even lead to a decline in SOM, while fertilizers combined with organics or organics used alone can maintain SOM levels (Bationo *et al.*, 1996). Research in the past decade has focused on separating SOM into different fractions that are related to functional properties, and particularly into a biologically meaningful fraction that is related to nutrient-supplying capacity (Magid *et al.*, 1996). Certain fractions, such as microbial biomass and the light fraction have been positively correlated with N mineralization or

N availability (Barrios *et al.*, 1996). Kapkiyai (1996) found in kabete, Kenya that additions of farmyard manure (FYM) over 18 years increased the content and relative proportions of soil microbial biomass and particulate organic matter compared with additions of maize stover, though the amounts of FYM added also were much larger than those of maize stover. These more labile soil organic fractions were correlated to higher crop yields.

2.5.5 Competitors for Phosphorus-Sorption Sites

Organic materials have been shown to reduce the P-sorption capacity of the soil and increase P availability. The magnitude and duration of the effect varied with the soil type, the quality of the organic material, and the amounts added (Bumaya & Naylor, 1988; Iyamuremye *et al.*, 1996). In general, only materials with >2.5 g P kg^{-1} have been shown to reduce the P-sorption capacity.

The mechanisms involved in this process are quite complex, as outlined in a review by Iyamuremye (1996). The most commonly cited mechanism refers to action of organic acids produced from decomposition or root exudation. It is widely proposed that organic anions (i) complex (or chelate) with ions of Fe and Al in soil solution, preventing the precipitation of phosphate, and also reducing Al and Fe toxicity, (ii) compete with P for sorption sites, and/or (iii) solubilize P from me insoluble Ca, Fe, and Al phosphates (Tian *et al.*,1993). The most effective organic anions are the di- and tri-carboxylic acids such as tricarboxylic citric acid and dicarboxylic malic, tartaric and oxalic acids, whereas monovalent acetate was found to have little effect (Iyamuremye *et al.*, 1996).

2.5.6 Indirect Effects on Nutrient Acquisition

Organic materials also can have several other effects on soils and plants that influence nutrient acquisition and uptake by plants. Root growth can increase as a result of reduced exchangeable Al in the soil, caused by complexation with organic anions that are produced by decomposition of organic materials. It also can increase through an increase in pH caused by the addition of basic cations from organic materials (Kretzschmar *et al*., 1991). Organic materials also can stimulate root growth either directly or through their effect on soil bacteria that can suppress root pathogens and produce plant growth hormones (Marschner, 1995).

Applications of organic materials also can reduce or increase the numbers of pests and weeds, again depending on the quality of the material. Mulching with low-quality materials that decompose slowly has been shown to decrease weed biomass, while high-quality materials that decompose quickly have little effect (Salazar *et al*., 1993). The increased soil-water content resulting from mulch cover can, however, increase the incidence of pests. There is some evidence that the parasitic weed *Striga* sp. that reduces maize yields in much of Africa can be curtailed by applications of organic materials (Ransom, 1996). The decrease is probably caused by several factors, including increased soil-water content, higher soil-available N levels, and perhaps even the suicidal germination of striga seeds caused by the products of organic decomposition (Ransom, 1996). Soil physical properties such as structure, water content, and temperature can be affected by incorporation or surface application of organic materials. As an example, Tian *et al*. (1993) found that during drier periods lower quality mulches resulted in higher yields, as mineralization was probably higher because of the more favorable microclimate, lower soil temperatures, and higher soil water content produced by the low-quality mulch.

The role of organics is varied and complex, as detailed above; the challenge is to use organics of differing quality in combination with inorganic fertilizers to optimize nutrient availability to plants. This requires knowing how the nutrient content and C quality of organic materials will add to and compensate for or will reduce nutrient availability from inorganic fertilizers. The term *interaction* is frequently used to describe the net effects of the combined use of organic and inorganic sources. This term implies to some a magic effect of organic materials, whereas to others it merely means a statistical interaction. A better phrase than interactions might be added benefits (or disadvantages) resulting from the combined use of organic and inorganic inputs compared with inorganics alone. In general, the nutrients supplied or removed (immobilized) by the addition of organics are additive to those supplied by inorganic nutrient sources (Paustian et al., 1992 and Giller *et al.*, 1997). Added benefits, or disadvantages, of combined nutrient additions are probably more related to the quality of the C substrate of the organic material and its effects on nutrient availability.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental site

The highlands of western Kenya, which are part of the Lake Victoria Basin, have one of the densiest rural populations in the world—500 to 1200 people per km^2 (Hoekstra & Corbett, 1995). Annual rainfall ranges from 1200 to 1800 mm with a bimodal distribution. Elevation averages 1200 m, and the main soils are high P sorbing Alfisols and Oxisols, originally quite fertile but now widely depleted of N and P. Characterization studies identified declining soil fertility as the main factor limiting crop production (Hoekstra, 1988).

The study was conducted at Bukura Agricultural college farm during the short rains (SR) season and long rains (LR) season of the year 2009 and 2010 respectively. The long rain season occurs between March to July and short rain season from September/October to December with peaks in April and November, respectively.

Bukura is at an altitude of 1463 m above sea level, 0^{0}30’N latitude and 34^{0}30’E longitude (Jaetzold and Schmidt, 1983). It receives a bimodal rainfall ranging between 1800 to 2000 mm per year. This is distributed over two main cropping seasons namely; the long rains season and short rains season. The SRS is normally less reliable than the LRS. The temperature ranges between 22-28^{o}C (max) and 8-10^{o}C (min). The site falls in the Lower Midland (LM) 1 agro-ecological zone, which is suitable for sugarcane production (Jaetzold and Schmidt, 1983). Soils at Bukura are classified as Rhodic to orthic Ferralsols (FAO/ UNESCO, 1988). The soils are well drained, deep to very deep and dark reddish brown to strong brown friable clay.

Farming in the region is largely undertaken by smallholder farmers, practicing a mixture of food, cash crop and tree production. Maize and beans are the most common food crops grown in the area mainly as intercrops while sugarcane is the main cash crop, hence the need to introduce a short season export cash crop like the eggplant (*S. melongena* L.). The main livestock kept are both indigenous and improved breeds of cattle, sheep, goats and chicken.

Farmers realize the value of fertilizers in western Kenya. About 40% of them use some DAP, but at lower than recommended rates and often too late for optimum timing of applications (Swinkels, R. and Franzel, S., 1997). In spite of the extreme land pressure, about 52% of the farmers leave a portion of their farm in weedy fallows (Swinkels, R. and Franzel, S., 1997). Fallowing is often not a matter of choice, because either the land is severely depleted or labor and agricultural inputs are not available .This provides an entry point for the organic inputs to be grown *in situ* (Hoekstra, 1988).

3.2 Rainfall patterns of the experimental site

Normal amount of rainfall was received during the two seasons of the experimental period (Appendix II). Bukura received a total of 617 mm and 1077 mm of rain during the 2009SR and 2010LR respectively. It this is attributed unusual rains received in January and February, 2010.

3.3 Soil sampling and analysis

Soils were collected from the experimental site and analyzed for physical and chemical properties before the commencement of field experiments.

3.3.1 Soil sampling

Ten soil samples from experimental site were taken from the top 0-20 cm depth, randomly using a soil auger and bulked to get a representative sample. These were put in labeled paper bags before being taken to the laboratory for analysis. The samples were air dried by spreading them on polythene sheets in a well ventilated room. Air-dry soil samples were crushed using a pestle and mortar and passed through a 2 mm sieve.

The resultant sub-samples were crushed further and passed through a 60 mm mesh screen for total nitrogen and organic carbon analyses.

3.3.2 Determination of soil pH

Procedure outlined in Okalebo *et al.*, (2002) was used to measure the soil pH. A pH meter with a glass electrode was used to measure the pH where a ratio of 2.5:1 (water to soil suspension) was used. Thus 50 ml of distilled water was added to 20 g of the 2 mm air-dried soils in a beaker then stirred. The resultant suspension was allowed to stand for 30 minutes and stirred again. The pH meter was calibrated by immersing its electrode in buffer solutions of pH 7 and 4 for one minute. Soil pH was measured by immersing the calibrated pH meter electrode in the soil water suspension.

3.3.3 Determination of total organic carbon

Procedure outlined in Okalebo *et al.*, (2002) was used to determined total organic carbon (OC) by wet combustion oxidation using sulphuric acid (H_2SO_4) and potassium dichromate (K_2CrO_7) oxidation.

3.3.4 Available soil phosphorus (Olsen P)

Available P was determined by extraction of soils using 0.5 M Sodium bicarbonate ($NaHCO_3$) solution buffered to pH 8.5 (Olsen *et al.*, 1954). Orthophosphate ion in the extract was analyzed by ascorbic acid based colorimetry as given in Okalebo *et al.*, (2002).

3.3.4.1 Soil extraction

The air-dried soil (2mm) was weighed to 2.5g and put into a stoppered plastic bottle and 50 ml of Olsen extractant added before shaking in a mechanical shaker for 30 minutes as described by Okalebo *et al.*, (2002) .The suspension was then filtered through Whatman No. 42 filter paper to give a clear filtrate that was analyzed colorimetrically. 10 ml of each standard and sample solution was pipetted into 50 ml volumetric flasks and topped with distilled water. The mixture was stoppered and shaken before being left to stand for one hour.

3.3.4.2 Colorimetric determination of P

The soil extractants were assayed for available P by ascorbic acid reducing solution (Murphy and Riley, 1962). The standard P solution concentration of 250 ppm was used.

3.3.5 Total nitrogen

Total nitrogen was determined by Kjeldahl oxidation method, which involves complete breakdown of soil organic matter by digesting the soil to 360^oC in order to convert organic N to ammonium nitrogen (NH_4-N) before its determination in the digest.

3.3.5.1 Soil acid digestion

0.3 g of air dried soil sieved through < 0.25 mm (60 mesh) was weighed into a dry clean labeled digestion tube and 4.4 ml digestion mixture ($H_2SO_4/LiSO_4/Sc/H_2O_2$) was added. The digestion mixture was stored at 2^oC. From the digestion mixture, 4.4 ml was taken and added to each of the two reagent blank tubes. Digestion was carried out at 360^oC for two hours and further one hour to a clear sand white colour, after which the digest was allowed to cool. The digest was topped up to 50 ml mark with distilled water and mixed well.

3.3.5.2 Colorimetric determination of nitrogen

The entire soil digest and two reagent blanks were diluted to a ratio 1:9 (v/v) with distilled water. Using reagent N1 (sodium salicylate/ sodium citrate/ sodium tartarate/ sodium nitroprusside), reagent N2 ($NaOH/NaHCl_2$) was also and vortex. The mixture was allowed to stand for 2 hours before the absorbance was measured using a spectrophotometer at 650 nm. The concentration of N in the solution was read from a standard calibration curve.

3.3.6 Exchangeable bases and cation exchange capacity

Soils were analyzed for exchangeable bases and cation exchange capacity (CEC) at the Department of Agronomy laboratory, Mumias Sugar Company. Exchangeable bases were determined by extraction of the soil samples with excess 1 M NH_4OAc solution. The contents of potassium, calcium and magnesium in the extract were determined by flame photometry (K) and atomic absorption spectrophotometry (Ca, Mg). Standard curves were constructed for each cation from which readings were taken. A similar procedure as above was used to determine cation exchange capacity (CEC) except that 5 g acid washed sand was used with 2.5 g of soil sample in ethanol elution. KCl solution was used in the second leaching stage.

3.3.7 Soil particle size analysis

The soil particle size was determined using the hydrometer method. This method is based on the effect of particle size differential settling velocities within a water column (Okalebo et al, 2002). The settling velocity is also a function of liquid temperature, viscosity and specific gravity of the falling particle. When all other factors are held constant, the settling velocity is proportional to the square of the radius of the particle as stated in Stoke’s law.The distribution of sand, clay and silt obtained was used to assign and classify their textures based on the soil textural triangle by USDA.

3.4 Initial soil physical and chemical properties

Results of soil physical and chemical properties were as shown in table 4.1, while ratings developed by Landon (1991) and used in interpretation of soil analysis results are shown in appendix I. The pH at site was low (5.4) and this is rated as acidic (Landon 1991). Low levels of soil exchangeable potassium ranging between 0.1 to 0.2 Cmol kg^{-1} was recorded at all the site. The amount of nitrogen was medium in soils while that of organic carbon range was low. Soil CEC was medium. The soil physical properties in table 3.1 indicate that the soil textural class at the site is sandy clay. A higher content of sand compared to the other particles was recorded at the site.

Table 3.1: Physical and chemical analysis of the experimental soil at Bukura in 2009SR season.

Physical properties				**Chemical properties**					
Sand %	Silt %	Clay %	Texture	PH	Total N (%)	P (ppm)	K Cmol kg^{-1}	OC (%)	CEC Cmol kg^{-1}
45.6	15.4	39	Sandy clay	5.4	0.41	17	0.1	2.12	21.9

3.5 Sources of experimental materials

Seeds of eggplant (*Solanum melongena* L.) used in both seasons were obtained from Kenya Seed Company. Inorganic fertilizers were purchased from local agrochemical dealers while the compost was locally made using mainly maize stovers and the farm yard manure was collected at Bukura agricultural college farm. The same farmyard manure and compost were used during short rains season of 2009 and long rains season of 2010. The manure and compost were stored in a water proof shelter.

3.6 Inorganic sources of fertilizer used in the study

3.6.1 Calcium ammonium nitrate (CAN)

CAN is a mixture of Ammonium nitrate (produced by neutralizing nitric acid and ammonia) and finely pulverized limestone or dolomite, granulated together. It contains 21–27 percent N, half in the form of ammonium and the rest in the form of nitrate. Its use does not make the soil acid by virtue of the carbonate in it.

3.6.2 Di-ammonium phosphate (DAP)

Diammonium phosphate, (NH4)2HPO4, is manufactured by the reaction of ammonia and phosphoric acid. Its nitrogen to phosphate ratio makes it an excellent direct application product or one that blends well with other fertilizer materials to produce a variety of NPK fertilizers. It typically contains 18 percent N + 46 percent P_2O_5. DAP is typically 90% water soluble (expressed as a percentage of available P_2O_5) and the rest is citrate soluble. The typical pH of the product is 7.5 when it is measured on saturated slurry of the product. In the soil, the initial stages of the product's breakdown releases ammonia (NH3) and causes a small zone around the DAP particles in the soil to have a pH of about 8.0. After a short time and as the DAP continues to break down, the product has a net effect of acidifying the soil (Tisdale *et al*, 1985). In some countries, efforts are underway to fortify DAP with the needed micronutrients.

3.7 Organic inputs used in the study

3.7.1 Compost

Compost can be defined as organic manure or fertilizer produced as a result of aerobic, anaerobic or partially aerobic decomposition of a wide variety of crop, animal, human and industrial wastes (FORMAT, 2004). Compost is material of animal or plant origin or both "cured" appropriately and applied to soil to make it richer in certain aspects (chemical, biological and physical) (Bii, 1988).

Composting involves combining and decomposing various forms of plant and animal matter (cereal stover, leaves, weeds, wood, kitchen wastes, natural fibre, clothes, hair, bones etc.) (Bii,1988). Low quality plant residues such as maize stover, banana residues, wheat straw and sweet potato vines are not largely recycled into the fields but used either as livestock fodder or burnt at planting. The quality of compost from these materials can be improved by fortification of the residues with application of nitrogen fertilizer and manure during composting (Format, 2004). Unlike the use of chemical fertilizers which target feeding the crop, compost feeds the soil; crops then sequester nutrients from soil leaving the surplus (Finstein and Miller, 1985). Application of this compost can greatly improve crop yield especially that of maize hence a suitable fertilizer for use in nutrient depleted small hold farms.

The major advantage of compost lies in its ability to promote soil health, making it more favourable for the survival of many micro-flora and micro-fauna that inhabit in it (De Bertoldi, et al 1985). Fertilizers tend to exhaust soil humus which is readily solubilised into nutrients for plants in the presence of chemical fertilizers (Finstein and Miller, 1985). In the presence of humus, the readily soluble and excess nutrients do not reach as easily to contaminate ground and surface water as in soil devoid of humus (Ombiro, 1999).

3.7.2 Farm yard manure

Farmyard manure is a mixture of cattle urine, dung, feed refuse and bedding material e.g. straw (Wild, 1988). In mixed farming systems that characterize many smallholder farms, animal production is strongly dependent on local crop production, while local crop production is strongly dependent on the amount of manure produced and the amount and of nutrients therein (Williams *et al*., 1995). Farmyard manure therefore is an integral component of soil fertility management in many areas of tropics and its importance as a source of nutrients for crop production is widely recognized (Bationo et al., 2004). For example, FYM is used by over 79% of the farmers in western Kenya (Bekunda and Woomer, 1996). Use of farm yard manure is one of the traditional methods of returning nutrients to the land.

There is a major difference between FYM and commercial fertilizers in terms of nutrient availability in that some of the nutrients in FYM exist in organic forms and need to be converted to inorganic forms before being available to plant use (Bationo and Mukwunye, 1991). When used as fertilizer, the short- term (i.e. within several months) release of nutrients from FYM is important. Farmyard manure may be regarded as a slowly available source of plant nutrients compared to inorganic fertilizer. Along with nutrients, manure supplies valuable organic matter to help improve soil physical properties, and increase the activity of beneficial soil microbes (Kapkiyai *et al.*, 1999).Brady (1974) identified three outstanding characteristics of animal manures. These are;

i) Considerable variability in moisture and nutrient content.

ii) A relatively low nutrient content in comparison with commercial fertilizer.

iii) An imbalanced nutrient ratio, being considerably lower in P than N and K.

The nutrient content of manure can vary, according to what has been fed to the animals, methods of collecting, handling and storage (Probert *et al.*, 1995; Kihanda, 1996). Its nutrient content depends on the species and size of the animal from which it was derived, the quality of fodder the animal received, the composition of the bedding material and its handling and storage before it is spread on the land (Brady 1974; Tisdale *et al.*, 1985).

Characterization studies by Williams *et al* (1995) gave the following ranges in nutrient content of manure in Africa; 0.23-1.76 N%; 0.08-1.0% P; 0.2-1.46% K; 0.1-1.3% Ca and 0.1-0.5% Mg. High quality manure has been defined as that with >1.6%N or C: N ratio of <10 while low quality manure has <0.65N or C: N ratio of >17 (Bationo *et al.*, 2004). Several studies suggested methods to improve the quality of manures on smallholder farms (Lekasi *et al.*, 2001). These include; feeding concentrates, zero-grazing rather than the traditional kraaling, storing manure under cover rather than in the open, and on concrete rather than soil floors. According to Giller et al (1997), crop responses to manure application observed in farmer’s fields are highly variable due to differences among farmers and between regions in the chemical composition of manures, in the rates of manure application and in the frequency of application on each field. Although the bulkiness of FYM is a major constraint in its use, it is nevertheless valued as a source of N where fertilizers are expensive and where there is cheap labour (Wild, 1988).

Although the application of manure alone produces a significant response, it is not a complete alternative to mineral fertilizers (Quinones *et al*., 1997). In most cases the use of manures is part of an internal flow of nutrients within the farm and does not add nutrients from outside the farm (Bationo *et al*., 2004). The effective utilization of manure as a source of plant nutrients is often constrained by poor quality and limited availability mainly due to poor management. Research highlights have shown that use-efficiency of manures can be enhanced by different management practices including the timing and methods of manure application, and integrated nutrient management (Ojiem *et al*., 2004).Although bulkiness and availability of FYM are major constraints in its use, it is nevertheless valued as a source of N where fertilizers are expensive and where there is cheap labour (Wild, 1988). Most manure are characterized as intermediate-low quality resources and hence prescribed to be used in a mixture with inorganic fertilizers (Palm et al., 2001). However, studies in investigating the benefits of sole versus combined application of manures and inorganic fertilizers have given variable and inconsistent results (Palm *et al*., 1997b) and no conclusive recommendations have, therefore, been possible.

3.7.3 Green manure

Green manures play a key role in providing subsequent crops with nutrients, maintaining soil quality, and helping to control weeds and pests (Krauss et al., 2010). Green manuring involves spreading plant material with high nitrogen content on fields and sometimes also working it into the soil (Versteeg, M.N.,et al., 1998). The most important features of a green manure are large dry matter production and high ability to fix nitrogen (Wivstad, 1997).Green manure can be used directly or after composting as a nutrient input that will, after decomposition, be taken up by crops to produce biomass and grain. The effectiveness of green manuring as a soil fertility management technology depends on the stage of crop during incorporation, placement (incorporated or surface placement), nutrient content and carbon to nitrogen ratio of material which influences decomposability and mineralization.

Young and succulent plant materials tend to decompose at faster rate compared to materials from mature plants, while incorporation enhances mineralization relative to surface applied plant material. Using green manures from deep rooting perennial agro-forestry trees allows organic matter to be tapped and nutrients to be drawn from deeper levels of soil more than is possible from animal or annual plant manures (Larson, 1996). For instance, use of Crotalaria as green manure has been found to improve productivity of maize-bean cropping systems in eastern Africa (Fischler et al., 1999).

As highlighted by Byerlee and Heisey (1992), green manures may not provide sufficient and balanced nutrients (such as phosphorus, potassium, etc) required by subsequent crop for improved productivity although they are a good source of nitrogen. The key to achieving the maximum benefit from green manure is synchronization of nutrient release from decomposing green manure with demands of subsequent crop. (Fischleret al., 1999).

Herbaceous green manure legumes like mucuna grown specifically for soil fertility restoration have not been widely adopted by farmers in SSA. Given that green manures compete for land resources with other food crops, and do not contribute directly to income or food security (Snapp et al., 2002) and given that land is very limited, it pauses a challenge as this as this is a soil fertility management option that might not always or readily fit in farmers cropping cycles. A potentially practical solution to this challenge is utilization of alternative plants such as using water hyacinths. Gunnarsson and Petersen (2007) in a review entitled “water hyacinths as a resource in agriculture and energy production” concluded that dried water hyacinths was a feasible alternative as green manure in many developing countries since hyacinths can be rich in nitrogen, have up to 3.2% of dry matter and have a carbon to nitrogen (C/N) ratio of about 15. Chemical analyses have indicated a high nutrient content of water hyacinth, 20% crude protein and very high dry matter production (Abdelhamid and Gabr, 1991), making water hyacinth a potentially suitable alternative to traditional green manure crops. Legume green manures offer a low cost opportunity for maintaining soil fertility by mainly improving nitrogen supply to the soil. This can be achieved if the species chosen as green manure crops are compatible with climatic conditions and soil characteristics of the area (Buckles *et al.,* 1998). Screening of green manuring herbaceous legumes in the mid-altitude areas of mount Kenya region was conducted between 1995 and 1996 and out of 25 species screened, a few best-bet species were identified; Mucuna (*Mucuna pruriens*) and Crotalaria (*Crotalaria ochroleuca*) were found to be suitable for intercropping with maize. Both legumes established easily, nodulated profusely and were found to be resistant to pests. Although inoculation with appropriate rhizobia may increase the level of nodulation, both legumes produced effective nodules in the absence of any external inoculation (Gitari, *et al.,* 1997; Mureithi, *etal.,* 1998).

Tithonia diversifolia, commonly known as Mexican sunflower, is a non-Nitrogen fixing shrub of the family *Asteraceae*, which was probably introduced into Africa as ornamental plant (Jama *et al*., 2000). Tithonia is an aggressive plant that grows to height of about 3 m. It produces large quantities of biomass, tolerates regular pruning and can be easily established from seed and cuttings (Buresh and Niang 1997). It is widely distributed throughout the middle altitude elevations of the humid and sub humid tropics

(Buresh and Niang 1997). In western Kenya, it is widespread where it grows along the roadsides, waterways, abandoned lands and on cultivated farmlands (Jama *et al.*, 2000). It is however, mainly used to mark farm boundaries. The common practice by farmers is to top tithonia hedge once or twice a year to reduce competition with crops in the adjacent fields, and provide good looking hedge and fuel wood (Kiptot, 2007). The abundance and adaptability of tithonia to various environments, coupled with its rapid growth rate and very high vegetative matter turnover, make it suitable agroforestry species for soil rejuvenation (Olabode *et al.*, 2007; Ademiluyi and Omotoso, 2008).

Tithonia has aroused much research interest because of the relatively high nutrient concentrations that are found in its biomass. Furthermore, the processes by which Tithonia enhances crop yields are not fully understood and thus Jama *et al.* (2000) and Kiptot (2007) recommended more research to document the occurrence and to understand the processes for enhanced nutrient availability and crop production with integrated use of tithonia and mineral fertilizers compared to sole use of fertilizers.

3.7.4. Characteristics of organic materials used in the study

Chemical properties of the three organic manures are shown in Table 3.2. The samples of FYM and compost had PH levels above 7, while tithonia had pH 6.5.The nitrogen levels were also quite high with values above 0.5% while organic matter levels were medium in compost, high in FYM and very high in tithonia as seen in high carbon levels. In addition, the phosphorus and potassium levels in all the manures were very high. The N and P contents of the manures were tested in the laboratory and according to the results, the doses of manures were set in such a way that all the treatments contain same amount of N and P.

Table 3.2: Chemical analysis of different organic sources used in this study

Contents	FYM	Compost	Tithonia
N (%)	1.05	0.58	3.1
P(mg/kg)	421.6	114.4	30
K (%)	2.2	0.99	4.1
OC (%)	10.92	4.06	42
pH(1:2.5)	7.33	7.23	6.5

3.8 Experimental design and model, treatments and establishment of test plants

3.8.1 Experimental design and model

The experiment was done at Bukura Agricultural College farm, 20 km South West of Kakamega town, Kakamega District during short rains of 2009 and long rains of 2010. The experimental design was a split plot with three replications, where the two levels of mineral fertilizers treatments of 50% research recommended rate (110 kgha^{-1}DAP and 300 kgha^{-1}CAN) which contains 83kg N ha^{-1} and 61.5kg P ha^{-1}and 100% Research recommended rate (220 kgha^{-1} DAP and 600 kgha^{-1}CAN) containing 166kg N ha^{-1} and 123kg P ha^{-1} (KARI, 1994) were randomized in main plots and while three types of organic manures; FYM, Compost at rate of 10-15ton ha^{-1} (12-18 kg/plot or 1-1.5 kg/M^2) and Tithonia at rate of 6 ton ha^{-1} (7.2 kg/plot or 0.6 kg per M^2)and control treatments were randomized within the subplots. Each plot measured 3 x 4 m with 1 m paths between the blocks and 0.5 m paths between plots.

The Generalized statistical model for the split plot design experiment is:

$Xjklm = \mu + \alpha j + \beta k + \varepsilon\ jk + \lambda l + \gamma jl + \varepsilon jklm$

Whereby:

Xjklm = plot observation

μ = mean of plot observation

αj = main treatment effect

βk = replication or block effect

$\varepsilon\, jk$ = experimental error(1)

λl = sub-treatment effect

γj = Interaction : main treatment X sub-treatment

$\varepsilon jklm$ = Experimental error(2)

3.8.2 Treatments

The main treatments consisted of two levels of inorganic fertilizer derived from the application of DAP (18:46:0) and CAN (21-26%N) applied during transplanting and top dressing respectively. The research recommended rates are 220 kg ha^{-1} (10g/hole) of DAP and 600 kg ha^{-1} (100g/plant) of CAN applied in three splits. This translates to 166 kg N ha^{-1} and 123 kg P ha^{-1} .Three types of organic manures and control (without addition of organic manures) were sub-treatments. (Table 3.3).The inorganic fertilizer treatments were applied as follows; 50%RRR (83 Kg N ha^{-1}, 61.5 Kg P ha^{-1}) and 100%RRR (166 Kg N ha^{-1}, 123 Kg P ha^{-1}).The Organic fertilizer types and their control comprised the sub- treatments; Control (Without addition of organic manures). The treatment combinations are shown in Table 3.3.

Table 3.3: Treatment combinations of the inorganic fertilizer two levels and the three organic manures and control

Treatment	Nitrogen(Kg N ha^{-1})	Phosphorus(Kg P ha^{-1})	Organic fertilizer
T1	83	61.5	Control
T2	83	61.5	Tithonia
T3	83	61.5	Compost
T4	83	61.5	FYM
T5	166	123	Control
T6	166	123	Tithonia
T7	166	123	Compost
T8	166	123	FYM

NB: FYM=farm yard manure, 50%RRR(83 Kg N ha^{-1}, 61.5 Kg P ha^{-1}) and 100%RRR (166 Kg N ha^{-1}, 123 Kg P ha^{-1}).

Farm yard manure and tithonia were applied to the marked plots two weeks before transplanting of the seedlings by evenly spreading them within the appropriate experimental plots and incorporated to a depth of 15 cm.

3.8. 3 Experimental layout

The experiment was conducted at Bukura Agricultural College farm in Kakamega District. The experimental plot sizes were 3 x 4 m and soil sampling done on the plots before transplanting for soil analysis. Split plot design with three replications was used where; the levels of inorganic fertilizer rates (50% and 100%RRR) were randomized in the main plots. The three sources of organic manures; FYM, Compost applied at rate of 10-15tonha^{-1} (12-18 kg/plot or 1-1.5 kg/M^2) and Tithonia applied at rate of 6 tonha^{-1}(7.2 kg/plot or 0.6 kg per M^2) and control treatments were randomized within the subplots.

BLOCKI

T1	T4	T2	T3	T8	T6	T7	T5

BLOCKII

T2	T3	T1	T4	T7	T5	T8	T6

BLOCKIII

T4	T1	T3	T2	T5	T6	T7	T8

Fig.3.1. Experimental layout at Bukura farm during 2009 SR season

(See Table 3. 1 for treatment combination descriptions)

3.8.4 Establishment of test plants

Eggplant seedlings were raised in a seedbed of 1m wide and convenient length on 4th August, 2009 and 17th January, 2010. DAP (18%N, 46%P_2O_5) at recommended rate was uniformly applied to the seed bed and lightly mixed with the soil using a rake; seeds were sown in furrows 30 cm apart and thinly covered with top soil. The seedlings were ready for transplanting 42 days after sowing i.e. on 15th September, 2009 and 1st March, 2010 when they were 8-10 cm in height. The experimental field was ploughed and harrowed into a fine tilth and plots were marked. Farm yard manure and tithonia were applied to the marked plots two weeks before transplanting of the seedlings by evenly spreading them within the appropriate experimental plots and incorporated to a depth of 0-0.15 m. Fourty two (42) day old seedlings of uniform size were selected and transplanted into the marked plots as per the treatments. The spacing of 75x60 cm was used resulting in a final plant population of 35 plants per plot.

During transplanting, DAP and compost was applied while CAN applied three weeks later. The normal routine field management practices such as weeding, pest and disease control were carried out as recommended by Ministry of Agriculture in Kenya.

3.9 Parameters for observation

3.9.1. Plant growth

At the vegetative stage on 1st December, 2009 and 15th April 2010 i.e.75 days after transplanting, random samples of five plants from each plot were taken for determination of and Plant height (cm) and Fresh weight of the plant (including stem and leaves).the measurements were determined using a tape measure for the plant height and spring balance for the plant fresh weight.

3.9.2 Fruit yield and its quality

Egg plant fruits were picked weekly starting 10th December, 2009 and 25th April,2010 through the harvesting period for estimation of yield parameters total yield as tonnes per ha. The surface of the fruit should be bright and glossy. The fruits were ready to harvest from the time it was one quarter grown to near ripe. Harvesting was done by cutting the fruit from the stem and leaving a short piece of stalk on the fruit when they are about two thirds maximum size. Random samples of 10 fruits from each plot were taken in the third picking to determine the physical fruit quality i.e. fruit length and diameter. The fruits were cut through longitudinally and measured their length and diameter using a ruler.

3.9.3 Data analysis

Analysis of variance (ANOVA) was done to determine the treatment differences in, growth, yield and fruit quality parameters using Genstat statistical package (3rd edition). The Duncan Multiple Range Test (DMRT) was used to compare treatment means at $p< 0.05$.

CHAPTER FOUR

RESULTS

4.1 Plant growth

4.1.1 Plant height

There was a significant interaction ($p<0.05$) between the rate of inorganic fertilizers and the organic manures on the plant height (Table 4.1(a) and (b)).

Table 4.1(a) ANOVA table for plant height (cm) of eggplants during 2009SR season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
Blocks	2	49.5700	24.7850	21.15	
INORGANIC	1	118.3704	118.3704	101.03	0.010
Residual(a)	2	2.3433	1.1717	5.45	
ORGANIC	3	1272.8946	424.2982	1973.48	<.001
INORGANIC.ORGANIC	3	14.4779	4.8260	22.45	<.001
Residual(b)	12	2.5800	0.2150		
Total	23	1460.2363			

NB: d.f.=degrees of freedom, s.s.=sum of squares, m.s.=mean sum of squares, v.r.= variance ratio(F), F pr=F probability

Table 4.1(b) ANOVA table for plant height (cm) of eggplants during 2010LR season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
Blocks	2	61.9558	30.9779	27.40	
INORGANIC	1	100.4504	100.4504	88.86	0.011
Residual(a)	2	2.2608	1.1304	4.32	
ORGANIC	3	1163.3646	387.7882	1480.42	<.001
INORGANIC.ORGANIC	3	3.8646	1.2882	4.92	0.019
Residual(b)	12	3.1433	0.2619		
Total	23	1335.0396			

NB: d.f.=degrees of freedom, s.s.=sum of squares, m.s.=mean sum of squares, v.r.= variance ratio(F), F pr=F probability

As indicated in Table 4.4, the combination of farm yard manure (FYM) and inorganic fertilizers had significantly ($p<0.05$) higher plant height of 58 cm and 64.5 cm compared to other organic sources of manure in 2009 SR. During 2010 LR, a similar trend was observed with plant height of 57.3 cm and 62 cm for FYM compared to 39 cm and 42.33 cm for controls respectively. The interaction effect of inorganic and organic nutrient sources on plant height generally increased from tithonia, compost and farmyard manure in that order (Fig. 4.1).The combinations of 50%RRR (Control) inorganic fertilizers and the organic manures (T2, T3 and T4) resulted in plant taller than 100%RRR (Control) treatment (T5).

The inorganic fertilizer level significantly ($p < 0.05$) affected the mean plant height. A significantly higher ($p < 0.05$) mean plant height was recorded on 100%RRR than the 50%RRR during both 2009 SR and 2010 LR seasons (Table 4.5).A significantly higher ($p<0.05$) mean plant was recorded during 2009 SR than 2010 LR. Applying 100% RRR gave significantly higher mean plant height of 51.89 cm and 50.77 cm during 2009 SR and 2010 LR respectively.

The different sources of organic manures had a highly significant ($p \leq 0.001$) effect on the plant mean height and caused an increase on growth of eggplant (Table 4.3). During both seasons, a significantly higher ($p<0.05$) mean plant height was recorded among plants treated with organic manure compared with their control (Table 4.6). FYM had the greatest effect on plant height followed in descending order by compost, tithonia and control.

Generally, 2009 SRS had higher mean plant height compared to the 2010 LR. For instance the main treatment of 100% RRR of inorganic fertilizer had plant mean height of 51.89 cm and 50.77 cm during the 2009 SR and 2010 LR season respectively.

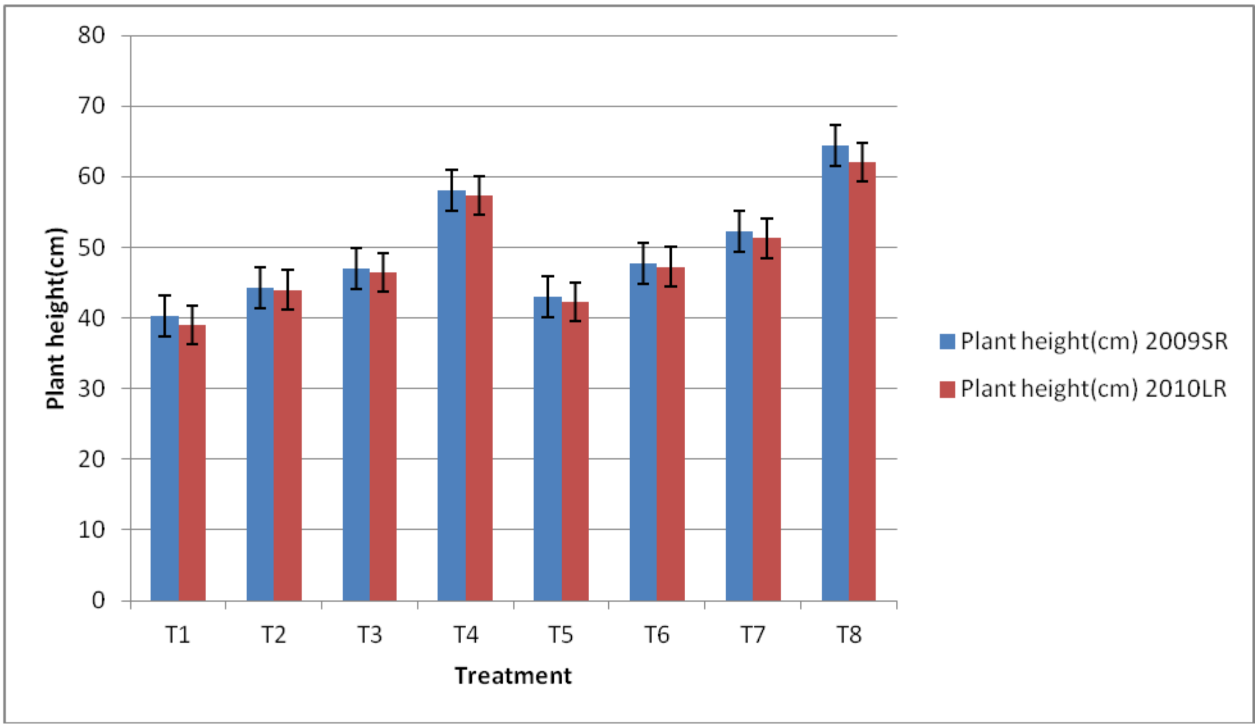

Fig.4.1.Plant mean height (cm) of eggplant 75 days after transplanting from the different treatments (T1-T8) in both the 2009 SR and 2010 LR.

Table 4.2: Table of means on effect of inorganic fertilizers combined with different organic manures on vegetative characters of eggplant during the two seasons 2009SR and 2010LR

Treatments		**Plant height(cm)**		**Plant fresh weight(g)**	
Level of inorganic fertilizers	Organic manures	**2009SR**	**2010LR**	**2009SR**	**2010LR**
50% of RRR	Without(control)	40.33	39	181	179
	Tithonia	44.33	44	252.33	250.67
	Compost	47	46.4	320	318.93
	FY manure	58	57.3	370.17	371
Mean		47.42	46.68	280.88	279.9
100% of RRR	Without(control)	42.93	42.33	231.67	230
	Tithonia	47.67	47.27	281.67	280
	Compost	52.33	51.27	370	368.97
	FY manure	64.5	62	407.67	405
Mean		51.89	50.77	322.75	320.99
Mean	Without(control)	41.63	40.67	206.33	204.5
	Tithonia	46	45.63	267	265.33
	Compost	49.67	48.93	345	343.95
	FYM manure	61.25	59.65	388.92	388
LSD at 5%	Inorganic fert.	1.9	1.87	3.67	4.06
	Organic manures	0.58	0.64	1.61	1.64
	Interactions	1.45	1.42	2.9	3.15

Table 4.3: Table of means on effect of inorganic fertilizers combined with different organic manures on fruit yield and its quality

Treatment		Fruit yield(ton/ha)		Fruit length(cm)		Fruit diameter(cm)	
Level of inorganic fertilizer	**Organic manures**	**2009SR**	**2010LR**	**2009SR**	**2010LR**	**2009SR**	**2010LR**
50% of RRR	Without	17.87	14.74	7.53	7.8	6.07	6.2
	Tithonia	19.47	19.58	8.33	8.6	6.47	6.67
	Compost	22.36	21.18	8.83	8.9	6.73	6.87
	FY manure	27.91	25.83	9.34	9.6	6.8	7.03
Mean		21.90	20.33	8.52	8.73	6.52	6.69
100% of RRR	Without(control)	26.99	23.33	9.17	9.47	7.33	7.37
	Tithonia	33.72	27.22	9.6	9.83	7.4	7.47
	Compost	39.37	36.68	9.83	10.03	7.63	7.67
	FY manure	49.17	44.17	10.03	10.13	7.83	7.9
Mean		37.31	32.85	9.66	9.87	7.55	7.6
Mean	Without(control)	22.43	19.04	8.35	8.63	6.7	6.78
	Tithonia	26.59	23.40	8.97	9.22	6.93	7.07
	Compost	30.86	28.93	9.33	9.47	7.18	7.27
	FY manure	38.54	35.00	9.7	9.87	7.32	7.47
LSD at 5%	Inorganic fert.	1.41	3.25	0.09	0.036	0.25	0.29
	Organic manures	0.69	2.18	0.15	0.09	0.08	0.06
	Interaction	1.15	3.13	0.19	0.11	0.19	0.24

Table 4.4:Comparison of means of parameters of eggplant as influenced by different treatments at Bukura college farm

Treatment	Plant Height(cm)		Plant weight(g)		Fruit yield(ton/ha)		Fruit length(cm)		Fruit diameter(cm)	
	2009 SR	2010 LR	2009 SR	2010 LR	2009 SR	2010 LR	2009 SR	2010 LR	2009 SR	2010 LR
T1	40.33g	39g	181g	179g	17.87g	14.74h	7.53g	7.8g	6.07f	6.2g
T2	44.33e	44e	252.33e	250.67e	19.47f	19.58g	8.33f	8.6f	6.47e	6.67f
T3	47d	46.4d	320c	318.93c	22.36e	21.18f	8.83e	8.9e	6.73d	6.87e
T4	58b	57.3b	370.17b	371b	27.91d	25.83d	9.34d	9.6c	6.8d	7.03d
T5	42.93f	42.33f	231.67f	230f	26.99d	23.33e	9.17d	9.47d	7.33c	7.37c
T6	47.67d	47.27d	281.67d	280d	33.72c	27.22c	9.6c	9.83b	7.4c	7.47c
T7	52.33c	51.27c	370b	368.97b	39.37b	36.68b	9.83b	10.03a	7.63b	7.67b
T8	64.5a	62a	407.67a	405a	49.17a	44.17a	10.03a	10.13a	7.83a	7.90a

NB: Means followed by the same letter along the columns are not significantly different using DMRT at ($P<0.05$).

Table 4.5: Comparison of means of growth and yield parameters of egg plants as influenced by inorganic fertilizer levels at Bukura college farm

Inorganic fert. levels	Plant Height(cm)		Plant weight(g)		Fruit yield(ton/ha)		Fruit length(cm)		Fruit diameter(cm)	
	2009 SR	2010 LR	2009 SR	2010 LR	2009 SR	2010 LR	2009 SR	2010 LR	2009 SR	2010 LR
50%RRR	47.42b	46.68b	280.88b	279.9b	21.90b	20.33b	8.52b	8.73b	6.52b	6.6b
100%RRR	51.89a	50.77a	322.75a	320.99a	37.31a	32.85a	9.66a	9.87a	7.55a	7.6a

NB: Means followed by the same letter along the columns are not significantly different using DMRT at ($P< 0.05$).

Table 4.6: Comparison of means of growth and yield parameters of egg plants as influenced by organic fertilizer levels at Bukura college farm

Organic fertilizers	Plant Height(cm)		Plant weight(g)		Fruit yield(ton/ha)		Fruit length(cm)		Fruit diameter(cm)	
	2009 SR	2010 LR	2009 SR	2010 LR	2009 SR	2010 LR	2009 SR	2010 LR	2009 SR	2010 LR
Control	41.63d	40.67d	206.33d	204.5d	22.43d	19.04d	8.35d	8.63d	6.7d	6.78d
Tithonia	46c	45.63c	267c	265.33c	26.59c	23.4c	8.97c	9.22c	6.93c	7.07c
Compost	49.67b	48.93b	345b	343.95b	30.86b	28.93b	9.33b	9.47b	7.18b	7.27b
FY M	61.25a	59.65a	388.92a	388a	38.54a	35.0a	9.7a	9.87a	7.32a	7.47a

NB: Means followed by the same letter along the columns are not significantly different using DMRT at ($P< 0.05$). FYM= Farm Yard Manure

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4.1.2 Plant fresh weight

There was a highly significant interaction ($p \leq 0.001$) between the rate of inorganic fertilizers and the organic manures on the plant fresh weight values (Table 4.7(a) and (b)).

Table 4.7(a) ANOVA table for Fresh plant Weight (g) of eggplants during 2009SR season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
Blocks	2	111.518	55.759	12.77	
INORGANIC	1	10521.094	10521.094	2409.64	<.001
Residual(a)	2	8.732	4.366	2.66	
ORGANIC	3	118682.865	39560.955	24142.98	<.001
INORGANIC.ORGANIC	3	479.615	159.872	97.57	<.001
Residual(b)	12	19.663	1.639		
Total	23	129823.486			

NB: d.f.=degrees of freedom, s.s.=sum of squares, m.s.=mean sum of squares, v.r.= variance ratio(F), F pr=F probability

Table 4.7(b) ANOVA table for Fresh plant weight (g) of eggplants during 2010LR season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
Blocks	2	82.116	41.058	7.69	
INORGANIC	1	10131.150	10131.150	1897.07	<.001
Residual(a)	2	10.681	5.340	3.15	
ORGANIC	3	119981.011	39993.670	23614.44	<.001
INORGANIC.ORGANIC	3	550.018	183.339	108.25	<.001
Residual(b)	12	20.323	1.694		
Total	23	130775.300			

NB: d.f. =degrees of freedom, s.s. =sum of squares, m.s. =mean sum of squares, v.r. = variance ratio (F), F pr=F probability

As indicated in Table 4.4, the farm yard manure (FYM) had significantly higher ($p<0.05$) plant fresh weight of 407.67g (T8) and 370.67g (T4) when combined with 50% and 100%RRR rates of inorganic fertilizer additions, respectively, in 2009 SR. During 2010 LR, a similar trend was observed with plant fresh weight of 405g (T8) and

371g (T4) for FYM compared to 230g (T5) and 179g (T1) for controls respectively. There was no significant ($p<0.05$) difference between T4 and T7 during both seasons The interaction effect on plant fresh weight generally increased from tithonia, compost and farmyard manure in that order (Fig. 4.2). The combination of 50%RRR inorganic fertilizers and the organic manures (T2, T3 and T4) resulted in mean plant heights higher than the 100%RRR control treatment (T5).

A highly significant ($p<0.001$) effect was realized on the plant mean fresh weight when the plants were treated with an increasing rate of inorganic fertilizer of 50% to 100% of the research recommended rates improved plant fresh weight significantly in both seasons of 2009 SR and 2010 LR (Table 4.5). During the 2009 SR, the 50% and 100% mean plant fresh weight was 280.88g and 322.75g respectively. However, the 2009 SR had slightly higher mean plant fresh weight than 2010 LR season. This was evident where 100%RRR had a mean plant fresh weight of 322.75g and 320.99g for 2009 SR and 2010 LR, respectively.

The different sources of organic manures had a highly significant effect ($p\leq0.001$) on the plant mean fresh weight. During both seasons, a significantly higher ($p<0.05$) mean plant fresh weight was recorded among plants treated with organic manure compared with control (Table 4.6). FYM had the highest effect on plant mean fresh weight followed in descending order by compost and tithonia. The use of FYM in the 2010 LR season had a mean plant fresh weight of 388g compared to 343.95g and 265.33g of compost and tithonia respectively. During both seasons FYM had the highest mean effect followed by compost and tithonia in that order.

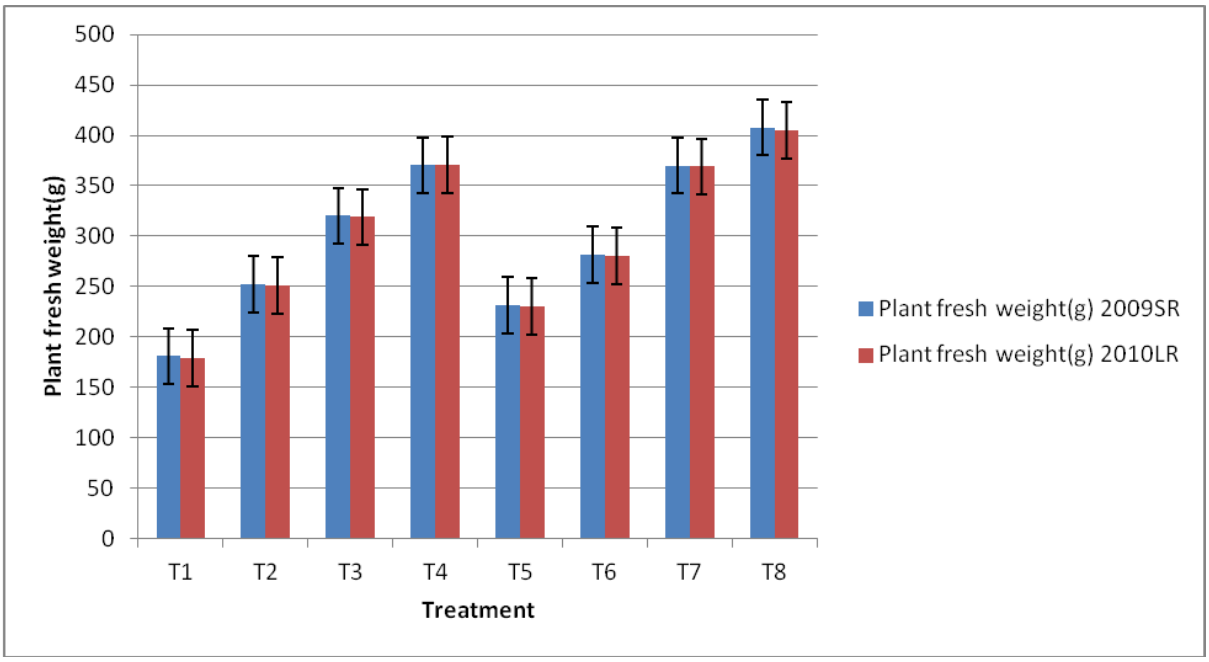

Fig.4.2. **Plants mean fresh weight (g) of different treatments (T1-T8) from both seasons of 2009 SR and 2010 LR.**

4.2 Fruit yield and its quality

4.2.1 Fruit yield

Highly significant interaction ($p \leq 0.001$) between the inorganic fertilizers and the organic manures was realized with positive effects on the fresh fruit yield in both seasons (Table 4.8(a) and (b)).

Table 4.8(a) ANOVA table for Fruit yield (ton/ha) of eggplants during 2009SR season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
Blocks	2	69.5523	34.7761	54.29	
INORGANIC	1	1424.5004	1424.5004	2223.86	<.001
Residual(a)	2	1.2811	0.6406	2.13	
ORGANIC	3	851.8957	283.9652	945.61	<.001
INORGANIC.ORGANIC	3	116.2637	38.7546	129.05	<.001
Residual(b)	12	3.6036	0.3003		
Total	23	2467.0967			

NB: d.f. =degrees of freedom, s.s. =sum of squares, m.s.=mean sum of squares, v.r.= variance ratio(F), F pr=F probability

Table 4.8(b) ANOVA table for Fruit yield (ton/ha) of eggplants during 2010LR season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
Blocks	2	94.029	47.015	13.73	
INORGANIC	1	940.377	940.377	274.57	0.004
Residual(a)	2	6.850	3.425	1.15	
ORGANIC	3	860.224	286.741	95.96	<.001
INORGANIC.ORGANIC	3	123.135	41.045	13.74	<.001
Residual(b)	12	35.858	2.988		
Total	23	2060.473			

NB: d.f. =degrees of freedom, s.s. =sum of squares, m.s.=mean sum of squares, v.r.= variance ratio(F), F pr=F probability

During the 2009 SR season the treatment 100%RRR + FYM (T8) had fruit mean yield of 49.2 ton ha^{-1} compared to 27.0 ton ha^{-1} of its control. Treatments T4 and T5 did not have a significantly different ($p<0.05$) mean fresh fruit yield during 2009 SR season, however, during the 2010 LR season T4 recorded significantly higher ($p<0.05$) than T5 (Table 4.4).The data generally indicates that 2009 SR season had higher mean fruit yield compared the 2010 LR season in all the treatments.

The effect of inorganic fertilizers was highly significant ($p<0.001$) on fruit yield. A significantly higher ($p<0.05$) mean fresh fruit yield was recorded when the plants are treated with fertilizers with an increasing rate from 50% to 100% of the research recommended rates(RRR) during both seasons of 2009 SR and 2010 LR (Table 4.5). During 2009 SR season, 50%RRR and 100%RRR treatments recorded a significantly different ($p<0.05$) a mean fruit yield of 21.9 ton ha^{-1} and 37.31 ton ha^{-1} respectively. Similarly, during the 2010 LR season mean fruit yield of 20.3 ton ha^{-1} and 32.9 ton ha^{-1} respectively were realized.

The treatments of different sources of organic manures had a highly significant effect ($p<0.001$) on the fruit mean yield. In both seasons the mean fruit yield of plant treated with FYM remained the highest compared with those treated with compost and tithonia.

During 2009 SR season, a highly significant ($p<0.05$) mean fruit yield of 30.5 ton ha^{-1}, 30.9 ton ha^{-1}, 26.6 ton ha^{-1}for plant supplied with FYM, compost and tithonia in that order. The lowest mean fruit yield of 22.4 ton ha^{-1} was displayed by plants treated with inorganic fertilizers only without addition of organic manure (control). During the 2010 LR, the mean fruit yield of plants treated with inorganic fertilizer only (control) was 19.04 ton ha^{-1} while those treated with FYM, compost and tithonia yielded 35.0 ton ha^{-1}, 28.93 ton ha^{-1} and 23.4 ton ha^{-1} respectively.

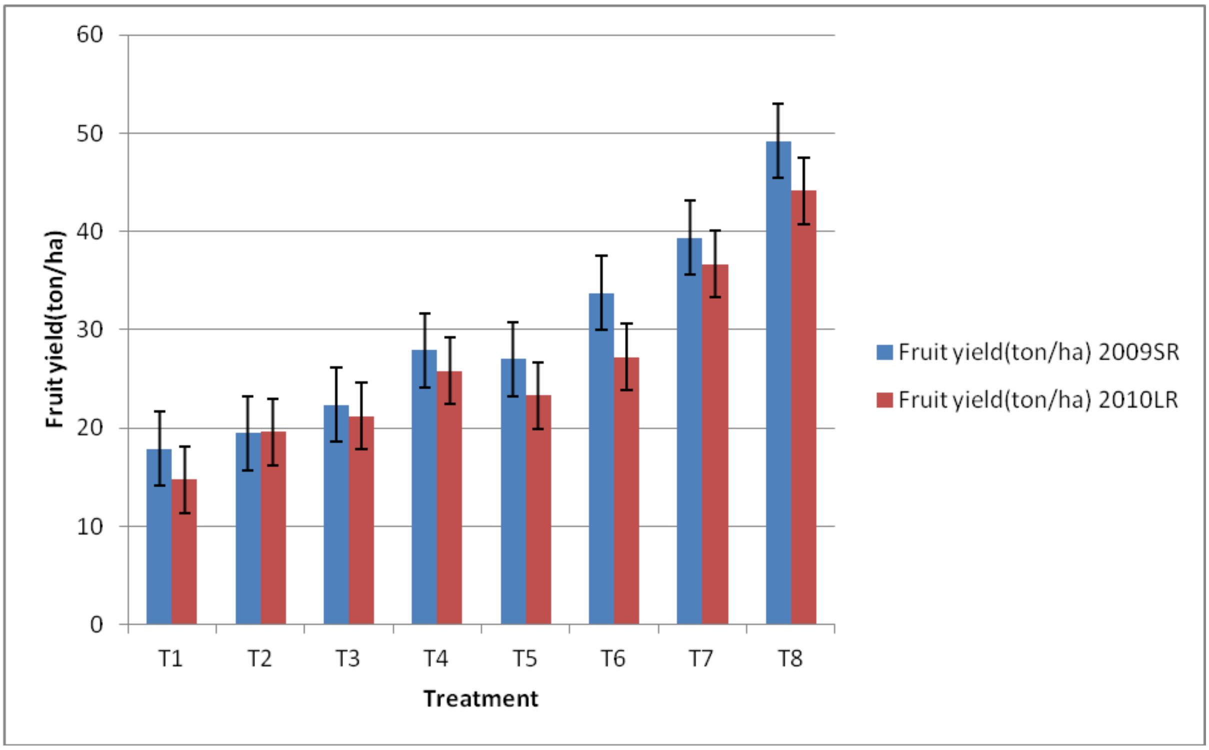

Fig.4.3. Mean fruit yield (ton ha^{-1}) of different treatments (T1-T8) from both seasons of 2009SR and 2010LR.

4.2.2 Fruit quality

4.2.2.1 Fruit length

A highly significant interaction ($p < 0.001$) between inorganic fertilizer rates and organic manures had effect on the fruit length (Table 4.9(a) and (b)).

Table 4.9(a) ANOVA table for Fruit length (cm) of eggplants during 2009SR season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
Blocks	2	1.00750	0.50375	172.71	
INORGANIC	1	7.82042	7.82042	2681.29	<.001
Residual(a)	2	0.00583	0.00292	0.20	
ORGANIC	3	5.96458	1.98819	137.64	<.001
INORGANIC.ORGANIC	3	0.75458	0.25153	17.41	<.001
Residual(b)	12	0.17333	0.01444		
Total	23	15.72625			

NB: d.f.=degrees of freedom, s.s.=sum of squares, m.s.=mean sum of squares, v.r.= variance ratio(F), F pr=F probability

Table 4.9(b) ANOVA table for Fruit length (cm) of eggplants during 2010LR season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
Blocks	2	1.010833	0.505417	1213.00	
INORGANIC	1	7.820417	7.820417	18769.00	<.001
Residual(a)	2	0.000833	0.000417	0.09	
ORGANIC	3	4.801250	1.600417	349.18	<.001
INORGANIC.ORGANIC	3	0.981250	0.327083	71.36	<.001
Residual(b)	12	0.055000	0.004583		
Total	23	14.669583			

NB: d.f. =degrees of freedom, s.s.=sum of squares, m.s.=mean sum of squares, v.r.= variance ratio(F), F pr=F probability

During the 2009SR season the treatment T8 maintained a significantly larger ($p<0.05$) fruit mean length than other treatments as shown in Table 4.4. No significant difference was observed between treatments T4 and T5 were fruit mean length of 9.34 cm and 9.17 cm, respectively, was recorded. During 2010LR, treatment T8 and T7 recorded 10.13 cm and 10.03 cm respectively and had no significant difference between treatments

($p<0.05$). However, both displayed a significantly larger fruit mean length than other treatments during the season (Table 4.4).

Inorganic fertilizer levels had a highly significant effect ($p<0.001$) on the fruit quality .A significantly higher ($p<0.05$) mean fruit length was recorded with 100%RRR than 50% RRR from both seasons of 2009 SR and 2010 LR (Table 4.5). During the 2009 SR, 100% RRR yielded longer ($p<0.05$) fruits with mean fruit length of 9.66 cm compared with 8.52 cm by 50%RRR. Also, during 2010 LR the 50% RRR and 100% RRR rates produced fruits of mean diameter of 8.73 cm and 9.87 cm respectively.

The data further indicated that integration of different sources of organic manures had a highly significant effect ($p\leq0.001$) on the fruit mean length during the two seasons. In both seasons there was a strong indication that FYM had the highest effect on fruit length and diameter compared with plants treated with compost, tithonia and control. During the 2009 SR, the mean length of fruits of the control was 8.35 cm while those treated with FYM, compost and tithonia had a mean fruit length of 9.70 cm, 9.33 cm and 8.97 cm respectively. Also, in 2010 LR, the mean fruit length of fruits treated with FYM, compost and tithonia were 9.87 cm, 9.4 cm and 9.22 cm, respectively, and the control recorded 8.63 cm.

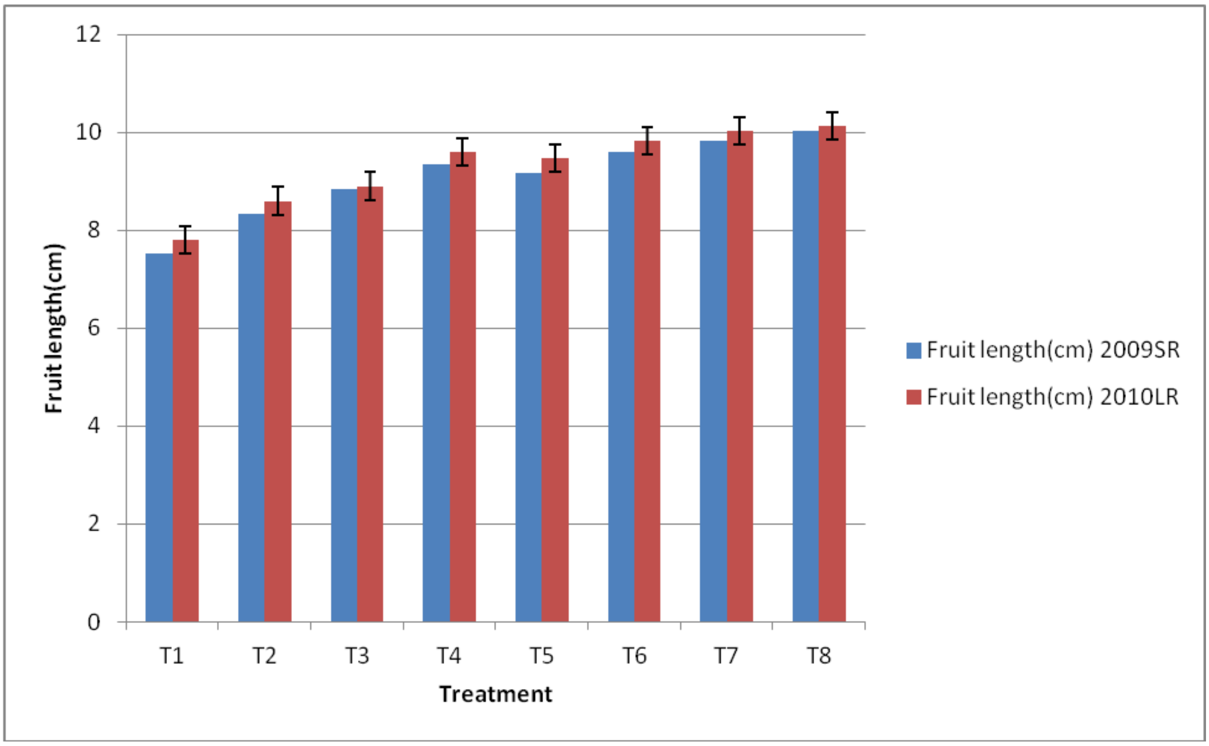

Fig.4.4. Mean fruit length (cm) of different treatments (T1-T8) from both seasons of 2009SR and 2010LR.

4.2.2.2 Fruit diameter

A highly significant interaction ($p < 0.001$) between inorganic fertilizer rates and organic manures was found on the fruit diameter differences (Table 4.10(a) and (b)).

Table 4.10(a) ANOVA table for Fruit diameter (cm) of eggplants during 2009SR season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
Blocks	2	0.735833	0.367917	18.02	
INORGANIC	1	6.406667	6.406667	313.80	0.003
Residual(a)	2	0.040833	0.020417	5.65	
ORGANIC	3	1.343333	0.447778	124.00	<.001
INORGANIC.ORGANIC	3	0.123333	0.041111	11.38	<.001
Residual(b)	12	0.043333	0.003611		
Total	23	8.693333			

NB: d.f.=degrees of freedom, s.s.=sum of squares, m.s.=mean sum of squares, v.r.= variance ratio(F), F pr=F probability

Table 4.10(b) ANOVA table for Fruit diameter (cm) of eggplants during 2010LR season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
Blocks	2	0.975833	0.487917	17.48	
INORGANIC	1	4.950417	4.950417	177.33	0.006
Residual(a)	2	0.055833	0.027917	11.82	
ORGANIC	3	1.531250	0.510417	216.18	<.001
INORGANIC.ORGANIC	3	0.137917	0.045972	19.47	<.001
Residual(b)	12	0.028333	0.002361		
Total	23	7.679583			

NB: d.f.=degrees of freedom, s.s.=sum of squares, m.s.=mean sum of squares, v.r.= variance ratio(F), F pr=F probability

During the 2009 SR season the treatment T8 maintained a significantly larger ($p<0.05$) fruit mean diameter than other treatments as shown in Table 4.4. No significant difference was observed between treatments T3 and T4, which had fruit mean diameters of 6.73 cm and 6.8 cm respectively. Similarly treatment T5 and T6 had no significant difference ($p<0.05$) by recording 7.33 cm and 7.40 cm respectively. During 2010 LR, plants in all treatments had significant difference ($p<0.05$) in their mean fruit diameter.

Inorganic fertilizer levels had a highly significant effect ($p<0.001$) on the fruit diameter. A significantly higher ($p<0.05$) mean fruit was recorded in plants100% RRR than 50% RRR from both seasons of 2009 SR and 2010 LR (Table 4.5). During the 2009 SR, 100% RRR yielded longer ($p<0.05$) fruits with mean fruit diameter of 7.55 cm compared with 6.52 cm by 50% RRR. Also, during 2010 LR the 50% RRR and 100% RRR rates produced fruits of mean diameter of 6.6 cm and 7.6 cm respectively.

The data further indicates that integration of different sources of organic manures had a highly significant effect ($p\leq0.001$) on the fruit mean diameter during the two seasons. In both seasons there was a strong indication that FYM had the highest effect on fruit length and diameter compared with plants treated with compost, tithonia and control. During the 2009 SR, the mean fruit length of fruits of the control was 6.7 cm while those treated with FYM, compost and tithonia had a mean fruit length of 7.32 cm, 7.18 cm and 6.93 cm respectively. Also, in 2010LR, the mean fruit length of fruits treated with FYM, compost and tithonia were 7.47 cm, 7.27 cm and 7.07 cm, respectively, and the control had fruit length 6.78 cm.

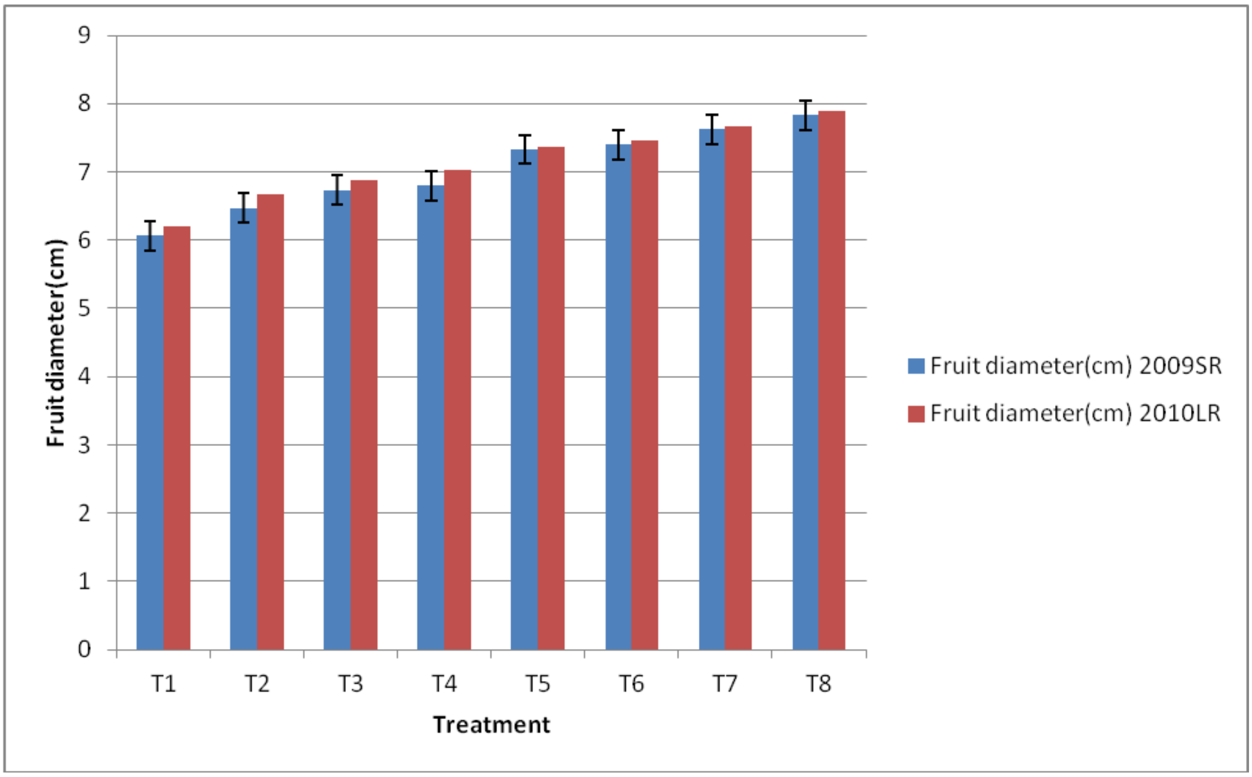

Fig.4.5. Mean fruit diameter (cm) of different treatments (T1-T8) from both seasons of 2009SR and 2010LR.

CHAPTER FIVE

DISCUSSION

5.1 Soil chemical properties

Results of soil chemical analysis revealed that the soil at Bukura were poor in fertility. This was evident in the low soil levels of phosphorous, organic matter as well as medium to low cation exchange capacity. According to Landon (1991) CEC values of between 8 to 10 Cmol Kg^{-1} of soil are indicative of the minimum value in the top 30 cm of soil for satisfactory crop production under irrigation or inadequate rain when other factors are favourable. The positive response of eggplants to the application of inorganic and organic fertilizers and their combination in all the parameters measured (plant height, plant fresh weight, fruit yield and quality could be attributed to the low levels of nitrogen and phosphorus in the soils at the experimental site.

5.2 Plant growth

5.2.1 Effect of inorganic fertilizer levels

In this study, increasing the inorganic fertilizers rate from 110 $kgha^{-1}$ DAP & 300 $kgha^{-1}$ CAN (control) to 220 $kgha^{-1}$DAP & 600 $kgha^{-1}$CAN (Control) induced an increase in vegetative growth of the eggplants expressed as plant height and plant fresh weight. This was due to the initial soil characteristics of the experimental site that consisted of low levels of macro nutrients (NPK). Nitrogen and phosphorous are the two major macro-nutrients normally supplied to the plant in form of fertilizers. In this regard, increasing the levels of inorganic fertilizers which supplied nitrogen, phosphorus and carbon had beneficial effect on activation of the cell division and cell enlargement that stimulated growth of eggplant plants. The observations are in agreement with the results observed by Said (1997) on sweet pepper and Nandekar and Sawarkar (1990) on eggplant who reported increase on growth of the plants with increase in inorganic fertilizer rate.

5.2.2 Effect of different sources of Organic manures

Addition of different sources of organic manures had a significant effect on vegetative growth of eggplants expressed by their height and fresh weight compared to controls. Organic soils provided more than the required nutrients of nitrogen and phosphorus. Janjasri P. and Aninja S. (2010) reported that organic manure normally contains complex compounds and provides not only a variety of nutrients but also add humus the most important constituent of the soil. Humus provides excellent substrate for plant growth. The eggplants applied with organic sources of manure especially farm yard manure were exceptionally healthy, taller and heavier plants. This could be attributed to the fact that the nutrients in the organic manure are released gradually through the process of mineralization as reported by Benton (1998). This helped in maintaining optimal soil levels over prolonged periods of time. Some of the organic substances released during the mineralization may act as chelates that help in the absorption of iron and other micro-nutrients (Salisbury and Ross, 1987).

Addo-Queye *et al*. 2011, observed that Organic fertilizers improve soil water holding capacity as well as the CEC and nutrients are released slowly to crop plants. Organic inputs have a number of effects on nutrients availability. They add new organic matter to the soil and contribute to the maintenance of physical fertility, and result in better soil moisture status. Two main functions of organic manures in soils are the supply of nutrients and increase in the organic matter content of soils. During the decomposition and mineralization process, part of the residue-carbon ends up in more recalcitrant form, which contributes to the organic matter pool. The significance of organic based fertilizers as suppliers of nutrients to plant growth is determined by the rate of nutrient release; the higher the rate of nutrient release the less the soil organic matter. The slow or gradual release of nutrients by organic fertilizers is called the additive effect of organic fertilizers. This is in contrast to inorganic fertilizers that release nutrients rapidly and may fit the plant demand during the crop growth. Due to improved soil properties it enables the roots to grow deeper ensuring strong stems and taller plants. The organic materials have relatively higher PH compared with the soils, hence should have raised the pH of soils increasing the availability of most nutrients, particularly P (Munda G.C. *et al*, 2011)

Tithonia diversifolia, one of the forms of organic sources of fertilizer, was applied by incorporating its leaf biomass in the soil. The vegetative growth obtained from this was significantly lower than plants receiving compost and farm yard manure. This difference could be due to the fast rate of decomposing of tithonia providing large quantities of nutrients that the plant cannot absorb resulting in losses through leaching (Gachengo *et al*, 2004). This may have depressed the vegetative growth in the 2010 LR season because there was a lot of rain during the experimental period. It has been reported that tithonia leaves produce biochemical substances during the decomposition that may retard growth of vegetables (Baruah, 1993).

5.2.3 Effect of interaction between inorganic and organic fertilizers

The term interaction is frequently used to describe the net effects of the combined use of organic and inorganic sources. This term implies to added benefits (or disadvantages) resulting from the combined use of organic and inorganic inputs compared with inorganics alone. In general, the nutrients supplied or removed (immobilized) by the addition of organics are additive to those supplied by inorganic nutrient sources (Paustian et al., 1992 and Giller *et al*., 1997).

Concerning the combined treatments between inorganic fertilizers and organic manures, superior vegetative growth was produced by plants fertilized with full dose of inorganic fertilizers (100%) combined with farm yard manure as compared with other organic combinations. In general, since the experimental soil had low organic matter and mineral nutrition, fertilization by organic manure could improve its content of organic matter, which in turn led to improved soil structure. Therefore, addition of organic manures and full dose of inorganic fertilizers alone or in combination, increased the exchangeable water soluble N and P and the uptake of the elements in turn increased cell division and enlargement (Cooke, 1972). Similar observations were reported by Darwish (2002) on tomato; Abd El-Rahman, (2003) and Younes (2003) on pepper. The results of the chemical analysis in Table 4.1 also indicated that FYM had relatively higher levels of both nitrogen and phosphorus than the other organic manures, hence contributing to its superiority. Farmyard manure can also improve nutrient and water use efficiency as well as yields of common crops in the humid/sub humid transition zones of SSA (Juo and Kang, 1989).

It was observed that Organic materials reduces the P-sorption capacity of the soil and increase P availability by (i) forming complex (or chelate) with ions of Fe and Al in soil solution, preventing the precipitation of phosphate, and also reducing Al and Fe toxicity, (ii) compete with P for sorption sites, and/or (iii) solubilize P from insoluble Ca, Fe, and Al phosphates. These observations concurs with findings made by Iyamuremye *et al.* (1996) who concluded that organic materials could reduce the P-sorption capacity of the soil, enhance P availability, improved P recovery or result in better utilization by plants. The increased availability of P caused promotion of root growth, particularly of lateral and fibrous roots, hence improved vegetative growth.

Organic materials added Carbon into the soil provides substrate for microbial growth, and subsequent microbial activity. The turnover resulting from the decomposition of organic materials improves the nutrient cycling and availability to the plants especially, N and P which likely improved root development and subsequently vegetative growth. Similar observation was made by Smith *et al*, (1993) who found that addition of organic residues could increase microbial pool sizes and activity, C and N mineralization rates, and enzyme activities, all these affect nutrient cycling. Since C is often the element most limiting to microbial growth and activity in soils, the amount and metabolic activity, or C quality, of organic additions will influence rates of nutrient cycling. This is evident in Table 3.2 which shows that FYM had relatively higher OC compared compost and made it better organic manure.

In general since the experimental soil had low organic matter and mineral nutrition Table 3.2, application of organic manure could improve its content of organic matter, which in turn led to improved soil physical properties such as structure, water holding capacity, and stabilizing temperature. Gatachew A., 2009, also reported similar observation. Therefore, addition of organic manures and full dose of inorganic fertilizers alone or together in combination, increased exchangeable water soluble of N and P and the uptake of these elements this in turn likely increased cell division and cell enlargement. Tian *et al*. (1993) found that during drier periods organic manures resulted in higher yields, as mineralization was probably higher because of the more favorable microclimate, lower soil temperatures, and higher soil water content retained by the manures. These results allow for a general conclusion that neither chemical fertilizers alone, nor organic sources used exclusively, could sustain productivity of soils under high intensive cropping systems.

5.3 Fruit yield and its quality

5.3.1 Effect of inorganic fertilizer levels

Data in Table 4.4 shows total fruit yield as well as the average fruit length and diameter as influenced by the inorganic fertilizer treatments of T1 and T5 (Control). The results indicate that all the above measurements tended to increase with the dose of inorganic fertilizer than those of half dose (50%). These results could be due to the improved vegetative growth of those plants treated with full dose of inorganic fertilizer as reported earlier. So the plants had higher fresh weight. This in turn induced more photosynthetic rates that built high yield of carbohydrates which promoted cell division and enlargement hence resulting in vigorous vegetative plants with more and larger fruits than those plants fertilized with half dose (50%) of the inorganic fertilizers. Said (1997) also obtained similar results in tomato plants.

5.3.2 Effect of different sources of organic manures

In general, all organic fertilizers were sufficient to support the production of high total yield and enhanced the fruit traits as compared to plants treated with inorganic fertilizers alone. The results also indicate that of the three organic manures, FYM was the most the most superior compared to compost and tithonia. The superiority of FYM was due to its high contents of N and P, organic matter (OC) and pH as shown in Table 3.2, this in turn led to increased vegetative growth and consequently favoured carbohydrate build up which resulted in more plant growth and yield of eggplant. Chindo and Khan (1986) reported that addition of suitable organic manure led to higher yields. This could be attributed to the fact that the nutrients in the organic manure are released gradually through the process of mineralization (Benton, 1998) maintaining optimal soil levels over prolonged periods of time. Some of the organic substances released during the mineralization may act as chelates that help in the absorption of iron and other micro-nutrients (Salisbury and Ross, 1987).

Organic materials have also been observed to increase microbial biomass and activity in soils (Vinten *et al*., 2002); which suggesting a more responsive microbial community in such soils. The use of organic manures generally ensures effective and efficient management of soil by providing nutrients in correct quantity and proportion in environmentally beneficial forms (Gruhn *et al*., 2000).

5.3.3 Effect of interaction

Paustian et al., 1992 and Giller *et al*., 1997 defined the term interaction as magic effect of organic materials, whereas to others it merely means a statistical interaction. A better phrase than interactions might be added benefits (or disadvantages) resulting from the combined use of organic and inorganic inputs compared with inorganic fertilizers alone. Achieng *et a*l., 2010, reported that in general, the nutrients supplied or removed (immobilized) by the addition of organics are additive to those supplied by inorganic nutrient sources.

The most favorable treatment combination was 100% RRR + FYM compared with the other treatments. The superiority of this treatment may be due to increased uptake of N and P which resulted in increased plant weight due to increased number of leaves and branches. The improved plant growth led to better carbohydrate build up which increased the plant fruit yield and their fruit length and diameter. In this regard, Cook(1972) reported similar results and explained that addition of suitable organic manure in the soil improved the soil physical and chemical properties which encouraged better root development, increased nutrient uptake and water holding capacity which lead higher fruit yield and better fruit quality.

The higher yield of eggplants from organic materials plus inorganic fertilizer treatments than sole inorganic fertilizer treatment is an indication that integrated use or organic and inorganic nutrient sources of N could be advantageous over the use or inorganic fertilizer alone. Earlier studies demonstrated that use of organics could enhance efficiency of chemical fertilizer (Dudal and Roy, 1995). Other researchers observed higher eggplant yields through application of high quality organic inputs in combination with inorganic fertilizer as compared to sole application of inorganic fertilizers (Esilaba *et al*., 2005). Integration of inorganic and organic nutrient inputs could therefore be considered as a better option in increasing fertilizer use efficiency and providing a more balanced supply of nutrients. Vanlauwe *et al*., (2002) reported that combination of organic and inorganic nutrient sources resulted into synergy and improved conservation and synchronization of nutrient release and crop demand, leading to increased fertilizer efficiency and higher yields.

Organic materials are also known to be capable of supplying substantial amounts of essential nutrients (Palm *et al*., 1997) and so may improve on utilization of P by plants. They also do act as sources of P (Eijk, 1997) for the plant as some added into the soil via organic residues is converted to inorganic P during mineralization (Iyamuremye and Dick, 1996). It is also thought that addition of decomposable organic matter also promotes activities of microorganisms which enhance solubilization of insoluble phosphates through production of chelating agents (Stevenson, 1986).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

This study showed that both inorganic fertilizers and organic manures have their own roles to play in soil fertility management but none could solely supply all the nutrients and other conditions of growth for producing eggplant. Increased growth and yield parameters in this study may be associated with the supply of essential nutrients by continuous mineralization of organic manures, enhanced inherent nutrient supplying capacity of the soil and its favorable effect on soil physical and biological properties. As per the objectives of the study set out in section 1.3, the following conclusions can be drawn:

1. Increasing the inorganic fertilizers from 50% to 100% research recommended rates leads to increased growth and yield and fruit quality parameters of eggplant.

2. All the organic manures used significantly enhanced growth, yield and fruit quality of eggplant. Though tithonia yielded the lowest eggplant among the organic resources tested in this study, the observed increase in eggplant yield with application of tithonia compared with the control, demonstrated that it makes a significant contribution to crop production.

3. Results indicated treatments gave significantly ($p<0.05$) higher yields than the recommended rate of inorganic fertilizer, suggesting that organic materials improved nutrient use efficiency from inorganic fertilizer. The results revealed that among the different combinations of inorganic and organic manure treatments, eggplant responded best to the application of 100% RRR + FYM. The growth characters and yield attributes as well as the fruit quality of eggplant were most significantly enhanced by the

application of 100% RRR + FYM and their use should be promoted. Overall conclusion is that organic sources; FYM, compost and *Tithonia* applied in combination with inorganic fertilizer could be used as nutrient sources and can meet nutrient requirement for eggplant in the following order FYM> compost > tithonia.

6.2 RECOMMENDATIONS

Based on the outcome of this research, the following recommendations are made:

1. Farmers would benefit by incorporating 10-15 tonha^{-1} (1-1.5 kg/M^{2}) of FYM combined with 110 kgha^{-1} DAP and 300 kgha^{-1}CAN (83kg N ha^{-1} and 61.5kg P ha^{-1}) to improve on the growth, yield and quality of eggplants.
2. Future research should focus on how higher quality organic materials can substitute for inorganic fertilizers, by establishing prescriptive guidelines that relate the quality of the organic material to its nutrient substitution value.
3. Promote livestock confinement, through zero-grazing to increase availability of FYM to the farmers.
4. Promote preservation and use of farm yard manure from zero grazing sheds or units and slaughter houses.

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APPENDICES

APPENDIX I: Ratings and interpretation of values of soil test parameters (Landon, 1991)

Ratings and interpretation of PH values

PH range	Rating	**Interpretation**
>8.5	Very high	Alkaline
7.0-8.5	High	Alkaline to neutral
5.5-7.0	Medium	Acid to neutral
<5.5	Low	Acid soils

1:2.5 Soil: Water suspension

Ratings values of exchangeable K

K Cmol kg^{-1}	Ratings
0.03-0.2	Low
0.2-0.4	Medium
0.4-0.8	High
>0.8	Very high

Available K: Ammonium acetate extraction

Ratings of OC and N

Ratings	OC%	N%
Very low	<2	<0.1
Low	2-4	0.1-0.2
Medium	4-10	0.2-0.5
High	10-20	0.5-1
Very high	>40	>1

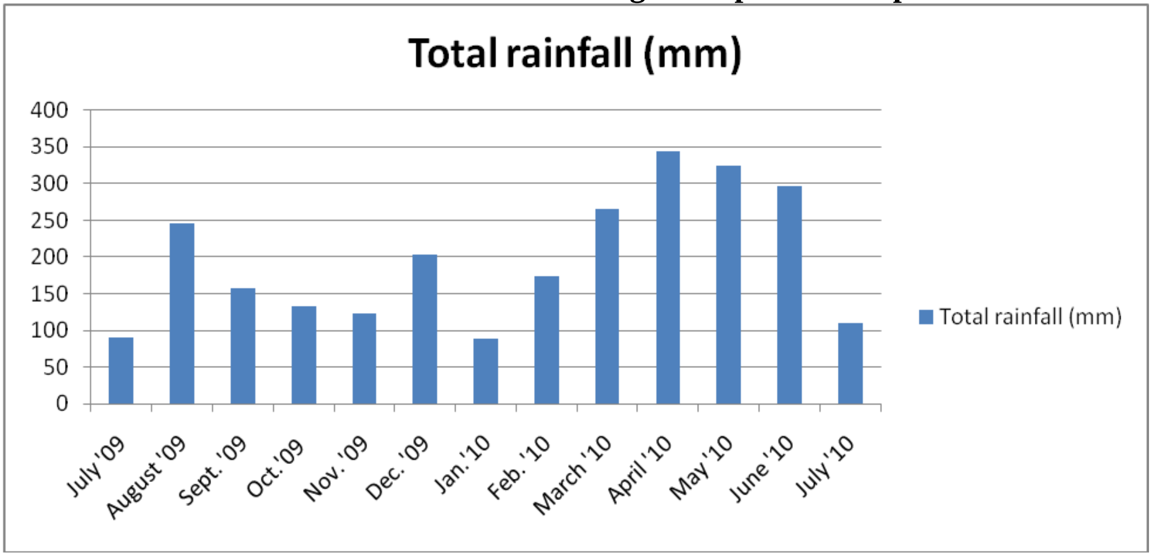
OC Walkley Black (% of soil by dry weight) & N Kjedahl method (% of soil by weight)

Ratings of CEC values for top soil

CEC Cmol kg^{-1}	Rating
>40	Very high
25-40	High
15-25	Medium
5-15	Low
<5	Very low

CEC: Ammonium acetate extraction

APPENDIX II: Rainfall data at Bukura during the experimental period



Source: Bukura agricultural college meteorological station