EFFECT OF NUTRIENT MANAGEMENT AND MOISTURE CONSERVATION PRACTICES ON GROWTH, YIELD AND QUALITY OF SNAP BEAN (*Phaseolus vulgaris* L.) IN CENTRAL KENYA

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN AGRONOMY

DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION
FACULTY OF AGRICULTURE
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2015

DECLARATION

I declare that this is my original work and has not been presented for an award of a degree in any other university.

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Glory to God for his providence, wisdom, life and protection throughout the entire period in pursuing my Masters degree.

To my parents, Mr. and Mrs. Charles Omwenga; my siblings: Nicholas, Tabitha, Lillian, Anita, Phillip, Brenda; and my niece, Victoria.

ACKNOWLEDGEMENTS

I thank the Almighty God for the perseverance and strength to carry out my study and research successfully.

I thank the University of Nairobi for the scholarship awarded to me to pursue a Master of Science in Agronomy. I am grateful to my supervisors Prof. George N. Chemining'wa, Dr. Jane L. Ambuko and Prof. John H. Nderitu for their guidance, support, encouragement and constructive critiques during the entire period of study.

I would like to thank the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) for funding the research and wish to have more collaboration with them in the future.

I would also like to thank farmers in Kirinyaga South and Embu East sub-counties who participated in the field trials and the Ministry of Agriculture staff in the two Sub-counties who assisted in identification of the experimental sites.

Finally, I would like to appreciate everyone who in one way or another contributed to the successful completion of my study; I am indebted to you and God bless you abundantly.

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GENERAL ABSTRACT

Snap bean (*Phaseolus vulgaris* L.) is one of the major vegetables produced in Kenya mainly for the export market. Low soil fertility and limited moisture availability are the main factors hindering the realization of potential snap bean yields and high quality pods. On-farm trials were established at Kimbimbi in Kirinyaga South district and Kawanjara in Embu East district of Kenya to evaluate the effect of nutrient management options and moisture conservation practices on the growth, yield and quality of snap bean. In the first trial, the following nutrient management regimes were evaluated: control (no fertilizer), farmyard manure (5 t/ha) + minjingu phosphate rock (30 kg P/ha), farmyard manure (5 t/ha) + diammonium phosphate (26.9 kg N/ha and 30 kg P/ha), farm yard manure (5 t/ha) + calcium ammonium nitrate (60 kg N/ha), diammonium phosphate (43.2 kg N/ha and 48.2 kg P/ha) + calcium ammonium nitrate (46.8 kg N/ha) top dressed at 21 days after emergence, farmer practice [diammonium phosphate (30 kg N/ha and 33.5 kg P/ha) + calcium ammonium nitrate (40 kg N/ha) top dressed at 21 days after emergence] and diammonium phosphate (43.2 kg N/ha and 48.2 kg P/ha) + calcium ammonium nitrate (46.8 kg N/ha) top dressed at 21 days after emergence + wuxal foliar feed (pre-flowering). These treatments were laid out in a randomized complete block design and replicated three times. In the second trial, the following moisture conservation practices were evaluated: control (no ridges + no mulch), tied ridges, untied ridges, mulch + no ridges, mulch + tied ridges and mulch + untied ridges. Treatments were laid out in a randomized complete block design and replicated three times. Data collected in both trials included plant emergence, plant vigor, number of days to 50% flowering, number of days to 50% pod formation, insect pest infestation, disease infestation, plant stand at first harvest, number of pods per plant, pod length, extra fine pod yield, fine pod yield and total marketable pod yield. Data were subjected to analysis of variance and mean separation was done using the least significant difference test at p=0.05.

Results of the first trial showed that fertilizer application significantly reduced the number of days to 50% pod formation in Mwea. Snap bean plants achieved 50% flowering and 50% pod formation earlier in Mwea than Embu by four and five days respectively. All the fertilizer treated plots significantly improved snap bean pod yield, yield components and quality compared to no-fertilizer control plots. In both sites, diammonium phosphate (DAP) + calcium ammonium nitrate (CAN) + foliar feed and DAP + CAN produced more vigorous snap bean plants, higher number of pods per plant and higher extra fine, fine and marketable pod yields than the farmer practice and all the other treatments. There were no significant differences between DAP + CAN + foliar feed and DAP + CAN in growth and yield parameters. The DAP + CAN + foliar feed treatment had a higher net profit than the farmer practice and other treatments. Results of the second trial showed that tied and untied ridges with or without mulch accelerated the time to 50% pod formation of snap bean plants in Embu. Use of ridges (tied or untied) with or without mulch led to increases in number of pods per snap bean plant, extra fine pod yield, fine pod yield and marketable pod yield. Mulch without ridges increased only the number of pods and fine pod yield in Mwea.

The study has demonstrated that application of foliar feed in combination with DAP (43.2 kg N/ha and 48.2 kg P/ha) + CAN (46.8 kg N/ha) and use of mulch + untied ridges can enhance snap bean productivity and profitability under farmers' fields in central Kenya.

CHAPTER ONE: INTRODUCTION

1.1 Background information

The agriculture sector is the mainstay of the Kenyan economy, and is the second most important subsector (KARI, 2012). It contributes 24% of the Gross Domestic Product (GDP) directly and 27% of it indirectly through linkages with manufacturing, distribution and other service related sectors. Approximately 45% of government revenue is derived from agriculture and the sector contributes over 75% of industrial raw materials and more than 50% of the export earnings (KARI, 2012). It is the largest employer in the economy, accounting for 60 percent of the total employment. Over 80% of the population, especially living in rural areas derives its livelihood mainly from agricultural related activities (KARI, 2012).

The total domestic value in the horticulture sector in 2013 amounted to Ksh 177 billion occupying an area of 605,000 ha with a total production quantity of 132 million MT (HCDA, 2014). As compared to 2012, the total value and area increased by 17% and 19%, respectively, while productivity had a variation of only 2%. Increase in value was attributed to improved farm gate prices particularly for vegetables and fruits (HCDA, 2014). The value of horticultural exports as of 2013 was Ksh. 94.7 billion with flowers constituting 48.7% of the total value. The overall exports in terms of value and quantity increased by 7% and 20%, respectively, as compared to 2012. The values and quantities of vegetables dipped by 20% and 41%, respectively, as compared to 2012 and 2011 due to increased surveillance by the European Union market, one of the main export destinations for Kenyan bean and peas, against non-compliance with set maximum residue levels (HCDA, 2014).

Snap bean (*Phaseolus vulgaris* L.) is an annual warm season crop grown for its immature seed pod (Infonet-Biovision, 2012). The main snap bean producing regions in Kenya are Kirinyaga, Murang'a, Taita taveta, Meru and Machakos accounting for 39.6, 12.3, 9.2, 8.7 and 6.3% of the total production respectively (HCDA, 2014). The crop is grown majorly as a monocrop mostly by rural small scale farmers whose farm sizes range from 0.25 to 1 hectare (Nderitu et al., 2007). Other major snap bean producing countries in Africa include Egypt, Ghana, Morocco, Senegal and Zimbabwe.

In eastern and central Africa, snap bean is primarily grown for export with a small quantity consumed in the domestic market (HCDA, 2014). The crop is exported mainly to the United Kingdom, France, Germany and Netherlands (Kamanu, 2012). Despite the rejections by the snap bean market due to non-compliance with set maximum residue levels (MRLs), exports from Kenya improved from 22,553 MT in 2012 to 31,973 MT in 2013 due to integration of the traceability system in the supply chain enabling exporters to monitor chemical use by farmers directly (HCDA, 2014). Processing of snap bean, including canning and freezing, is steadily increasing and local consumption has also increased over the last few years, thus providing a domestic market for the crop (HCDA, 2005).

Globally, the yield for snap bean ranges between 8 and10 tonnes per hectare, with high yields of more than 14 tonnes per hectare being recorded in China, USA and Latin America (CIAT, 2006). The average yield in smallholder farms in eastern and central Africa is low ranging between 4 and 8 tonnes per hectare (Kimani et al., 2004). Enhanced snap bean productivity is hindered by a number of biotic and abiotic constraints. The major biotic constraints are insect pests and diseases which result in high yield losses. The diseases include anthracnose, bean rust, angular leaf spot and common mosaic virus, while the major pests are bean stem maggot, aphids, thrips and nematodes (Kimani et al., 2004). Two key abiotic constraints in snap bean production are low soil fertility, characterized by low levels of soil nitrogen, phosphorous and potassium, and inadequate moisture.

Soil fertility decline remains the major cause of declining food production on smallholder farms of sub-Saharan Africa and this decline is mainly attributed to soil nutrient depletion, following intensification of land use without proper land management practices and inadequate external inputs (Sanchez and Jama, 2002). For instance, in the central Kenya highlands, farms are characterized by widespread failure to make sufficient soil fertility replenishment investments, resulting in declining soil fertility, low returns to agricultural investment, decreased food security and general high food prices consequently threatening food security in this region (Odera et al., 2000).

Studies have indicated that the decline in soil fertility is due to a combination of factors such as high rates of soil erosion, nutrient leaching, removal of crop residues and continuous cultivation of land without adequate fertilization and fallowing (Okabelo et al., 2006). Soil nutrient depletion, which is indicated by negative nutrient balances, is the major cause of low yields. The average annual loss in soil nutrients of 42 kg N, 3 kg P and 29 kg K/ha in Kenya is among the greatest in Africa (Smaling et al., 1997). A study by Gachimbi (2002) revealed that the rising cost of inputs has resulted in many smallholder farmers reducing or abandoning the use of chemical fertilizer altogether in central Kenya. This aggravates the soil infertility situation and results in further decline in crop yields since for a majority of farms the available manure is not enough to fertilize the whole farm, in addition to the insufficient inorganic fertilizer. Research by

Kimani et al., (2004) reported that soils in central Kenya are more acidic due to continuous cultivation and use of Di-ammonium phosphate fertilizers. In Kirinyaga, nutrient depletion is wide spread due to continuous cropping with little nutrient replenishment (Kimani , 2006)

Use of fertilizers to replenish soil nutrients is an important way to improve soil fertility, but the nutrients applied in mineral fertilizers by the smallholder farmers in central Kenya remain low due to insufficient amounts used. For instance, the use of inorganic fertilizers is as low as less than 20 kg N and 10 kg P/ ha (Murithi et al., 1994). The amount is inadequate (below the recommended level of 60 kg N/ ha) to meet the crop nutrient requirement for optimum crop productivity in the area. In order to address these challenges, studies in the central highlands of Kenya and other areas in sub-Saharan Africa have identified nutrient management options that would help the low-resource farmers mitigate problems of food insecurity and improve soil production capacity (Bationo et al., 2003).

Snap bean growing regions receive inadequate rainfall and are often faced with droughts that have become more frequent and severe possibly due to climate change. Climate change makes the weather more unpredictable and droughts more frequent and severe (Abdzad Gohari, 2013). Soil moisture stress is among the primary limiting factors in crop production as it affects many physiological and biochemical processes (Purcell et al., 2007). The success of a crop depends upon the amount of moisture stored, which also depends on the nature of soil. Moisture loss from the soil by evaporation (Jalota et al., 2001) and erratic rainfall in the middle of the season lead to crop failure. High grain yield loss is reported to occur when moisture stress occurs at critical growth stages including flowering, podding and pod filling (Al-Kaisi and Broner, 2012). This appears to suggest that in order to increase legume grain yield, soil moisture stress has to be alleviated. Some of the methods to improve soil moisture availability and enhance yields include mulching, conservation tillage and irrigation among others (Gicheru et al., 2004). No-tillage method and mulch management have been reported to have improved soil moisture storage (Gicheru et al., 2004)

Hence, the use of moisture conservation practices like mulching and use of ridges would ensure an increase in yield of snap bean, leading to an increase in income and improvement of the country's food security.

1.2 Problem statement and justification

Snap bean production is constrained by low soil fertility and limited moisture availability that have resulted in reduced yields. Soil fertility decline is mainly attributed to soil nutrient depletion following intensification of land use without proper land management practices and inadequate external inputs (Sanchez and Jama, 2002). Low levels of soil nitrogen, phosphorous and potassium can lead to low snap bean crop yield. Nitrogen, phosphorous and potassium are important for plant growth and their application to snap bean plants leads to improved plant growth, yield and green pod quality (Asmaa et al., 2010). The use of inorganic fertilizers exclusively to supply the deficient nutrients can be very expensive and environmentally unfriendly. Nutrient management options that entail integration of mineral fertilizers with organics improve the agronomic efficiency of the external inputs used and provide a more balanced supply of nutrients. Previous studies in Kenya, Uganda and Tanzania have developed nutrient management options that could help farmers mitigate problems of food insecurity and improve the resilience of the soil's productive capacity. However, some of these nutrient management options have not been evaluated in farmers' fields in Kenya.

Snap bean growing regions in Kenya like Kirinyaga, Machakos and Naivasha receive inadequate rainfall and are often faced with droughts that have become more frequent and severe possibly due to climate change and variability which is predicted to continue over a long period (Jarvis, 2009). Emam et al., (2010) and Abdzad Gohari (2012) reported that yield of beans significantly decreased under drought stress conditions. Farmers in the snap bean growing areas have the option of producing the crop under irrigation but this is expensive and often out of reach for most small holder farmers. The most cost effective approach is the adoption of moisture conservation practices like mulching and ridging which, coupled with supplementary irrigation, can enhance snap bean crop water productivity. Hence, the use of nutrient management options and moisture conservation practices which would ensure an increase in yield of snap bean production, leading to an increase in income and improvement of the country's food security, were evaluated.

1.3 Objectives of the study

The main objective of the study was to develop nutrient management options and moisture conservation practices for enhancing snap bean productivity in central Kenya.

The specific objectives of the study were:

1. To determine the effect of different nutrient management options on growth, yield and quality of snap bean.

2. To determine the effect of moisture conservation practices on growth, yield and quality of snap bean.

1.4 Hypotheses

1. Newly developed nutrient management options enhance growth, yield and quality of snap bean

2. Moisture conservation practices enhance growth, yield and quality of snap bean

CHAPTER TWO: LITERATURE REVIEW

2.1 Ecology and importance of snap bean

Snap bean (*Phaseolus vulgaris* L.) is an annual warm season crop grown for its immature seed pod (Infonet-Biovision, 2012). The optimum temperature range for growing snap bean is 20-25°C, but it can be grown in temperatures ranging between 14 and 32°C. It grows best on well drained, silty loams to heavy clay soils high in organic matter with pH 5.5-6.5 (Infonet-Biovision, 2012). Compact soils with little organic matter do not give good yields of beans, unless organic matter is provided, preferably in the form of good quality compost or well decomposed farmyard manure (Infonet-Biovision, 2012).

Extreme temperatures (above 30^0c) result in poor flower development and poor pod set (Infonet-Biovision, 2012). However, snap bean matures fast in warm areas and can be grown between 1000 and 2100 meters above sea level. Rain-fed cultivation is possible in areas with well distributed, medium to high annual rainfall (900-1200 mm), but to maintain a continuous production especially during the dry season, irrigation is essential. During the dry season up to 50 mm of water per week is required which could be applied through furrow or overhead irrigation (Infonet-Biovision, 2012).

Snap bean is one of the most important fresh market crops which is a source of calories, proteins, dietary fibers, minerals (zinc and iron) and vitamins for millions of people in both developing and developed countries (Kelly and Scott, 1992; Ndegwa et al., 2006). Its production is dominated by rural small scale farmers especially women and youth and is their major source of employment and income (Ndungu et al., 2004; Monda et al., 2003). Snap bean is grown majorly for fresh and processing markets and, compared to dry bean, it has a high market value, matures earlier, requires less energy to cook and has longer harvest duration (Ugen et al., 2005).

In eastern and central Africa, snap bean is primarily grown for export with a small quantity consumed in the domestic market (HCDA, 2014). Despite the rejections by the snap bean market due to non-compliance with set maximum residue levels (MRLs), exports from Kenya improved from 22,553 MT in 2012 to 31,973 MT in 2013 due to integration of the traceability system in the supply chain enabling exporters to monitor chemical use by farmers directly (HCDA, 2014).

In Kenya, snap bean production is second to cut flowers in foreign exchange earning. The total production of snap bean in 2013 was 38,398 MT valued at Kshs 1.8 billion (Table 1.1). The area, yields and value increased by 7.1, 14.6 and 43.3% respectively. The leading counties producing snap bean were Kirinyaga, Murang'a, Taita taveta, Meru and Machakos accounting for 39.6, 12.3, 9.2, 8.7 and 6.3% of the total production respectively (HCDA, 2014).

Table 1.1: Production of snap bean in selected counties of Kenya.

	2011		2012		2013		
County	Quantity(MT)	Ksh(Million)	Quantity(MT)	Ksh(Million)	Quantity(MT)	Ksh(Million)	% value share
Kirinyaga	12114.00	395.50	10583.00	450.90	15222.00	869.40	47.70
Muranga	3368.00	103.50	3848.00	118.50	4731.00	158.80	8.70
Taita taveta	1497.00	52.40	1227.00	43.50	3514.00	147.60	8.10
Meru	3206.00	124.70	6615.00	261.60	3328.00	130.30	7.10
Embu	562.00	29.50	765.00	39.90	2083.00	124.20	6.80
Machakos	625.20	28.70	1759.60	75.20	2415.00	106.00	5.80
Laikipia	1500.00	99.00	1080.00	76.00	1380.00	89.00	4.90
Narok	1254.00	61.80	1718.00	101.00	1046.00	60.40	3.30
Others	472.60	93.50	5924.00	106.00	4679.00	137.80	7.60
Total	24598.80	988.60	33519.60	1272.60	38326.00	1823.50	100.00

Source: (HCDA, 2014). MT – metric tonnes

The main snap bean importing countries are United Kingdom, France and Germany. Other east and central African countries with a high potential of snap bean production are Tanzania, Uganda and Rwanda (Kimani et al., 2004; Ugen et al., 2005)

As a quick maturing crop, snap bean serves as a key component in intensifying production in small holder farmer systems. Its ability to fix nitrogen means that it can encourage much needed, even long term improvement in soil fertility; its contribution to households food income, diet, health and even environment security makes it have great potential for addressing food insecurity, income generation and poverty alleviation in the region (Ugen et al., 2005).

2.2 Constraints to snap bean production

Common bean production is constrained by several stresses, notably biotic (field and post harvest pests and diseases) and abiotic (drought, excessive rain/floods, poor soil fertility, heat and cold stress), each of which can cause significant reductions in yield (Wortmann et al., 1998). Snap bean farmers face several constraints which include diseases and pests (Monda et al., 2003; Katafiire et al., 2011). Rusts (*Uromyces appendiculatus*), angular leaf spot (*Phaeoisareopsis griseola*) and anthracnose (*Colletotrichum lindemuthianum*) are the most important and widely distributed diseases of snap bean in east Africa and losses due to angular leaf spot and anthracnose were 384 200 and 328 000 respectively (Wortmann et al., 1998; Katafiire et al., 2011). The main pests affecting bean production are aphids, bean stem maggots, mites and white flies (Mwangi, 2008) and the losses caused by bean stem maggots as estimated by Wortmann et al., (1998) were 297 100 t/ha.

Declining soil fertility is a major problem in bean production areas in eastern Africa. The major edaphic constraints include low soil nitrogen and phosphorus, soil acidity and toxic levels of aluminium and manganese (Lunze et al., 2007). With fertile, well-drained and good soil conditions, higher yields of beans can be obtained (Wortmann et al., 1998). According to the atlas of common bean production in Africa (Wortmann et al., 1998), phosphorus is deficient in 65 to 80% of soils and nitrogen in 60% of soils in bean production areas of eastern and southern Africa, while about 45 to 50% of soils are acidic with a pH less than 5.2 and containing high levels of either Aluminium or Manganese. Estimated bean production losses due to edaphic stresses in eastern, central and southern Africa are about 1,128 million tons per year (Wortmann et al., 1998). The authors estimated that bean yield losses due to nitrogen and phosphorus deficiencies were 389,900 and 355,900 t/ha respectively. Stresses such as poor soil fertility are long term and predictable (Lunze et al., 2011), while others like drought, some pests and diseases spurred by climate change could be short term but acute in nature (Katafiire et al., 2011).

Drought is another major constraint to snap bean production. Drought refers to a prolonged period without considerable precipitation that may result in reduction in soil water content causing a deficit in plant water (Tardieu, 1996). Wortmann et al., (1998), estimated that grain yield losses in common dry bean due to drought were 396,000 t/ha. Soil water deficits that occur during reproductive growth are considered to have the most adverse effect on crop yield (Costa-Franca et al., 2000). Drought has been shown to decrease the number of flowers by up 47% (Xia, 1997) and cause 21% to 65% pod abortion (Mwanamwenge et al., 1999).

Drought effects differ depending on the frequency, duration and the intensity of stress and the stage of growth of the affected crop (Nunez-Barrios et al., 2005). Drought stress results in significant bean seed yield reductions in about 60 % of the total global bean producing areas (Rosales-Serna et al., 2004). Drought has been worsened by climate change and variability which is predicted to continue over a long period (Jarvis, 2009)

In Africa, an estimated 682,000 hectares of beans are cultivated in semi-arid environments, with annual yield losses to drought of 781,000 tons across all environments (Wortman et al., 1998). The drought endemic area stretches from eastern and central Ethiopia, south through eastern Kenya and Rift valley. Kenya has the largest area of beans under threat of drought, often resulting from failure of the short rains. Moreover, climate models predict that these regions will become drier with global change (Williams et al., 2007).

Access to European Union markets is becoming increasingly difficult as a result of strict safety and quality standards. Rejections of snap bean due to non-compliance with set maximum residue levels (MRLs) led to a decrease in exports in the past few years but the volume of exports increased from 22,553 MT in 2012 to 31,973 MT in 2013 (HCDA, 2014). Small-holder snap bean farmers rely on fungicides and insecticides to reduce diseases and pests and the overuse of these products causes the chemical residue of the snap bean to rise beyond the maximum level that is accepted by the European Union market (Kimani, 2002). Continued use of chemicals leads to reemergence of disease resistant pathogen races, increased cost of production and adverse effects on the environment and human health (Burkett-Cadena et al., 2008).

High postharvest losses coupled with lack of value addition technologies is another challenge in snap bean production (HCDA, 2014; Katafiire et al., 2011). Snap bean is categorized as a highly perishable vegetable that deteriorates quickly if not provided with proper temperature management. Post harvest losses at farm level in Kenya are in the range of 1-20% and are attributable to overgrown pods, pests, diseases and pod defects (Katafiire et al., 2011). The consumption of fresh and frozen beans has been on the increase, hence, there is need for proper handling and management from harvest to export (Monda et al., 2003; Katafiire et al., 2011). Snap bean value addition technologies increase price supply convenience products to consumers preventing postharvest losses and increase food availability (Katafiire et al., 2011).

2.3 Integrated soil fertility management

Integrated soil fertility management (ISFM) options are a set of soil fertility management practices that include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity (Vanlauwe et al., 2010). It is an approach that stresses sustainable and cost-effective management of soil fertility (Sanginga and Woolmer, 2009; Vanlauwe et al., 2010) and relies on a holistic approach that embraces the full range of factors and consequences of soil degradation-biological, chemical, physical, social, economic, health and nutrition (Bationo et al., 2006). It attempts to make the best use of soil nutrient stocks, locally available soil amendment resources and mineral fertilizers to increase land productivity while maintaining and enhancing soil fertility.

The use of organic matter is a traditional practice characterized by use of low cost, eco-friendly inputs which have tremendous potential for supply of nutrients hence, reduce dependence on chemical fertilizers. The use of compost and farmyard manure are the most common inputs used to improve soil fertility by small scale farmers (Kankwatsa et al., 2008). The need for both organic and mineral inputs to sustain soil health and crop productivity through ISFM is important and recommended because of positive interaction (Vanlauwe et al., 2010). The quantities of organic manure required to meet crops demand is not available to small scale farmers, hence, to obtain required yield, inorganic fertilizes should be incorporated. The use of organic manure as a source of nutrient or to improve the efficiency of mineral fertilizers is well established in some regions and a number of fertilizer recommendations have been formulated. However, for organic manure to have substantial effects, they are required in large amounts, which are not readily available and accessible to small scale bean growers (Thung and Rao, 1999).

Soil organic matter is one of the most important soil components which determine soil quality (Carter, 2002). An increase in soil organic matter content helps reverse land degradation and often increases soil fertility and crop production (Weil and Magdoff, 2004). Organic matter use has been associated with desirable soil properties including increased water holding capacity (Hogan, 2010), cation exchange capacity, lower bulk density and fostering beneficial micro-organisms (Drinkwater et al., 1995; Doran, 1995), pH stabilization and faster infiltration rate (Stamatiadis et al., 1999), increased soil enzyme activities (Garcia- Ruiz et al., 2008), better aeration, enhanced absorption and release of nutrients, and making the soil less susceptible to leaching and erosion (Sekhon and Meelu, 1994; Reijntjes et al., 1992). It also leads to improvement of the soil structure, porosity, compression strength, and soil nutrient content (Pinanamonti and Zorzi, 1996) thereby improving plant growth, crop yield and quality (Pinanamonti and Zorzi, 1996; Rodrigues et al., 1996).

The nutrient concentration in farmyard manure is usually low and varies greatly depending upon source, conditions, and duration of storage. The nitrogen, phosphorous and potassium contents in manure range widely from 0.01 to 1.9 percent on dry weight basis due to its variable nature of production and storage (Inoko, 1984). Estimates of organic manure based on dry matter content available in farms varied from 3.1 to 18.9 t/ ha in central Kenya (Opala, 2001). Due to scarcity of the organic manure, small scale farmers are forced to apply the manure in the planting holes or furrows rather than broadcasting it.

Over-application of fertilizers induces neither substantially greater crop nutrient uptake nor significantly higher yields (Smaling and Brown, 1996) rather excessive nutrient applications are economically wasteful and can damage the environment. Under application can retard crop growth and lower yields in the short term and in the long run, jeopardize sustainability through soil mining and erosion (Smaling and Brown, 1996). Extensive use of inorganic fertilizers and the resulting poor soil conditions have resulted in the use of organic amendments for soil nutrient improvement which has acquired importance in these days to achieve sustainable productivity and soil nutrient management.

In Africa, low and declining soil fertility and poor availability of nitrogen, phosphorous, and in some cases potassium for plant growth often hampers the production of legumes (Chemining'wa et al., 2007). Declining soil fertility is mainly attributed to soil nutrient depletion following intensification of land use without proper land management practices and inadequate external inputs (Sanchez and Jama, 2002). The low level of chemical fertilizer use, decline in soil organic matter, and insufficient attention to crop nutrient studies contribute the most to the loss of soil fertility in the region (Kumwenda et al., 1996). Most African farmers practice low-input agriculture that depends on organic matter in the soil to sustain production. Low-input systems enhance soil organic matter through crop rotation, intercropping, application of animal and green manures, fallowing, and reduced tillage (Kumwenda et al., 1996), but as pressure on land and crop intensification increase, these options do not remain practical. Farmers need to know how to combine organic fertilizers with chemical fertilizers, apply improved pest and weed management techniques, and adopt high yielding crop varieties (Kumwenda et al. 1996). Insufficient attention to effective crop nutrition and soil fertility management studies has also made it difficult to improve yields in Africa, even when improved germplasm has been made available. More research, expanded extension, and greater integration of knowledge could provide farmers with a stronger incentive to improve yields, maintain soil fertility, and sustain agriculture (Kumwenda et al., 1996).

2.4 Effect of inorganic fertilizers on snap bean production

Soil fertility is one of the primary constraints to agricultural production in Sub Saharan Africa (Gruhn et al., 2000). Increasing population pressure on the continent has contributed to this constraint, leading to reduced sizes of land holdings and consequently to reduced fallow periods. This is particularly true where population densities are high, such as highland areas of east Africa. This has led to concerns over the long term sustainability of agriculture. The reduced ability to use traditional soil fertility management practices such as fallow and rotation to restore soil fertility limits farmers to the main other option, that of increased soil fertility inputs. These include organic inputs (either green manure or livestock manure) and inorganic chemical fertilizer (Gruhn et al., 2000).

Compared to the rest of the world, fertilizer use in Sub Saharan Africa is low, and continues to decline. In 1996, SSA consumed on average only 8.9 kgs of fertilizer per hectare of arable land, compared to 97.7 kgs globally. While fertilizer use per hectare grew in developing countries overall by a rate of 3.1 % annually, it declined in SSA (Gruhn et al., 2000). Partially as a consequence, per capita food production has been declining since early 1990s (De Jager, 1998). In SSA, livestock continue to provide a large share of soil fertility amendments, as they do globally. In developing countries overall, more than half of total fertilizer is provided in the form of livestock manures; this rises to 70% in lower income countries (Fresco and Stienfield, 1997). Given the low use of inorganic fertilizer and the significant changes in output markets and technology that would be needed to increase demand for fertilizer, the dependency on manure for soil fertility inputs is likely to continue for some time. Kenya is typical of this situation. Most agricultural production occurs in the medium to high potential highlands, in the context of small (1-5 ha) mixed farms growing maize and beans, tea or coffee, over half of which keep either traditional zebu cattle or cross bred dairy cattle. Due to good bimodal rainfall (over 1200ml in highland areas) and intensive annual cropping, soil nutrient balances are negative on farms (De Jager, 1998), and sloppy terrains in some areas contribute further to soil degradation. Fertilizer use is low, averaging 39 kg/ha in central Kenya (Omamo et al., 2002) and so livestock have to play a key role in soil fertility management. This is particularly true in the crop-dairy system that dominates much of central and western Kenya.

Mineral fertilizer application is essential for plant growth, development and productivity of snap bean. Nitrogen is of vital importance for plant growth as a part of amino acids, proteins, enzymes and chlorophyll (Devlin and Witham, 1986). Nitrogen fertilizer plays a significant role in increasing snap bean crop yields (Naderi et al., 2008). Nitrogen deficiency results in stunted growth and chlorotic leaves caused by poor assimilate formation that leads to premature flowering and shortening of the growth cycle (Lincoln, 2006). Abdzad Gohari (2010) reported that nitrogen fertilization significantly increased seed yield, seed weight, number of pods per plant and number of seeds per plant in beans. Increasing NPK levels improved plant growth, yield and green pod quality of snap bean (Abdel-Mawgoud et al., 2005).Vegetative growth parameters of snap bean were gradually and significantly increased by increasing the level of nitrogen fertilizer application (Asmaa et al., 2010).

On Ferralsols (Oxisols) of Burundi, mineral fertilizer applied alone on beans was found to be non-economical, and under certain conditions bean yield was depressed. The recommended rate (kg/ ha) for Burundi was 15 – 30 for N, 50 – 60 for P_2O_5 and 30 for K_2O, with 2 to 5 tones organic manure (Ruraduma, 2002). In Uganda, Wortmann (1998) recommended applying a small amount of nitrogen at planting time and the major part of nitrogen fertilizer at the second weeding time, to favor bean productivity and nitrogen fixation. In on-farm trials with the objective of developing appropriate fertilization practice on snap bean, Kamanu et al., (2012) evaluated snap bean fertilizer application regimes in Mwea, central Kenya and concluded that the use of 92 kg N/ha and 110 kg P_20_5 (43 kg N/ha and 110 kg P_20_5/ ha both applied as diammonium phosphate and 49 kg N/ ha applied as calcium ammonium nitrate at 21 days after planting) produced the highest pod yield and was the most profitable regime for snap bean production in Mwea.

2.5 Effect of Minjingu phosphate rock on crop production

Phosphorous deficiency is widely reported as the most important bean production constraint in eastern, central and southern African countries (Wortmann et al., 1998). The low phosphorous availability to plants is explained by the nature of the soils that are highly weathered with low total phosphorus (P) and/or high P fixing capacity (Rao et al., 1999). One of the most sensible ways of replenishing soil fertility is the use of available natural resources, and phosphate rocks are one attractive alternative for replenishing phosphorus in soils that have been depleted of this nutrient. The success of phosphate rock applications in the main farming areas of East Africa has helped increased crop yields by large amounts (Van Straaten, 2002). Direct application of indigenous rock phosphates has been viewed as an attractive option for building soil P fertility because it potentially involves lower production costs and capital investments than production of water-soluble P fertilizers from indigenous rock phosphate sources (Rajan et al., 1996). There are many phosphate rocks (PR) deposits and occurrences in Sub-Saharan Africa (Van Straaten, 2002). The deposits of the PR are reported in many countries and exploited to some extent in Tanzania (Minjingu), Malawi (Tundulu), Zambia (Isoka), South Africa, DR Congo (Kanzi) and Burundi (Matongo). Minjingu rock phosphate fertilizer from northern Tanzania has a high phosphate content (12.8% total P, 3.03% neutral ammonium citrate soluble P) and has been found to be a cheap source of phosphate fertilizer (Karanja et al., 2004).

A number of studies have highlighted the suitability of Minjingu PR as a P source for crops in P-deficient soils (Buresh et al., 1997). For example, Bromfield et al., (1981) reported a relative agronomic effectiveness (RAE) of 75% for Minjingu PR in five seasons following application to maize in western Kenya. On acidic soils of Tonga in Rwanda, Nabahungu et al., (2007) studied the effects of MPR associated with limestone and green manures (*Tithonia* and *Tephrosia* biomass) on P uptake on maize yield. They found out that a combination of phosphate rock and green manure produced a yield advantage over the control, while application of phosphate rock alone had no effect. The recommendation was to combine organic resources with rock phosphate and lime which led to an increase in maize yields up to approximately 6 t / ha. Suwannarat et al.,

(1984) did a study on soybean and revealed that plots treated with rock phosphate recorded the highest grain yield. Use of minjingu rock phosphate has been demonstrated to have beneficial effects on snap bean in Tanzania but there are no reported studies on use of rock phosphate in snap bean in Kenya.

2.6 Effect of foliar feed application on snap bean production

Foliar fertilization is an agricultural practice of increasing importance and it is an environmentally friendly fertilization method, since the nutrients are directly delivered to the plant in limited amounts, thereby helping to reduce the environmental impact associated with soil fertilization (Kuepper, 2003; Lovatt, 1999). However, response to foliar feeds is often variable and not reproducible due to the existing lack of knowledge of many factors related to the penetration of the leaf-applied solution. According to Doring (1986), a combined soil and foliar application should be recommended to increase both plant productivity and yield quality. Foliar fertilizers usually penetrate the leaf cuticle or stomata and enter the cells facilitating easy and rapid utilization of nutrients.

Supplementary foliar fertilization during crop growth improves the mineral status of plants, delays nodule senescence and increases crop yield (Elayaraja, 2005; Latha, 2003). Manivannan et al., (2002) reported that application of foliar feed that contained NPK and chelated micronutrients recorded improved leaf area index, crop growth rate and production of beans. Application of nutrients as foliar feed at appropriate stages of growth becomes important for their utilization and better performance of the crop (Anandhakrishnaveni et al., 2004). Some snap bean farmers use foliar feed to invigorate the growth of their crops, but no studies have been conducted to determine the impact of this practice on snap bean productivity and profitability

2.7 Importance of water management in snap bean production

Water use in agricultural production is one of the most important environmental factors affecting plant growth and development (Mirzaei et al., 2005). Food production is the largest water user and is directly constrained by water scarcity (Yang et al., 2006). Lack of adequate water and its inconsistent distribution during growing season leads to water requirements of crops not being met adequately and exposure of plants to water stress (Abdzad Gohari, 2012). Bingru and Hongwen (2000) reported that supplying sufficient water to a plant during its growth and development is important for its physiological processes. Although water is scarce, options for utilizing it have been suggested. These options are: (i) increasing water productivity by reducing losses (ii) improving the use of rainfall and expanding rain-fed agriculture and (iii) pursuing virtual water conservation options (Allan, 1997; Hoekstra and Hung, 2005; Falkenmark, 2007).

In snap bean (*Phaselous vulgaris* L.) production, water management is important at all stages of plant development due to its influence on stand establishment, pod set and quality (Smesrud et al., 1997). Snap bean needs well distributed rainfall throughout the growing season (900-1200 mm per year) (KARI, 2007) to ensure vigorous growth. Proper irrigation is crucial for maintaining high snap bean yields and quality, but the crop cannot tolerate flooding. Snap bean grows best in soils with adequate organic matter which have high water holding capacity and do not need frequent irrigation (KARI, 2007). The optimum temperature range for growing snap bean is 20-25^{0}C, but can be grown in temperatures ranging between 14 and 32^{0}C. Extreme temperatures (above 30^0 C) result in poor flower development and poor pod set. However, snap bean mature faster in warmer areas. They are grown between 1000 and 2100 meters above sea level. Rainfed cultivation is possible in areas with well distributed, medium to high annual rainfall (900-1200 mm) but to maintain continuous production, especially during dry season, irrigation is essential. During the dry season, up to 50 mm of water per week is required. This could be applied through furrow or overhead irrigation (Infonet-Biovision, 2012).

Water management for snap bean in Kirinyaga is done through the use of untied ridges. The study was conducted to determine whether the use of tied ridges, tied ridge + mulch or untied ridges + mulching would perform better than the use of untied ridges or mulching only. Use of mulch in the production of snap bean is not practiced in the study area.

Snap bean crop water productivity can be enhanced by the adoption of an integrated water management approach. Integrated water management refers to agronomic practices that can adequately conserve soil moisture to meet the snap bean crop water requirements. To offset agricultural losses related to low and variable rainfall, moisture conservation practices should be adopted to conserve moisture in the soil thereby increasing growth, yield and quality of snap bean. The moisture conservation practices include mulches, tied ridges and untied ridges.

2.8 Effect of mulching on crop production

Mulch is a layer of material spread on the surface of the soil for a number of reasons; moisture conservation by reducing evaporation, minimization of weed growth (Islami and Farzamnia, 2009), protection of soil and plant roots from direct raindrop (Brady and Weil, 1999), improvement of plant establishment and development (Acquaah, 2004); stimulation of microbial activity; enhancement of oxygen availability to roots; moderation of soil temperatures; increases in soil porosity, water infiltration, nutrient availability and reduction of fertilizer leaching and soil compaction (Ekinci and Dursun, 2009; Arora et al., 2011).

The materials used in mulching differ; they can either be organic or inorganic. Organic mulches include leaves, hay, straws, sawdust and woodchips while inorganic mulches include rubber mulch, plastic mulch, rock and gravel mulch (Erhart and Hartl, 2003). To determine the material to use as mulch, a number of factors such as availability of the mulch, cost, appearance, effect on the soil-chemical properties, durability and decomposition rate are considered (Melilio et al., 1982). Application of mulch can either increase or decrease the amount of inorganic nitrogen present in the soil depending on the mulches' carbon to nitrogen ratio (Erhart and Hartl, 2003).

Straw mulch has a wide carbon to nitrogen ratio, light weight and neutral pH. It is biodegradable and possesses a good moisture retention capacity and weeds controlling properties and is, therefore, recommended as a mulching material. During straw mulch decomposition, the decaying matter is broken down and incorporated in the soil as particulate organic matter. This is followed by a release of nitrogen in form of soluble organic nitrogen. The soil micro-organisms could mineralize the dissolved organic nitrogen to ammonium which may be further oxidized to nitrate (Aerts and Chapin, 2000).

The two main important resources whose availability is affected by mulch are water and nitrogen (Mbagwu, 1991). Numerous studies show that application of mulch has benefits on water conservation. Pirboneh et al., (2012) concluded that the high volume of moisture stored in soil structure and reduction of evaporation was caused by mulching cultivated fields. Mchugh et al., (2007) concluded that the use of mulching reduces soil erosion and increases soil moisture content in the soil resulting to higher yields. Zhang et al., (2005) concluded that straw mulch reduced soil evaporation and increased plant water use efficiency. Other Studies have demonstrated that mulching leads to an improvement of plant establishment, development and yield performance (Agele, 2000; Acquaah, 2004). In arid and semiarid regions, about 40 to 70 percent of water loss by evaporation from the soil surface can be prevented by mulching (Jalota, 1993). Studies done by many investigators concluded that mulching increased nutrient availability and reduced fertilizer leaching and soil compaction, hence, increase in yield (Ekinci and Dursun, 2009; Arora et al., 2011). Other studies have either reported negative or no effects of mulches on water availability to the plant (Erhart and Hartl, 2003; Cook et al., 2006). Contradictory findings could be due to variability in the mulch application methods, amounts or mulching material used. Studies on the effect of mulch on snap bean growth, yield and quality are limited. This calls for studies to establish the effect of mulching on snap bean production and profitability in central Kenya where reliance on irrigation is very expensive.

2.9 Effect of ridging on crop production

Tied ridging, also called boxed ridging, is a form of micro basin technology which is an easy and cheap way of in situ water harvesting for small scale holder farmers (Jones and Stewart, 1990). It is a type of surface configuration whereby the ridges are “tied” to each other at regular intervals by cross ties, blocking the furrow and can be used when surface run-off is to be prevented (Friensen et al., 2009). The soil is ridged to a height of 20-30 cm and 10-20 cm high cross ties established at intervals of 2 m or more depending on the slope of the land, water infiltration rate and the expected rainfall intensity (Gusha, 2002; Brahane et al., 2006). The objective of the system is to collect local runoff and store it within the soil profile in the vicinity of the plant roots (Critchley et al., 1992). Intense rainfall before and after planting could result to runoffs from the field. Hence, micro basins reduce runoff and store the rainfall in the soil for use by the crop later in the season.

Tied ridges have been successfully used in Niger, Mali and Burkina Faso in West Africa to improve soil moisture conditions and physical properties with significant benefits for cotton, maize, cowpeas, millet and sorghum producers in the semi-arid areas (Friensen et al., 2009). In southern Africa, tied ridges are widely used in commercial farming situations as a means of controlling soil erosion (Critchley et al., 1992). Data from Kenya suggest that there are considerable yield advantages in using the ridging system. The data also show that, when used in combination with appropriate crops, ridges have demonstrated ability to reduce the risk of crop failure due to drought by concentrating the runoff (Critchley et al., 1992).

Both positive and negative effects of tied ridges on the crop productivity have been reported in different regions in Africa (Hulugalle, 1990; Vogel, 1993; Mesfin et al., 2009; Mesfin et al., 2010). The positive effects of tied ridges include: increased food security in areas with below normal rainfall and severe environmental degradation, reduced soil erosion and increased soil moisture content (Critchley et al., 1992) and land rehabilitation, reduction of soil erosion and soil conservation (Mchugh et al., 2007). The disadvantages of tied ridges include: higher labour than traditional tillage (Wiyo and Feyen, 1999; Mmbaga and Lyamchai, 2001; Mchugh et al., 2007), occasional high soil losses due to the level crop ridges being overtopped during heavy rainstorms and ineffectiveness on steep slopes (Critchley et al., 1992).

A study conducted by Kabanza (2007) showed that tied ridges had higher sorghum grain yields than the control plot. Araya et al., (2010) conducted a study and concluded that about 16-30% of the seasonal rainfall resulted in runoff when crops were grown without water conservation, whereas the in situ conservation practices resulted in significantly low runoff. The study also showed that tied ridging and mulching increased the soil water in the root zone by more than 13% when compared with flat beds. Further, the grain yield and rainwater use efficiency increased significantly with tied ridging during below average rainfall years. Gebrekidan et al., (2003) and Bayu et al., (2012) reported that sorghum growth and yield responded significantly to tied ridges. However, the magnitude of the sorghum yield response and the relative efficiency of the tied ridges varied with soil type, the total amount, distribution of rainfall during the cropping season and fertilization (Gebrekidan et al., 2003; Bayu et al., 2012). Based on these observations, Bayu et al., (2012) concluded that tied-ridging is not a solution in all areas where moisture deficiency is a problem. Karimvand (2013) and Mehrpooyan et al., (2010) reported that the use of ridges in cowpea had increased the number of grains per pod, pod weight and yield. Kaluli et al., (2005) showed that ridges preserved soil moisture. Studies done by Shuhuai Jiang et al., (2012) showed that ridges are able to improve soil moisture in bean crops, thereby exerting influence on the growth and development stages. Mulungu et al., (2006) reported that the use of ridges increased the number of pods per plant, pod length and yield per plant in common bean. Studies on the effect of tied and untied ridges on snap bean production are limited. Therefore, there is a need to conduct a study on the effect of ridging on snap bean growth, yield and quality in central Kenya.

CHAPTER THREE: EFFECT OF DIFFERENT NUTRIENT MANAGEMENT OPTIONS ON GROWTH, YIELD AND QUALITY OF SNAP BEAN (*Phaseolus vulgaris* L.) IN CENTRAL KENYA

3.1 Abstract

Snap bean (*Phaseolus vulgaris* L.) is a major vegetable produced in Kenya mainly for the export market. Low soil fertility is one of the factors hindering the realization of snap bean potential yields and high quality pods. Nutrient management options comprising combinations of organic and inorganic fertilizers offer an environmental friendly and cost effective option to improve snap bean production among smallholder farmers. The objective of this study was to evaluate different nutrient management regimes on growth, yield and quality of snap bean in Kirinyaga and Embu counties of Kenya. The following nutrient management regimes were evaluated: control (no fertilizer), farmyard manure (5 t /ha) + minjingu phosphate rock (30 kg P/ha), farmyard manure (5 t /ha) + diammonium phosphate (26.9 kg N/ha and 30 kg P/ha), farmyard manure (5 t/ha) + calcium ammonium nitrate (60 kg N/ha), diammonium phosphate (43.2 kg N/ha and 48.2 kg P/ha) + calcium ammonium nitrate (46.8 kg N/ha) top dressed at 21 days after emergence, farmer practice [diammonium phosphate (30 kg N/ha and 33.5 kg P/ha) + calcium ammonium nitrate (40 kg N/ha) top dressing (21 days after emergence)] and diammonium phosphate (43.2 kg N/ha and 48.2 kg P/ha) + calcium ammonium nitrate (46.8 kg N/ha) top dressed at 21 days after emergence + wuxal foliar feed containing 5% N, 20 % phosphate, 5 % potassium, 0.01% boron, 0.004% copper, 0.02% iron, 0.012% manganese, 0.001% molybdenum and 0.004% zinc at pre flowering. The treatments were laid out in a randomized complete block design and replicated three times. Data collected included plant emergence, plant vigor, number of days to 50% flowering, number of days to 50% pod formation, insect pest infestation, disease infestation, plant stand at first harvest, number of pods per plant, pod length, extra fine pod yield, fine pod yield and total marketable pod yield. Data were subjected to analysis of variance using GENSTAT discovery edition 14 and mean separation done using the least significant difference (LSD) test at p=0.05. Results showed that fertilizer application significantly reduced the number of days to 50% pod formation in Mwea. Snap bean plants achieved 50% flowering and 50% pod formation earlier in Mwea than in Embu by an average of four and five days, respectively . All the fertilizer treated plots significantly improved snap bean yield, yield components and quality compared to control plots. In both sites, diammonium phosphate (DAP) + calcium ammonium nitrate (CAN) + foliar feed and DAP + CAN increased snap bean plant vigor, number of pods per plant and extra fine, fine and marketable pod yields compared to the farmer practice and the other treatments. However, there were no significant differences between DAP (43.2 kg N/ha and 48.2 kg P/ha) + CAN (46.8 kg N/ha) + foliar feed and DAP (43.2 kg N/ha and 48.2 kg P/ha) + CAN (46.8 kg N/ha) in growth and yield attributes. The DAP + CAN + foliar feed treatment had a higher net profit than the farmer practice and all the other treatments. Snap bean plants grown at Embu were more vigorous, produced higher number of pods per plant, longer average pod length and higher marketable pod yield than snap bean grown in Mwea.

The current study has demonstrated the potential of using foliar feed in combination with DAP (43.2 kg N/ha and 48.2 kg P/ha) and CAN (46.8 kg N/ha) to enhance snap bean productivity and net profit. Further trials are required to establish the optimal foliar feed rates under farmers' field conditions.

3.2 Introduction

Snap bean (*Phaseolus vulgaris* L.) is an annual warm season crop grown for its immature seed pod (Infonet-Biovision, 2012). It is an important source of calories, proteins, dietary fibers, minerals and vitamins for millions of people in both developing and developed countries (Ndegwa et al., 2006). In Kenya, the total snap bean production in 2013 was valued at Kshs 1.8 billion and the area under its production was 4,500 hectares. Kirinyaga, Murang'a, Taita taveta, Meru and Machakos were among the leading counties in snap bean production and accounted for 39.6, 12.3, 9.2, 8.7 and 6.3% of the total production respectively (HCDA, 2014). Snap bean productivity in Kenya is constrained by low soil fertility, diseases, insect pests and drought among other factors.

Declining soil fertility is a major constraint in enhancing bean productivity in eastern Africa (Lunze et al., 2007). The major edaphic constraints include low soil nitrogen, phosphorus, soil acidity and toxic levels of aluminium and manganese (Lunze et al., 2007). According to the atlas of common bean production in Africa (Wortmann et al., 1998), phosphorous is deficient in 65 to 80% of soils and nitrogen in 60% of soils in bean production areas of eastern and southern Africa, while about 45 to 50% of soils are acidic with a pH less than 5.2 and containing high levels of either Aluminium or Manganese. Estimated bean production losses due to edaphic stresses in eastern, central and southern Africa are about 1,128 million tons per year. Wortmann et al., (1998), estimated that bean yield losses due to nitrogen and phosphorous deficiencies were 389,900 and 355,900 t/ ha respectively. Soil tests carried out in Mwea and Embu snap bean growing sites indicated deficient levels of nitrogen and zinc (Kamanu, 2012).

Snap bean productivity may be enhanced using an integrated nutrient management approach. Integrated nutrient management is the maintenance of soil fertility and nutrient supply to plants at optimum levels to sustain required productivity through optimizing the benefits arising from the use of all possible sources of inorganic and organic components of nutrient supply (FAO, 1993). It involves incorporation of chemical fertilizers, organic manure and crop residues which should be well suited with the local farming system for them to be widely accepted (FAO, 1993). The use of organic matter is a traditional practice characterized by use of low cost, eco-friendly inputs which have tremendous potential for supply of nutrients and thus reduce dependence on chemical fertilizers. Compost and farmyard manure are the most common inputs used to improve soil fertility by small scale farmers (Kankwatsa et al., 2008).

Mineral fertilizer application is essential for growth, development and productivity of snap bean plants. Nitrogen fertilizer plays a significant role in increasing snap bean growth, pod yield and quality (Naderi et al., 2008; Asmaa et al., 2010). Abdel-Mawgoud et al., (2005) reported that increasing N, P and K fertilizer levels increased the green pod yield and quality of beans. Phosphorous deficiency is widely reported as the most important bean production constraint in eastern, central and southern African countries (Wortmann et al., 1998). One effective way of replenishing soil fertility is the use of available natural resources, and phosphate rocks are one attractive alternative for replenishing phosphorus in soils that have been depleted of this nutrient. The success of phosphate rock applications in the main farming areas of East Africa has helped increased crop yields by large amounts (Van Straaten, 2002). Studies on soybean showed that plots treated with phosphate rock significantly increased soybean grain yield (Suwannarat et al., 1984; Barbagelata et al., 2002). Application of foliar feed that contains N, P, K and chelated micronutrients has been demonstrated to increase productivity of beans (Manivannan et al., 2002)

Farmers in Mwea and Embu use varying fertilizer application regimes in the production of snap bean but their effect on the productivity and profitability of this crop has not been established. A study was therefore conducted to determine the effect of different nutrient management options on growth, yield, quality and profitability of snap bean in central Kenya.

3.3 Materials and methods

3.3.1 Experimental sites

On farm snap bean field trials were conducted in two sites in central Kenya; namely, Kimbimbi area of Mwea east division in Kirinyaga South district and Kawanjara area of Runyenjes division in Embu East district. Planting was done on 20th June 2013 and 6th July 2013 respectively. Furrow irrigation and sprinkler irrigation were used in Kirinyaga South district and Embu East district trials, respectively, to supplement uneven rainfall.

Kimbimbi site is situated at an elevation of 1214 m above sea level and geographically located on 0^{o}36’21.66” S and 37^{o}22’01.24”E. It is a warm lowland area with minimum and maximum temperatures of 17^{o} C and 26^{o} C, respectively, and an average annual rainfall of 950 mm p.a. The rainfall pattern is bimodal with the long rains occurring in April to May and the short rains in October to December. Relative humidity varies from 52 to 67%. The experimental site is located in lower midland zone 4 (LM4), a semiarid area with soils classified as Nitisols which have a good water holding capacity. Kawanjara site is in the upper midland 2 (UM2) agro-ecological zone and geographically located on 0^{o}32’21.768”S and 37^{o}27’ 22.1034”E. It experiences a temperature range between 12° C and 27° C, with an average annual rainfall of 1495 mm. The soils in the district are developed on parent materials derived from Mount Kenya which have humid top soils of moderate to high fertility (mainly Nitisols) which are rich in organic matter.

Analysis of soil and manure was done at the beginning of the trials at National Agricultural Research Laboratories (NARL). Soil samples were collected at a depth of 0-30 cm and thoroughly mixed to get a composite sample. The soils were analyzed for pH, total N, total organic carbon, macronutrients and micronutrients in both sites (Appendix 1). Farmyard manure used for planting was also analyzed for macronutrients and micronutrients (Appendix 2). The results showed that in Mwea the soil pH was 4.85, with low levels of nitrogen, phosphorous and zinc while in Embu soil pH was 5.85, with adequate levels of nitrogen, phosphorous and zinc. The average temperatures and rainfall during the study period (June to October, 2013) were recorded in both sites (Appendices 3 and 4).

3.3.2 Experimental design, treatments and crop husbandry practices

The treatments comprised:

1. Farmyard manure (5 t/ha) at planting + Mijingu phosphate rock (30 kg P/ha);
2. Farmyard manure (5 t/ha) at planting + diammonium phosphate (26.9 kg N/ha and 30 kg P/ha);
3. Farmyard manure (5 t/ha) at planting + calcium ammonium nitrate (60 kg N/ha) which was split into 30 kg N/ha at planting + 30 kg N/ha top dress at 21 days after emergence;
4. Diammonium phosphate + calcium ammonium nitrate: 43.2 kg N/ha and 48.2 kg P/ha as diammonium phosphate at planting and 46.8 kg N/ha top dress as calcium ammonium nitrate at 21 days after emergence;
5. Farmer practice [Diammonium phosphate (30 kg N/ha and 33.5 kg P/ha) + calcium ammonium nitrate (40 kg N/ha) top dressing at 21 days after emergence];

6. Diammonium phosphate + calcium ammonium nitrate: 43.2 kg N/ha and 48.2 kg P/ha as diammonium phosphate at planting and 46.8 kg N/ha top dress as calcium ammonium nitrate at 21 days after emergence + wuxal foliar feed (pre-flowering);

7. Control (negative)-no fertilizer was applied

The fertilizer application regimes used were based on previous studies supported by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) in Kenya, Tanzania, Uganda and Rwanda. Wuxal foliar feed was sprayed once at pre-flowering stage (30 days after planting) at the rate of 4 liters/ha. Wuxal foliar feed is a NPK rich fertilizer solution which contains 5% N, 20 % P, 5 % K, 0.01% boron, 0.004% copper, 0.02% iron, 0.012% manganese, 0.001% molybdenum and 0.004% zinc.

The treatments were laid out in a randomized complete block design and replicated three times. The experimental plots measured 5 m by 4 m with a distance of 1 m and 1.5 m between plots and blocks, respectively. Snap bean variety Serengeti was used in the trial. Planting distance was 50 cm between rows and 10 cm within the rows. Well decomposed and dried farmyard manure was mixed in the furrows after which snap bean seeds were planted.

The land was cleared and ploughed in the dry season to avoid large clogs and harrowed to ensure a fine tilth. Snap bean variety used was Serengeti, which was seed dressed with Moncerene® (active ingredients Imidacloprid, Thiram and Pencycuron) at the rate of 8 ml/kg seed to manage bean fly. Diseases and pests were managed by regular scouting and then spraying whenever pest populations justified control. Pesticides Fastac® (active ingredient Alphacypermetrin) was applied at the rate of 5 ml / 20 litres of water to control aphids, leafminers, whiteflies and thrips. For control of bacterial diseases, rust, leaf spots, blights and mildews, Ortiva® (active ingredient

Azoxystrobin) and Mancozeb® (active ingredient Mancozeb) were sprayed at the rate of 10 ml/ 20 litres of water and 50 g/ 20 litres of water respectively. Hand weeding was done regularly to keep the plots weed free. Supplementation of rainfall was done through furrow irrigation at Kimbimbi, Kirinyaga south district and sprinkler irrigation at Kawanjara, Embu east district. Birds were managed by the use of scare crows and manual chasing.

3.3.3 Data collection

The data collected included: percentage crop emergence, plant stand at first harvest, number of days to 50% flowering, number of days to 50% pod formation, disease and insect pest infestation scores, yield (extra fine, fine and rejects) and yield components (number of pods per plant and pod length).

Plant emergence was assessed at one, two and three weeks after planting by counting all the snap bean plants that had emerged in each plot. Days to 50% flowering and 50% podding were recorded by counting the number of days when 50% of the plants in a plot had the first open flower and first formed pod, respectively. The plant stand was determined at first harvest by counting all the snap bean plants in each plot. The severity of infestation by diseases like rust, anthracnose and angular leaf spot and severity of infestation by insect pests like whiteflies, aphids and mites was assessed using the CIAT scale (Schoonhoven and Corrales, 2010) where: 1, 2, 3 signified the absence of symptoms (resistance); 4, 5, 6 signified intermediate attack of diseases or insect pest; and 7, 8, 9 signified susceptibility of the snap bean to diseases or insect pests. Plant vigor was measured using the following scale: 1, 2, 3 high vigor; 4, 5, 6 intermediate vigor and 7, 8, 9 poor vigor.

During harvesting, three middle rows of snap bean plots covering 5 m^2 were sampled and pods graded into marketable (extra fine and fine) and unmarketable yield (rejects). Extra fine pods had a diameter of 0-6 mm, fine pods had a diameter of 6-8 mm and rejects had a diameter of 8-12 mm. All snap bean pods that were damaged, diseased or deformed were graded in the reject class. The graded snap bean pods were weighed using an electronic weighing balance and total number of pods recorded. The number of pods per plant was achieved by dividing the total pods produced by the snap bean plants in the three rows by the total number of snap bean plants in the three rows. Five pods per class were sampled and their pod lengths recorded.

3.3.4 Determination of the cost of the treatments

For each of the fertilizer application regimes, the cost of production and revenue accrued from the sale of total marketable pod yield were estimated. The cost of the fertilizers, farmyard manure, Serengeti seeds, pesticides, land hire, labour cost and irrigation for both Embu and Mwea sites were determined. The average price paid for extra fine and fine pod grades were ksh 55.00 and ksh 25.00 per kg of pods respectively. The prices of pesticides, seeds, labour and irrigation used in the calculation were the prevailing prices in Mwea and Embu during the four month period (June to October 2013).

The total yield of extra fine pods and total yield of fine pods in each fertilizer application regime was multiplied by the respective market class price/ kg. The total revenue in each fertilizer application regime was determined by adding the revenue of the two market classes as indicated below:

Revenue (Ksh/ha) = (yield of extra fine (kg) * price /kg) + (yield of fine (kg) * price/ kg).

The total revenue for the entire picking period was determined by adding the revenue from each harvest multiplied by the number of harvests.

Net profit was achieved by subtracting the total cost from the revenue (Kamanu et al., 2012) as indicated below:

Net profit = Revenue – total cost.

3.3.5 Data Analysis

The data collected were subjected to analysis of variance (ANOVA) using GENSTAT discovery edition 14. Mean separation was done using the least significant difference (LSD) test at $p=0.05$.

3.4 Results

3.4.1 Effect of fertilizer application regimes on the number of days to 50% flowering and 50% podding in snap bean

Fertilizer application regime had no effect on the number of days to 50% flowering. Fifty percent flowering was achieved ealier in Mwea than in Embu by an average of four days (Table 3.1)

Table 3.1: Effect of fertilizer application regimes on the number of days to 50% flowering in snap bean

Treatment	Mwea	Embu
Farmyard manure (5 t/ha) + MPR (30 kg P/ha)	39.0 a	43.33 a
Farmyard manure (5 t/ha) + DAP (26.9 kg N/ha and 30 kg P/ha)	39.0 a	43.00 a
Farmyard manure (5 t/ha) + CAN (60 kg N/ha)	39.0 a	43.33 a
DAP (43.2 kg N/ha and 48.2 kg P/ha) + CAN (46.8 kg N/ha)	39.0 a	43.00 a
FP [DAP (30 kg N/ha and 33.5 kg P/ha) + CAN (40 kg N/ha)	39.0 a	43.00 a
DAP (43.2 kg N/ha+ 48.2 kg P/ha) + CAN (46.8 kg N/ha) + foliar	39.0 a	43.33 a
Control (no fertilizer)	39.0 a	43.33 a
P value	-	0.47
LSD $_{p=0.05}$	-	NS
CV %	-	0.8

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05. FP=farmer practice; NS=not significant; CV=coefficient of variation; MPR=minjingu phosphate rock; DAP=diammonium phosphate; CAN=calcium ammonium nitrate; DAE= days after emergence

In Mwea, fertilizer application regime had a significant effect on the number of days to achieve 50% pod formation (Table 3.2). Plants in the control plots took significantly longer time to achieve 50% podding than all the other treatments. However, fertilizer application regimes had no effect on time to pod formation in Embu. Snap bean plants formed pods at least five days earlier in Mwea than in Embu.

Table 3.2: Effect of fertilizer application regimes on the number of days to 50% podding in snap bean

Treatment	Mwea	Embu
Farmyard manure (5 t/ha) + MPR (30 kg P/ha)	43.33 a	48.33 a
Farmyard manure (5 t/ha) + DAP (26.9 kg N/ha and 30 kg P/ha)	43.00 a	48.33 a
Farmyard manure (5 t/ha) + CAN (60 kg N/ha)	43.00 a	48.33 a
DAP (43.2 kg N/ha and 48.2 kg P/ha) + CAN (46.8 kg N/ha)	43.00 a	48.67 a
FP [DAP (30 kg N/ha and 33.5 kg P/ha) + CAN (40 kg N/ha)]	43.00 a	49.00 a
DAP (43.2 kg N/ha and 48.2 kg P/ha) +CAN (46.8 kg/ha) + foliar.	43.00 a	49.00 a
Control (no fertilizer)	44.00 b	48.33 a
P value	<.001	0.27
LSD $_{p=0.05}$	0.39	NS
CV %	0.2	0.5

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05; FP=farmer practice; NS=not significant; CV=coefficient of variation; MPR=minjingu phosphate rock; DAP=diammonium phosphate; CAN=calcium ammonium nitrate; DAE=days after emergence

3.4.2 Effect of fertilizer application regimes on insect pests and diseases in snap bean

Whiteflies, aphids and spider mites were detected in the snap bean crops in both sites. Bean stem maggots were detected only in Mwea. There were no significant differences in pest infestation among the various fertilizer application regimes in both sites. The scores were 1 for spider mites and aphids, 2.00 to 2.33 for whiteflies and 1.33 to 2.00 for bean stem maggot (Table 3.3)

Table 3.3: Effect of fertilizer application regimes in pest infestation (scores) in snap bean

	White flies		Aphids		Mites		BSM
Treatment	Mwea	Embu	Mwea	Embu	Mwea	Embu	Mwea
Farmyard manure + MPR	2.00	2.00	1.00	1.00	1.00	1.00	2.00
Farmyard manure + DAP	2.00	2.00	1.00	1.00	1.00	1.00	1.33
Farmyard manure + CAN	2.00	2.00	1.00	1.00	1.00	1.00	1.67
DAP + CAN	2.00	2.00	1.00	1.00	1.00	1.00	1.33
Farmer practice	2.00	2.00	1.00	1.00	1.00	1.00	1.33
DAP +CAN + foliar feed	2.33	2.00	1.00	1.00	1.00	1.00	1.33
Control (no fertilizer)	2.00	2.00	1.00	1.00	1.00	1.00	1.67
P value	-	-	-	-	-	-	0.25
LSD $_{p=0.05}$	-	-	-	-	-	-	NS
CV %	-	-	-	-	-	-	44.3

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05. NS=not significant; CV=coefficient of variation; BSM=bean stem maggot; MPR=minjingu phosphate rock; DAP=diammonium phosphate; CAN=calcium ammonium nitrate; DAE=days after emergence. Scale used: 1, 2, 3 absence of symptoms (resistance); 4, 5, 6 intermediate attack of insect pests and 7, 8, 9 susceptibility to insect pests.

Rust, anthracnose and angular leaf spot were detected in snap bean crops in both sites (Table 3.4). Common bean bacterial blight (CBB) was however detected only in Embu. There were no significant differences in disease severity among the different fertilizer application regimes. The average disease severity scores were 1.00 in rust and anthracnose, 1.00 to 2.00 in angular leaf spot and 2.33 to 3.33 in common bacterial blight (Table 3.4).

Table 3.4: Effect of fertilizer application regimes on disease infestation (scores) in snap bean

	Rust		Anthracnose		Angular leafspot		CBB
Treatment	Mwea	Embu	Mwea	Embu	Mwea	Embu	Embu
Farmyard manure + MPR	1.00	1.00	1.00	1.00	1.33	1.67	3.33
Farmyard manure + DAP	1.00	1.00	1.00	1.00	1.33	1.67	2.67
Farmyard manure + CAN	1.00	1.00	1.00	1.00	1.33	1.67	2.33
DAP + CAN	1.00	1.00	1.00	1.00	1.33	1.67	2.67
Farmer practice	1.00	1.00	1.00	1.00	1.33	2.00	3.00
DAP + CAN + foliar feed	1.00	1.00	1.00	1.00	1.00	1.67	3.00
Control (no fertilizer)	1.00	1.00	1.00	1.00	1.33	2.00	2.67
P value	-	-	-	-	0.47	0.47	0.66
LSD $_{p=0.05}$	-	-	-	-	NS	NS	NS
CV %	-	-	-	-	38.5	23.4	12.8

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05. NS= not significant; CV=coefficient of variation; MPR=minjingu phosphate rock; DAP=diammonium phosphate; CAN=calcium ammonium nitrate; DAE=days after emergence; CBB=Common bean bacterial blight. Scale used: 1, 2, 3 absence of symptoms (resistance); 4, 5, 6 intermediate attack of diseases and 7, 8, 9 susceptibility to diseases.

3.4.3 Effect of fertilizer application regimes on plant vigor at flowering and podding stages in snap bean

Fertilizer application regimes had significant effects on snap bean plant vigor in both Mwea and Embu sites (Table 3.5). In Mwea, plots with DAP + CAN, DAP + CAN + foliar feed and farmer practice produced more vigorous snap bean plants than plots with FYM + DAP, FYM + MPR and FYM + CAN. In Embu, plants in plots with FYM + DAP, farmer practice, DAP + CAN and DAP + CAN + foliar feed produced more vigorous plants than plots with FYM + CAN and FYM +MPR. In both sites, the control plot generally had less vigorous snap bean plants than most of the fertilizer treated plots.

Table 3.5: Effect of fertilizer application regimes on plant vigor (scores) at flowering and podding stages in snap bean

Treatment	Mwea	Embu
Farmyard manure (5 t/ha) + MPR (30 kg P/ha)	5.33 ab	5.33 bc
Farmyard manure (5 t/ha) + DAP (26.9 kg N/ha and 30 kg P/ha)	4.67 ab	2.67 a
Farmyard manure (5 t/ha) + CAN (60 kg N/ha)	5.33 ab	4.67 ab
DAP (43.2 kg N/ha and 48.2 kg N/ha) + CAN (46.8 kg N/ha)	3.67 a	3.00 a
FP [DAP (30 kg N/ha and 33.5 kg P/ha) + CAN (40 kg N/ha)]	4.00 a	2.67 a
DAP (43.2 kg N/ha and 48.2 kg P/ha) +CAN (46.8 kg/ha) + foliar	3.67 a	2.67 a
Control (no fertilizer)	7.00 b	7.00 c
P value	0.022	0.003
LSD $_{p=0.05}$	1.58	2.03
CV %	18.4	12.9

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05. FP=farmer practice; CV=coefficient of variation; MPR=mining phosphate rock; DAP=ammonium phosphate; CAN=calcium ammonium nitrate; DAE=days after emergence. Scale used: 1, 2, 3 high vigor; 4, 5, 6 intermediate vigor and 7, 8, 9 poor vigor

3.4.4 Effect of fertilizer application regimes on the number of pods per plant in snap bean

There were significant differences (p= 0.05) in the number of snap bean pods per plant produced in the different fertilizer application regimes in both Mwea and Embu sites (Table 3.6). In Mwea, DAP + CAN + foliar feed produced significantly higher number of pods per plant than other treatments. In Embu, DAP + CAN + foliar feed and DAP + CAN produced significantly higher number of pods per plant than FYM + DAP, FYM + CAN, farmer practice and FYM + MPR. The control plots produced significantly a lower number of pods per plant than most fertilized plots in both Mwea and Embu

Table 3.6: Effect of fertilizer application regimes on the number of pods per plant in snap bean

Treatment	Mwea	Embu
Farmyard manure (5 t/ha) + MPR (30 kg P/ha)	15.08 c	15.35 bc
Farmyard manure (5 t/ha) + DAP (26.9 kg N/ha and 30 kg P/ha)	16.58 c	21.76 b
Farmyard manure (5 t/ha) + CAN (60 kg N/ha)	16.88 c	19.84 b
DAP (43.2 kg N/ha and 48.2 kg P/ha) + CAN (46.8 kg N/ha)	22.35 ab	28.63 a
FP[DAP (30 kg N/ha and 33.5 kg P/ha) + CAN (40 kg N/ha)]	16.79 bc	19.53 b
DAP (43.2 kg N/ha and 48.2 kg P/ha) + CAN (46.8 kg/ha) + foliar	23.11 a	31.46 a
Control (no fertilizer)	9.62 d	9.98 c
P value	0.002	<.001
LSD $_{p=0.05}$	5.36	6.78
CV %	23.9	4.8

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05. FP=farmer practice CV=coefficient of variation; MPR=mining phosphate rock; DAP=ammonium phosphate; CAN=calcium ammonium nitrate; DAE=days after emergence

3.4.5 Effect of fertilizer application regimes on extra fine, fine, reject and average pod lengths in snap bean

There were significant differences in the lengths of extra fine snap bean pods produced among the different fertilizer application regimes both in Mwea and Embu sites (Table 3.7). In Mwea, plots with DAP + CAN produced longer extra fine snap bean pods than plots with FYM + MPR and control plots. Control plots produced shorter extra fine snap bean pods than the other treatments except FYM + MPR, FYM + CAN and farmer practice. In Embu, DAP + CAN, DAP + CAN + foliar feed and farmer practice plots produced longer extra fine snap bean pods than the control and FYM + MPR plots.

Table 3.7: Effect of fertilizer application regimes on extra fine pod length (cm) in snap bean

Treatment	Mwea	Embu
Farmyard manure (5 t/ha) + MPR (30 kg P/ha)	12.89 bc	12.90 bc
Farmyard manure (5 t/ha) + DAP (26.9 kg N/ha and 30 kg P/ha)	13.23 ab	13.38 ab
Farmyard manure (5 t/ha) + CAN (60 kg N/ha)	13.02 abc	13.46 ab
DAP (43.2 kg N/ha and 48.2 kg N/ha) + CAN (46.8 kg N/ha)	13.49 a	13.81 a
FP [DAP (30 kg N/ha and 33.5 kg P/ha) + CAN (40 kg N/ha)]	12.99abc	13.80 a
DAP (43.2 kg N/ha and 48.2 kg P/ha) +CAN (46.8 kg/ha) + foliar	13.44ab	13.99 a
Control (no fertilizer)	12.62c	12.44 c
P value	0.05	<.001
LSD $_{p=0.05}$	0.58	0.75
CV %	2.2	0.3

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05. FP=farmer practice; CV=coefficient of variation; MPR=mining phosphate rock; DAP=ammonium phosphate; CAN=calcium ammonium nitrate; DAE=days after emergence

There were significant differences in the lengths of fine snap bean pods produced among the different fertilizer application regimes in both Mwea and Embu (Table 3.8). In Mwea, DAP + CAN, DAP + CAN + foliar feed and FYM + DAP produced longer fine snap bean pods than the control, FYM + MPR and FYM + CAN treatments. In Embu, DAP + CAN + foliar feed produced longer fine snap bean pods than the FYM + MPR treatment. All the treatments except FYM + MPR had longer fine snap bean pods than the control.

Table 3.8: Effect of fertilizer application regimes on fine pod length (cm) in snap bean

Treatment	Mwea	Embu
Farmyard manure (5 t/ha) + MPR (30 kg P/ha)	14.26 b	14.69 bc
Farmyard manure (5 t/ha) + DAP (26.9 kg N/ha and 30 kg P/ha)	15.16 a	15.49 ab
Farmyard manure (5 t/ha) + CAN (60 kg N/ha)	14.49 b	15.47 ab
DAP (43.2 kg N/ha and 48.2 kg N/ha) + CAN (46.8 kg N/ha)	15.32 a	15.41 ab
FP [DAP (30 kg N/ha and 33.5 kg P/ha) + CAN (40 kg N/ha)]	14.76 ab	15.52 ab
DAP (43.2 kg N/ha and 48.2 kg P/ha) +CAN (46.8 kg/ha) + foliar	15.22 a	15.82 a
Control (no fertilizer)	14.45 b	14.02 c
P value	0.002	0.003
LSD $_{p=0.05}$	0.62	0.90
CV %	2.6	0.9

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05. FP=farmer practice; CV=coefficient of variation; MPR=mining phosphate rock; DAP=ammonium phosphate; CAN=calcium ammonium nitrate; DAE=days after emergence

There were significant differences in the average snap bean pod length among the various fertilizer application regimes in both Mwea and Embu sites (Table 3.9). In Mwea, all the treatments except FYM + MPR produced longer average snap bean pods than the control while FYM + MPR and control plots produced shorter snap bean pods than other treatments in Embu. No differences in pod length were noted between control and FYM + MPR treatments.

Table 3.9: Effect of fertilizer application regimes on average pod length (cm) in snap bean

Treatment	Mwea	Embu
Farmyard manure (5 t/ha) + MPR (30 kg P/ha)	13.54 ab	13.55 b
Farmyard manure (5 t/ha) + DAP (26.9 kg N/ha and 30 kg P/ha)	14.03 a	14.28 a
Farmyard manure (5 t/ha) + CAN (60 kg N/ha)	13.75a	14.63 a
DAP (43.2 kg N/ha and 48.2 kg N/ha) + CAN (46.8 kg N/ha)	14.32a	14.81 a
FP [DAP (30 kg N/ha and 33.5 kg P/ha) + CAN (40 kg N/ha)]	13.98a	14.77 a
DAP (43.2 kg N/ha and 48.2 kg P/ha) +CAN (46.8 kg/ha) + foliar	14.15a	14.88 a
Control (no fertilizer)	13.00b	13.29 b
P value	0.005	<.001
LSD $_{p=0.05}$	0.69	0.68
CV %	2.6	0.9

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05. FP=farmer practice; CV=coefficient of variation; MPR=mining phosphate rock; DAP=ammonium phosphate; CAN=calcium ammonium nitrate; DAE=days after emergence

3.4.6 Effect of fertilizer application regimes on extra fine, fine, total marketable and reject pod yields

There were significant differences (p=0.05) in the yield of extra fine pods produced under the different fertilizer application regimes in both Mwea and Embu sites (Table 3.10). In Mwea, DAP + CAN and DAP + CAN + foliar feed plots produced significantly higher yields of extra fine pods than FYM + DAP, FYM + CAN, FYM + MPR and the control. DAP + CAN + foliar feed outyielded FYM + DAP and FYM + CAN by 65.3 and 68.8% respectively. In Embu, DAP + CAN and DAP + CAN + foliar feed produced higher yields of extra fine pods than the other treatments. For example, DAP + CAN treatments out-performed FYM + MPR, FYM + DAP, FYM + CAN and farmer practice by 86.1, 96.0,109.9 and 66.8% respectively.

Table 3.10: Effect of fertilizer application regimes on extra fine pod yield production (kg/ha) in snap bean

Treatment	Mwea	Embu
Farmyard manure (5 t/ha) + MPR (30 kg P/ha)	2199 bc	1400 b
Farmyard manure (5 t/ha) + DAP (26.9 kg N/ha and 30 kg P/ha)	2747 b	1329 bc
Farmyard manure (5 t/ha) + CAN (60 kg N/ha)	2690 bc	1241 bc
DAP (43.2 kg N/ha and 48.2 kg N/ha) + CAN (46.8 kg N/ha)	4425 a	2605 a
FP [DAP (30 kg N/ha and 33.5 kg P/ha) + CAN (40 kg N/ha)]	3511 ab	1562 b
DAP (43.2 kg N/ha and 48.2 kg P/ha) +CAN (46.8 kg/ha) + foliar	4542 a	2479 a
Control (no fertilizer)	1277 c	603 c
P value	0.004	<.001
LSD $_{p=0.05}$	1419.0	752.0
CV %	24.9	13.0

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05. FP=farmer practice; CV=coefficient of variation; MPR=mining phosphate rock; DAP=ammonium phosphate; CAN=calcium ammonium nitrate; DAE=days after emergence

There were significant differences in fine pod yield among the fertilizer application regimes in both Mwea and Embu sites (Table 3.11). In both sites, DAP + CAN + foliar feed produced higher fine pod yield than the other treatments except DAP + CAN. In Mwea, control treatment had the lowest fine pod yield. No significant yield differences were noted among FYM + MPR, FYM + DAP, FYM + CAN and farmer practice treatments. The DAP + CAN + foliar feed treatment out yielded FYM + MPR, FYM + DAP, FYM + CAN and farmer practice treatments by 136.1, 69.8, 89.7 and 95.1 % respectively.

In Embu, control and FYM + MPR plots had significantly the lowest fine snap bean pod yield. Plots with DAP + CAN + foliar feed out yielded plots with FYM + MPR, FYM + DAP, FYM + CAN and farmer practice by 142.2, 39.2, 55.1 and 46.3% respectively. Embu site produced 141.6% more fine pod yield than Mwea site.

Table 3.11: Effect of fertilizer application regimes on fine pod yield production (kg/ha) in snap bean

Treatment	Mwea	Embu
Farmyard manure (5 t/ha) + MPR (30 kg P/ha)	3013 b	6489 d
Farmyard manure (5 t/ha) + DAP (26.9 kg N/ha and 30 kg P/ha)	4190 b	11288 bc
Farmyard manure (5 t/ha) + CAN (60 kg N/ha)	3749 b	10134 c
DAP (43.2 kg N/ha and 48.2 kg N/ha) + CAN (46.8 kg N/ha)	6209 a	14078 ab
FP [DAP (30 kg N/ha and 33.5 kg P/ha) + CAN (40 kg N/ha)]	3645 b	10746 bc
DAP (43.2 kg N/ha and 48.2 kg P/ha) +CAN (46.8 kg/ha) + foliar	7113 a	15718 a
Control (no fertilizer)	1802 c	3363 d
P value	<.001	<.001
LSD $_{p=0.05}$	1136	3390
CV %	2.4	13.9

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05. FP=farmer practice; CV=coefficient of variation; MPR=mining phosphate rock; DAP=ammonium phosphate; CAN=calcium ammonium nitrate; DAE=days after emergence

There were no significant differences in the reject pod yield produced among the fertilizer application regimes. However, there were significant differences in the reject pod yield produced among the different fertilizer application regimes in Embu site (Table 3.12). The DAP + CAN and DAP + CAN + foliar feed treatments produced higher rejects pod yield than the other treatments except farmer practice.

Table 3.12: Effect of fertilizer application regimes on reject pod yield production (kg/ha) in snap bean

Treatment	Mwea	Embu
Farmyard manure (5 t/ha) + MPR (30 kg P/ha)	758 a	1507 c
Farmyard manure (5 t/ha) + DAP (26.9 kg N/ha and 30 kg P/ha)	1172 a	1721 bc
Farmyard manure (5 t/ha) + CAN (60 kg N/ha)	893 a	1856 bc
DAP (43.2 kg N/ha and 48.2 kg N/ha) + CAN (46.8 kg N/ha)	1293 a	2594 a
FP [DAP (30 kg N/ha and 33.5 kg P/ha) + CAN (40 kg N/ha)]	1129 a	2159 ab
DAP (43.2 kg N/ha and 48.2 kg P/ha) +CAN (46.8 kg/ha) + foliar	1313 a	2474 a
Control (no fertilizer)	777 a	1524 c
P value	0.24	0.001
LSD $_{p=0.05}$	NS	491.0
CV %	11.9	7.9

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05. FP=farmer practice; NS=not significant; CV=coefficient of variation; MPR=mining phosphate rock; DAP=ammonium phosphate; CAN=calcium ammonium nitrate; DAE= days after emergence

In both Mwea and Embu sites, there were significant differences among the fertilizer application regimes in total marketable pod yield (Table 3.13). In both sites, plots with DAP + CAN and DAP + CAN + foliar feed had higher pod yields than all the other treatments. In Mwea, DAP + CAN + foliar feed treated plots out yielded FYM + MPR, FYM + DAP, FYM + CAN and farmer practice plots by 123.6, 68.0, 81.0 and 55.6% respectively. In Embu, DAP + CAN + foliar feed treated plots out yielded FYM + MPR, FYM +DAP, FYM + CAN and farmer practice plots by 130.7, 44.2, 60.0 and 47.8% respectively. Plants in the control plot had the lowest total marketable pod yield in both sites.

Table 3.13: Effect of fertilizer application regimes on total marketable pod yield production (kg/ha) in snap bean

Treatment	Mwea	Embu
Farmyard manure (5 t/ha) + MPR (30 kg P/ha)	5212 bc	7889 c
Farmyard manure (5 t/ha) + DAP (26.9 kg N/ha and 30 kg P/ha)	6937 b	12617 b
Farmyard manure (5 t/ha) + CAN (60 kg N/ha)	6439 b	11375 bc
DAP (43.2 kg N/ha and 48.2 kg N/ha) + CAN (46.8 kg N/ha)	10634 a	16683 a
FP [DAP (30 kg N/ha and 33.5 kg P/ha) + CAN (40 kg N/ha)]	7490 b	12308 b
DAP (43.2 kg N/ha and 48.2 kg P/ha) +CAN (46.8 kg/ha) + foliar	11655 a	18196 a
Control (no fertilizer)	3579 c	3966 d
P value	<.001	<.001
$LSD_{p=0.05}$	2678.0	3918.0
CV %	13.3	10.5

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05. FP=farmer practice; CV=coefficient of variation; MPR=mining phosphate rock; DAP=ammonium phosphate; CAN=calcium ammonium nitrate; DAE=days after emergence

3.4.7: Effect of fertilizer application regimes on profitability in snap bean production

The combined cost of land hire, irrigation, labour, seeds and pesticide per hectare was ksh 125, 800 in Mwea and ksh 126, 800 in Embu (Table 3.14). The cost of fertilizer per application regime ranged from ksh 0 (control) to ksh 34, 451.40 (Table 3.15, Appendix 5 and Appendix 6) while the total production cost of each fertilizer application regime varied from ksh 125, 800 to ksh 160, 251.40 in Mwea and ksh 126, 800 to ksh 161, 251.40 in Embu (Table 3.16, Appendix 5 and Appendix 6)

Table 3.14: Non- fertilizer production costs (ksh/ha)

Input	Production cost (Mwea)	Production cost (Embu)
Pesticides	5,700.00	5,700.00
Serengeti seeds	40,000.00	40,000.00
Irrigation	34,500.00	20,600.00
Labour costs	25,600.00	40,500.00
Land hire for 6 months	20,000.00	20,000.00
Total	125,800.00	126,800.00

Table 3.15: Cost of fertilizer per application regime (ksh/ha)

Treatment	Ksh/ha
Farmyard manure (5 t/ha) + MPR (30 kg P/ha)	28,720.00
Farmyard manure (5 t/ha) + DAP (26.9 kg N/ha and 30 kg P/ha)	28,620.00
Farmyard manure (5 t/ha) + CAN (60 kg N/ha)	29,376.00
DAP (43.2 kg N/ha and 48.2 kg N/ha) + CAN (46.8 kg N/ha)	29,251.40
FP [DAP (30 kg N/ha and 33.5 kg P/ha) + CAN (40 kg N/ha)]	21,925.80
DAP (43.2 kg N/ha and 48.2 kg P/ha) +CAN (46.8 kg/ha) + foliar	34,451.40
Control (no fertilizer)	0

Table 3.16: Total cost of each regime (ksh/ ha)

Treatment	Mwea	Embu
Farmyard manure (5 t/ha) + MPR (30 kg P/ha)	154,520.00	155,520.00
Farmyard manure (5 t/ha) + DAP (26.9 kg N/ha and 30 kg P/ha)	154,420.00	155,420.00
Farmyard manure (5 t/ha) + CAN (60 kg N/ha)	155,176.00	156,176.00
DAP (43.2 kg N/ha and 48.2 kg N/ha) + CAN (46.8 kg N/ha)	155,051.40	156,051.00
FP [DAP (30 kg N/ha and 33.5 kg P/ha) + CAN (40 kg N/ha)]	147,725.00	148,725.80
DAP (43.2 kg N/ha and 48.2 kg P/ha) +CAN (46.8 kg/ha) + foliar	160,251.40	161,251.40
Control (no fertilizer)	125,800.00	126,800.00

Net profit ranged from ksh -10,515/ ha (control) to ksh 267,384/ ha (DAP + CAN + foliar feed) in Mwea and ksh -9,560/ ha (control) to ksh 368,044/ ha (DAP + CAN + foliar feed) in Embu. In Mwea, farmer practice, DAP + CAN and DAP + CAN + foliar feed treatments had 11.3%, 98.6% and 118% higher net profit, respectively, than the average for all the treatments while FYM + MPR , FYM + CAN and FYM + DAP treated plots had 72.6%, 29.5% and 17.3% lower net profit than the average for all treatments, respectively (Table 3.17). In Embu, FYM + DAP, farmer practice, DAP + CAN and DAP + CAN + foliar feed treatments had 3.4%, 6.5%, 75.5% and 90.5% higher net profit, respectively, than the average for all the treatments while FYM + MPR and FYM + CAN treated plots had 56.7% and 14.4% lower net profit, respectively, than the average for all the treatments (Table 3.18). The DAP + CAN and DAP + CAN + foliar feed treatments had 78.5 and 95.9%, respectively, higher net profit than the farmer practice in Mwea. In Embu, the former two treatments had 64.8 and 78.8%, respectively, higher net profit than the farmer practice.

Table 3.17: Effect of fertilizer application regime on profit/ ha (ksh) in Mwea.

Treatment	Extra fine yield (kg/ ha)	Fine yield (kg/ ha)	Income (ksh/ ha)	Cost (ksh/ ha)	Profit (ksh/ ha)
FYM + MPR	2199	3013	120,945	154,520	33,575
FYM + DAP	2747	4190	255,835	154,420	101,415
FYM + CAN	2690	3749	241,675	155,176	86,499
DAP +CAN	4425	6209	398,600	155,051	243,549
Farmer practice	3511	3645	284,230	147,725	136,505
DAP+ CAN +Foliar feed	4542	7113	427,635	160,251	267,384
Control (no fertilizer)	1277	1802	115,285	125,800	-10,515
Mean	3056	4246	282,076	150,420	122,630

Income (Ksh/ha) = (Extra fine yield (kg) * price /kg) + (fine yield (kg) * price/ kg). Profit= Income–cost; FYM=farm yard manure; MPR=mining phosphate rock; DAP=ammonium phosphate; CAN=calcium ammonium nitrate. Extra fine price ksh. 55 per kg of pods, Fine price ksh. 25 per kg of pods.

Table 3.18: Effect of fertilizer application regime on profit/ ha (ksh) in Embu

Treatment	Extra fine yield (kg/ ha)	Fine yield (kg/ ha)	Income (ksh/ ha)	Cost (ksh/ ha)	Profit (ksh/ ha)
FYM +MPR	1400	6489	239,225	155,520	83,705
FYM + DAP	1329	11288	355,295	155,420	199,875
FYM + CAN	1241	10134	321,605	156,176	165,429
DAP +CAN	2605	14078	495,225	156,051	339,174
Farmer practice	1562	10746	354,560	148,726	205,834
DAP + CAN + foliar feed	2479	15718	529,295	161,251	368,044
Control (no fertilizer)	603	3363	117,240	126,800	-9,560
Mean	1603	10259	344,635	151,421	193,214

Income (Ksh/ha) = (Extra fine yield (kg) * price /kg) + (fine yield (kg) * price/ kg); Profit = Income- cost. FYM=farm yard manure; MPR=mining phosphate rock; DAP=ammonium phosphate; CAN=calcium ammonium nitrate. Extra fine price ksh. 55 per kg of pods, Fine price ksh. 25 per kg of pods.

3.5 Discussion

Application of fertilizer accelerated the time to 50% pod formation compared to the no-fertilizer control in Mwea. Tantawy et al., (2009) reported that phosphorus fertilizers contributed to early crop development and maturity. Snap bean plants reached 50% flowering and 50% pod formation earlier in Mwea than in Embu. This could be attributed to the higher mean monthly temperature of 33.3^{o}c in Mwea than mean monthly temperature of 28.8^{o}c in Embu (Appendix 3 and 4). Studies done by Baker and Reddy (2001) showed that temperature is one of the main environmental variables that determine time to flowering. Hadley et al., (1984) reported that increase in temperature accelerated development and maturity in most crops. The results of the current study also concur with the findings of Munyasa (2013) and Kabutbei (2014) who reported that an increase in temperature accelerated time to flowering and maturity in common bean genotypes.

The DAP + CAN + foliar feed, DAP + CAN and farmer practice treatments produced more vigorous snap bean plants than the no-fertilizer control treatment. Nitrogen is of vital importance for plant growth as it is a part of amino acids, proteins, enzymes and chlorophyll (Devlin and Witham, 1986). Asmaa et al., (2010) reported that vegetative growth parameters of snap bean were gradually and significantly increased by nitrogen fertilizer application. Kondracka et al., (2007) reported that phosphate deficiency reduced leaf growth, plant growth and rate of photosynthesis in beans.

The DAP + CAN + foliar feed and DAP + CAN treatments produced higher number of pods per plant than the farmer practice and other treatments. Yan et al., (1995) reported an increase in the number of pods per plant with increase in phosphorous levels while Mahmoud et al., (2010) reported an increase in the number of pods per plant and pod quality with increased levels of nitrogen. In this study, application of DAP + CAN + foliar feed did not significantly enhance the number of pods compared to DAP + CAN. Previous studies have demonstrated that macro and micronutrients applied on the foliage at critical stages of the crop were effectively absorbed and translocated to the developing pods, producing more number of pods and better filling in soybean (Jayabal et al., 1999). Stanley et al., (1963) reported that boron in foliar feed contributes to formation of high pod set. Potassium has a crucial role in the translocation and storage assimilates, hence, its application leads to formation of high pods (Marschner, 1995). The Wuxal foliar feed used is an NPK rich fertilizer solution that contains 5% N, 20% P, 5% K, 0.01% boron, 0.004% copper, 0.02% iron, 0.012% manganese, 0.001% molybdenum and 0.004% zinc.

The DAP + CAN + foliar feed and DAP + CAN treatments produced higher extra fine and total marketable pod yields than farmer practice and the other treatments. A number of studies demonstrated that increasing N and P fertilizers improved plant growth, yield and green pod quality of snap bean (Singer et al., 2000; Hafez et al., 2004; Abdel-Mawgoud et al., 2005; Souza et al., 2008 and El-Bassiony et al., 2010). Abdzad Gohari (2010) reported that nitrogen fertilization had a positive and significant effect on seed yield, seed weight, number of pods per plant and number of seeds per plant. Hamed (2003) reported a significant increases in bean yield with the use of phosphorus fertilizers. A study by Farkade et al., (2002) showed that increasing N: P fertilizer levels increased yield of snap bean. Similarly, Nanderi et al., (2008) showed an increase in snap bean crop yield with the use of nitrogen fertilizer.

Farmer practice had more snap bean pods per plant than FYM + MPR, FYM + DAP, FYM + CAN and control in Mwea. Slow release of nitrogen and other nutrients from farmyard manure during early growth could have attributed to the poor performance of the treatments with farmyard manure. Gichangi et al., (2007) noted that farmyard manure does not release nitrogen, phosphorous and potassium immediately after application. Hence, the need for integrating farmyard manure with immediate nitrogen, phosphorous and potassium releasing fertilization for proper and early growth of beans. The principle of integrated nutrient management would ensure higher yields obtained when manure is supplemented with N or with compound fertilizers. Other studies also indicate that the efficacy of FYM is improved by supplementation with inorganic fertilizers (Obaga et al., 2000; Onyango et al., 2000; Kute and Chirchir, 2000). However, in the current study, farmyard manure supplemented with either DAP or CAN did not perform as well as the fertilizer application regimes with higher rates of fast release inorganic fertilizers. This calls for further studies to establish the optimal combination of inorganic and organic fertilizers for snap bean production.

Snap bean plants grown in Embu out-performed snap bean grown in Mwea in all growth and yield attributes. Great variability in yield forming traits like number of pods per plant can be influenced by environmental factors (Nielsen and Nelson, 1998; Ferreira et al., 2000). Environmental conditions, mainly temperature and rainfall, greatly affect the growth, development and productivity of bean plants (Mouhouche et al., 1998; Ibarra-Perez et al., 1999). The difference between Mwea and Embu can probably be explained by the differences in the soil nutrients and the climatic conditions. From the soil analysis results (Appendix 1), soils in Embu contained adequate nitrogen, phosphorous and zinc levels but these were low in the soils in Mwea. The soil pH in Embu was medium acidic (pH 5.69) and lay between the ideal range in which snap bean plants are grown (pH 5.5-6.5), while in Mwea soil pH was strongly acidic (pH 4.85). In Embu, high mean monthly rainfall of 100.5 mm was received as compared to Mwea which received a mean monthly rainfall of 76.7 mm.

There were no significant differences between DAP (43.2 kg N/ha and 48.2 kg P/ha) + CAN (46.8 kg N/ha) + foliar feed and DAP (43.2 kg N/ha and 48.2 kg P/ha) + CAN (46.8 kg N/ha) treatments in growth and yield parameters. This may imply that foliar feed did not affect the growth and yield parameters or the dose applied was inadequate as it was applied only once at pre flowering. However, DAP + CAN + foliar feed had the highest net profit compared to DAP + CAN, farmer practice, FYM + DAP, FYM + CAN and FYM + MPR. Foliar application improved plant growth and production of green bean relative to FYM treated plots by supplying the plant with extra dose of necessary nutrients. Additional foliar application during the growth and development of crops can improve their nutrient balance, which leads to an increase in yield and quality (Kolota and Osinska, 2001; Dixon, 2003). Hence, planting snap beans with DAP (43.2 kg N/ha and 48.2 kg P/ha) + CAN (46.8 kg N/ha) + foliar feed may be recommended to farmers in Mwea and Embu. There is, however, need to optimize foliar feed application time and rates so as to enhance snap bean productivity.

3.6 Conclusion

From the results of this study, DAP (43.2 kg N/ha + 48.2 kg P/ha) + CAN (46.8 kg N/ha) + foliar feed and DAP (43.2 kg N/ha + 48.2 kg P/ha) + CAN (46.8 kg N/ha) produced vigorous snap bean with higher extra fine, fine and total marketable pod yields than other treatments. Use of DAP + CAN + foliar feed had significantly higher net profit than the other treatments. The current study has therefore demonstrated the potential of using foliar feed in combination with DAP (43.2 kg N/ha and 48.2 kg P/ha) and CAN (46.8 kg N/ha) to enhance snap bean productivity and net profit. Further trials are required to establish the optimal foliar feed rates under farmers' field conditions

CHAPTER FOUR: EFFECT OF MOISTURE CONSERVATION PRACTICES ON GROWTH, YIELD AND QUALITY OF SNAP BEAN (*Phaseolus vulgaris* L.) IN CENTRAL KENYA

4.1 Abstract

Snap bean or French bean is a strain of common bean (*Phaseolus vulgaris* L.) which is grown as a cash crop by large and small scale farmers in Kenya. Water use is one of the most important environmental factors affecting snap bean productivity hence conservation of the available water is critical. A study was conducted to evaluate the effect of moisture conservation practices on the growth and yield of snap bean plants in Mwea and Embu. The following moisture conservation practices were evaluated: control (no ridges + no mulch), tied ridges, untied ridges, mulch + no ridges, mulch + tied ridges and mulch + untied ridges. The treatments were laid out in a randomized complete block design and replicated three times. The data collected included plant emergence, plant vigor, number of days to 50% flowering, number of days to 50% pod formation, insect pest infestation, disease infestation, plant stand at first harvest, number of pods per plant, extra fine pod yield, fine pod yield and total marketable pod yield. Data were subjected to analysis of variance and mean separation was done using the least significant difference test at p=0.05. The results showed that tied and untied ridges with or without mulch accelerated the time to 50% pod formation of snap bean in Embu. Ridges (tied or untied) with or without mulch led to increases in number of pods per snap bean plant, extra fine pod yield, fine yield pod and total marketable pod yield. Ridging produced higher pod yield and yield parameters than no ridging. Mulching without ridging improved only the number of pods per plant and fine pod yield in Mwea. There were no significant differences between tied ridges + mulch and untied ridges + mulch in snap bean growth and yield attributes. Mulched plots with untied ridges had

significantly highest net profit compared to the other treatments. Hence, the use of mulch + untied ridges has the potential to increase snap bean productivity under farmers' fields in central Kenya.

4.2 Introduction

Snap bean (*Phaseolus vulgaris* L.) is an annual warm season crop grown for its immature seed pod (Infonet-Biovision, 2012). It is grown in Egypt, Kenya, Tanzania and Uganda in large scale for export (Abdel Mawgoud, 2005). With continuous population and economic growth, water resources have become increasingly scarce in many regions of the world. One of the main factors that limits further expansion of food production for the increasing population is water (Playan and Mateos, 2006; Yang et al., 2006; Falkenmark, 2007). Although water is scarce, there are many ways of using it more efficiently (Rosegrant, 2002). There are three options for capturing the additional water needed to meet the requirements of future food production: increasing water productivity by reducing losses, improving the use of rainfall and expanding rain-fed agriculture and pursuing virtual water options (Allan, 1997; WWC, 2004; Hoekstra and Hung, 2005)

Drought is the most vital environmental stress that limits production of crops. Wortmann et al., (1998), estimated that yield losses in common beans due to drought were 396,000 t/ha. Drought stress results in significant reduction in bean seed yield in about 60 % of the total global bean producing areas (Graham and Ranalli, 1997; Rosales-Serna et al., 2004). Emam et al., (2010) reported that yield of bean under drought stress significantly decreased.

Drought has major implications for global food supply because of the expected effects of gradual climatic change (Edmeades, 2013). Water management is important at all stages of plant development due to its influence on stand establishment, pod set and quality (Smesrud et al., 1997). Snap bean need well distributed rainfall throughout the growing season (900-1200 mm per year) (KARI, 2007) to ensure vigorous growth. Lack of adequate water and its inconsistent distribution during crop growing periods leads to water requirements of crops not met adequately and plants exposed to water stress (Abdzad Gohari, 2012). Productivity response to water stress is different for each crop and is expected to vary with the climate (Abdzad Gohari, 2013). Supplying sufficient water for a plant during its growth and development and prior to the occurrence of adverse effects of water stress is very important for plants' physiological processes (Bingru and Hongwen, 2000). To improve crop production, management practices that can easily be adopted by farmers to conserve soil moisture are viable options to improve growth and development of snap bean. The moisture conservation practices include mulches, tied and untied ridges.

Mulch is a layer of material spread on the surface of the soil for a number of reasons. These include moisture conservation by reducing transpiration, improvement of plant establishment and development, moderation of soil temperatures, increase in soil porosity, water infiltration and nutrient availability (Acquaah, 2004; Arora et al., 2011). Straw mulching has potential for increasing soil water storage (Shanging and Unger, 2001). In arid and semiarid regions, about 40 to 70 percent of water loss by evaporation from the soil surface can be prevented by mulching (Jalota, 1993). Zhang et al., (2005) found that with straw mulch, soil evaporation was reduced and plant water use efficiency increased. Zaongo et al., (1997) reported 27% increase in water use effeciency with mulch treatments. Mulches are able to modify the microclimate and growing conditions of crops (Albright et al., 1989), conserve more water and increase water use efficiency (Zhao et al., 1996). The ability of mulch to enhance water use efficiency in a soil-plant system could encourage mulching practice for the enhancement of crop production.

Studies done by Boutraa and Sanders (2001) and Arash khonok (2013) showed that mulching increased height, yield and seed pod per plant of common bean. Another study by Ghalandarzadeh (2013) concluded that the use of straw mulch increased the bean yield mainly due to the availability of adequate water for bean growth.

A tied ridge is a form of micro basin technology which is an easy and cheap way of in situ water harvesting for small scale holder farmers (Jones and Stewart, 1990). Tied ridges have received considerable attention in sub humid to semi-arid tropics and sub tropics of Africa. The effectiveness of tied-ridges depends on soil, slope, rainfall and design characteristics. The objective of the system is to collect local runoff and store it within the soil profile in the vicinity of the plant roots (Critchley et al., 1992). The use of tied ridges has been adopted in countries such as Kenya, Niger and Zimbabwe, however, it does not seem to be taken up spontaneously (Critchley et al., 1992). Data from Kenya suggest that there are considerable yield advantages in using the ridging system. The data also show that, when used in combination with appropriate crops, it has demonstrated ability to reduce the risk of crop failure due to drought by concentrating the runoff (Critchley et al., 1992). The technology has been successfully used in Niger, Mali and Burkina Faso in West Africa to improve soil moisture conditions and physical properties with significant benefit for cotton, maize, cowpeas, millet and sorghum producers in the semi-arid areas (Critchley et al., 1992).

Wortmann (2008) concluded in his study with pulses that tie-ridge tillage improved soil water availability compared with the traditional practice of planting without ridges. There was an increase in grain yield compared with traditional flat planting. Tekle (2014) in a study with cowpeas reported that the grain yield advantage of tied ridge was 26% over farmers practice. A study by Mburu (2007) showed that tied ridges stored more water than any of the other water conservation practices tested and 50-60% higher yield than the farmer practice and other conservation treatments. In Kenya, studies on the effects of tied ridges have been done mainly in arid and semi-arid areas for sorghum and cowpea production. However, studies on the effect of tied ridges on snap bean productivity are limited. Therefore, a study was conducted in Mwea and Embu to evaluate the effect of mulching and ridging on growth, yield and quality of snap bean.

4.3 Materials and methods

4.3.1 Experimental sites

On farm field trials were conducted in two sites in central Kenya namely, Kimbimbi area of Mwea East division in Kirinyaga South district and Kawanjara area of Runyenjes division in Embu East district. Furrow irrigation and sprinkler irrigation were used in Kirinyaga South district and Embu East district trials, respectively, to supplement uneven rainfall.

The Kimbimbi site is situated at an elevation of 1214 m above sea level and geographically located on 0^{0}36’21.66” S and 37^{0}22’01.24”E. It is a warm lowland area with minimum and maximum temperatures of 17^{0}C and 26 ^{0}C, respectively, and an average annual rainfall of 950 mm p.a. The rainfall pattern is bimodal with the long rains occurring in April to May and the short rains in October to December. Relative humidity varies from 52 to 67%. The experimental site is located in lower midland zone 4 (LM4), a semiarid area. The soils classified as Nitisols and have good water holding capacity. The Kawanjara site is in the upper midland 2 (UM2) agro-ecological zone and geographically located on 0^{o}32’21.768”S and 37^{o}27’ 22.1034”E. It experiences a temperature range between 12 °C and 27 °C, with an average annual rainfall of 1495 mm. Most of the soils in the district are developed on parent materials derived from Mount Kenya which have humid top soils of moderate to high fertility (mainly nitisols) which are rich in organic matter. Analysis of soil nutrient was done at the beginning of the trials. Soil samples were collected at a depth of 0-30 cm and thoroughly mixed to get a composite sample. The soils were analyzed for pH, total N, total organic carbon, macronutrients and micronutrients in both sites (Appendix 1). The results showed that in Mwea, the soil pH was 4.85, with low levels of nitrogen, phosphorous and zinc while in Embu, soil pH was 5.85, with adequate levels of nitrogen, phosphorous and zinc. The average temperatures and rainfall during the study period (June to October, 2013) were recorded in both sites (Appendices 3 and 4).

4.3.2 Experimental design, treatments and crop husbandry practices

The treatments comprised:

1. Tied ridges which were made by ridging the soil to heights of 30 cm, and establishing about 20 cm high cross-ties at intervals of 2 m. Tied ridges were 50 cm wide and 30 cm deep;
2. No ridges;
3. Untied ridges which were 50 cm wide and 30 cm deep;
4. Dry rice straw mulch (0.5 kg/m^2) + no ridges;
5. Dry rice straw mulch (0.5 kg /m^2) + tied ridges;
6. Dry rice straw mulch (0.5 kg/m^2) + untied ridges

The treatments were laid out in a randomized complete block design and replicated three times. The experimental plots measured 5 m by 4 m with a distance of 1 m and 1.5 m between plots and blocks, respectively. Snap bean variety Serengeti was used in the trial. The planting distance was 50 cm between the rows and 10 cm within the rows.

The land was cleared and ploughed and harrowed to ensure a fine tilth. Ridges were made at a distance of 50 cm apart and furrows made for plants to be planted without ridges. Snap bean variety Serengeti seed was dressed with Moncerene® (active ingredients Imidacloprid, Thiram and Pencycuron) at the rate of 8 ml/kg seed to manage bean fly. Diseases and pests were managed by regular scouting and then spraying whenever pest populations justified control. Pesticides Fastac® (active ingredient Alphacypermetrin) was applied at the rate of 5 ml /20 litres of water to control aphids, leafminers, whiteflies and thrips. For control of bacterial diseases, rust, leaf spots, blights and mildews, Ortiva® (active ingredient Azoxystrobin) and Mancozeb® (active ingredient Mancozeb) were sprayed at the rate of 10 ml/ 20 litres of water and 50 g/ 20 litres of water, respectively. Weeding was done regularly to keep the plots weed free. Supplementation of rainfall was done through furrow and sprinkler irrigation in Mwea and Embu, respectively. Birds were managed by the use of scare crows and manual chasing.

4.3.3 Data collection

The data collected included: percentage crop emergence, plant stand at first harvest, number of days to 50% flowering, number of days to 50% pod formation, disease and insect pest infestation scores, yield (extra fine, fine and rejects) and number of pods per plant.

Plant emergence was assessed at one, two and three weeks after planting by counting all the snap beans that had emerged in each plot. The number of days to 50% flowering and 50% podding were recorded by counting the number of days when 50 % of the plants in a plot had the first open flower and first formed pod, respectively. The plant stand was determined at harvest by counting all the snap bean plants in each plot. The severity of infestation by diseases like rust, anthracnose and angular leaf spot and severity of infestation by pests like whiteflies, aphids and mites was assessed using the CIAT scale (Schoonhoven and Corrales, 2010) where: 1, 2, 3 signified the absence of symptoms (resistance); 4, 5, 6 signified intermediate attack of diseases or insect pests; and 7, 8, 9 signified susceptibility of the snap beans to diseases or insect pests. Plant vigor was measured using the following scale: 1, 2, 3 high vigor; 4, 5, 6 intermediate vigor and 7, 8, 9 poor vigor.

During harvesting, three middle rows of snap bean plots covering 5 m^2 were sampled and pods graded into marketable (extra fine and fine) and unmarketable yield (rejects). Extra fine pods had a diameter of 0-6 mm, fine had a diameter of 6-8 mm and rejects had a diameter of 8-12 mm. All snap bean pods that were damaged, diseased or deformed were graded in the rejects class. The graded snap beans were weighed using an electronic weighing balance and total number of pods recorded. The number of pods per plant was achieved by dividing the total pods produced by the snap bean plants in the three middle rows by the total number of snap bean plants in the three middle rows. Five pods per class were sampled and their pod lengths recorded.

4.3.4 Determination of the cost of the treatments

For each of the various moisture conservation practices, the cost of production and revenue accrued from the sale of marketable pod yield were estimated. The cost of the fertilizers, straw for mulching, Serengeti seeds, pesticides, labour cost, land hire cost and irrigation for both Embu and Mwea sites were determined. The average price paid for extra fine and fine pod grades was ksh 55.00 and ksh 25.00 per kg of pods respectively. The prices of pesticides, seeds, labour and irrigation used in the calculation were the prevailing prices in Mwea and Embu during the four month period (June to October 2013).

The total yield of extra fine pods and total yield of fine pods in each moisture conservation practice was multiplied by the cost of the respective market class price/ kg. The total revenue in each moisture conservation practice was determined by adding the cost of the two market classes as indicated below:

Revenue (Ksh/ha) = (yield of extra fine (kg) * price /kg) + (yield of fine (kg) * price/ kg).

The total revenue for the entire picking period was determined by adding the revenue from each harvest multiplied by the number of harvests.

Net profit was achieved by subtracting the total cost from the revenue (Kamanu et al., 2012) as indicated below:

Net profit = Revenue – total cost.

4.3.5 Data Analysis

Data collected were subjected to analysis of variance (ANOVA) using GENSTAT discovery edition 14. Mean separation was done using the least significant difference (LSD) test at p=0.05

4.4 Results

4.4.1 Effect of moisture conservation practices on number of days to 50% podding in snap bean

There were significant differences among the moisture conservation practices in the number of days to 50% podding in Embu site only (Table 4.1). Mulch + tied ridges, mulch + untied ridges, tied ridges + no mulch and untied ridges + no mulch achieved 50% snap bean podding significantly earlier than mulch + no ridges and control (no ridges + no mulch) treatments. Snap bean plants in Mwea formed pods more than six days earlier than snap bean plants in Embu.

Table 4.1: Effect of moisture conservation practices on the number of days to 50% podding in snap bean

Treatment	Mwea	Embu
Control (no ridges + no mulch)	43 a	51.33 a
Tied ridges + no mulch	43 a	49.33 b
Untied ridges + no mulch	43 a	49.67 b
Mulch + no ridges	43 a	51.00 a
Mulch + tied ridges	43 a	49.33 b
Mulch + untied ridges	43 a	49.67 b
P value	-	0.014
LSD $_{p=0.05}$	-	1.23
CV %	-	1.9

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05; CV= coefficient of variation

4.4.2 Effect of moisture conservation practices on insect pests and diseases in snap bean

There were no significant differences among the various moisture conservation practices in pest infestation of snap bean plants (Table 4.2). Scores for whiteflies ranged from 2.00 (Mwea) to

3.33 (Embu) and for aphids and mites were 1.00 respectively in both sites. Bean stem maggots were detected only in Mwea site and the score ranged from 1.00 to 1.67.

Table 4.2: Effect of moisture conservation practices on pest infestation (scores) in snap bean

	White flies		Aphids		Mites		BSM
Treatment	Mwea	Embu	Mwea	Embu	Mwea	Embu	Mwea
Control (no ridges + no mulch)	2.00	3.33	1.00	1.00	1.00	1.00	1.33
Tied ridges + no mulch	2.00	3.00	1.00	1.00	1.00	1.00	1.00
Untied ridges + no mulch	2.00	3.33	1.00	1.00	1.00	1.00	1.00
Mulch + no ridges	2.00	3.00	1.00	1.00	1.00	1.00	1.33
Mulch + tied ridges	2.00	2.67	1.00	1.00	1.00	1.00	1.33
Mulch + untied ridges	2.00	2.67	1.00	1.00	1.00	1.00	1.67
P value	-	0.619	-	-	-	-	0.611
LSD $_{p=0.05}$	-	NS	-	-	-	-	NS
CV %	-	9.6	-	-	-	-	7.5

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05; NS= not significant; CV= coefficient of variation; BSM= bean stem maggot. Scale used: 1, 2, 3 absence of symptoms (resistance); 4, 5, 6 intermediate and 7, 8, 9 susceptibility.

There were no significant differences among the different moisture conservation practices on disease infestation on snap bean in both sites except for common bacterial blight in Embu (Table 4.3). The average disease severity scores were 1.00 for rust and anthracnose, 1.00 (Mwea) to 2.67 (Embu) for angular leaf spot and 2.33 to 4.00 for common bacterial blight in Embu. Common bacterial blight occurred only in Embu. Tied ridge + no mulch treatment had significantly lower common bacterial blight score than the control, untied ridges + no mulch and mulch + untied ridges treatments.

Table 4.3: Effect of moisture conservation practices on disease infestation (scores) in snap bean

	Rust		Anthracnose		Angular leafspot		CBB
Treatment	Mwea	Embu	Mwea	Embu	Mwea	Embu	Embu
Control (no ridges + no mulch	1.00	1.00	1.00	1.00	1.00	1.67 b	2.33 b
Tied ridges + no mulch	1.00	1.00	1.00	1.00	1.00	2.67 a	4.67 a
Untied ridges + no mulch	1.00	1.00	1.00	1.00	1.00	2.00 ab	2.33 b
Mulch + no ridges	1.00	1.00	1.00	1.00	1.00	2.67 a	4.00 ab
Mulch + tied ridges	1.00	1.00	1.00	1.00	1.00	2.33ab	3.33 ab
Mulch + untied ridges	1.00	1.00	1.00	1.00	1.00	2.00ab	2.67 b
P value	-	-	-	-	-	0.094	0.054
LSD $_{p=0.05}$	-	-	-	-	-	NS	1.68
CV %	-	-	-	-	-	11.5	7.9

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05; NS= not significant; CV= coefficient of variation. Scale used: 1, 2, 3 absence of symptoms (resistance); 4, 5, 6 intermediate and 7, 8, 9 susceptibility.

4.4.3 Effect of moisture conservation practices on plant vigor in snap bean

There were significant differences among the various moisture conservation practices on snap bean vigor only in Embu (Table 4.4). Plots with tied ridges, untied ridges, mulch + tied ridges and mulch + untied ridges produced more vigorous snap bean plants than plots with mulch + no ridges and the control (no ridges + no mulch).

Table 4.4: Effect of moisture conservation practices on plant vigor (scores) in snap bean

Treatment	Mwea	Embu
Control (no ridges + no mulch)	5.00 a	3.00 a
Tied ridges + no mulch	5.33 a	2.00 b
Untied ridges + no mulch	3.67 a	2.33 b
Mulch + no ridges	4.00 a	3.00 a
Mulch + tied ridges	4.67 a	2.00 b
Mulch + untied ridges	4.33 a	2.00 b
P value	0.493	<.001
LSD $_{p=0.05}$	NS	0.43
CV %	9.8	4

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05; NS= not significant; CV= coefficient of variation. Scale used: 1, 2, 3 high vigor; 4, 5, 6 intermediate vigor and 7, 8, 9 poor vigor

4.4.4 Effect of moisture conservation practices on the number of pods per snap bean plant

There were significant differences (p=0.05) among the various moisture conservation practices in the number of pods per plant in both Mwea and Embu sites (Table 4.5). In both sites, mulched plots with tied or untied ridges produced higher number of pods per plant than mulched plots with no ridges and the control (no ridges + no mulch) plots.

In Mwea, the number of pods per plant in un-mulched plots with tied ridges was higher than un-mulched plots with untied ridges and mulched plots with no ridges. Plots with no ridges and no mulch (control) produced the lowest number of pods per plant. In Embu, the number of pods per plant in un-mulched plots with tied ridges was not significantly different from the number of pods per plant in mulched plots with tied or untied ridges. Plots with untied ridges + no mulch had a higher number of pods per plant than mulched plots with no ridges and control (no ridges + no mulch) plots.

Table 4.5: Effect of moisture conservation practices on the number of pods per snap bean plant

Treatment	Mwea	Embu
Control (no ridges + no mulch)	14.69 e	19.20 c
Tied ridges + no mulch	25.10 b	29.56 a
Untied ridges + no mulch	22.12 c	26.79 b
Mulch + no ridges	16.67 d	19.92 c
Mulch + tied ridges	27.44 a	30.20 a
Mulch + untied ridges	27.65 a	30.21 a
P value	<.001	<.001
LSD $_{p=0.05}$	1.66	5.4
CV %	2.6	2.36

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05; CV= coefficient of variation

4.4.5 Effect of moisture conservation practices on extra fine, fine, reject and marketable pod yield production in snap bean

There were significant differences among the different moisture conservation practices in extra fine pod yield in Mwea site only (Table 4.6). Mulched plots with untied ridges produced higher extra fine pod yield than all the other treatments except mulched plots with tied ridges and plots with unmulched plots with untied ridges. Unmulched plots with untied ridges had higher extra fine pod yield than unmulched plots with tied ridges, mulched plots with no ridges and the control plots (no ridges + no mulch). Plots with mulch + untied ridges had 37.9 , 32.9, 21.8 and 51.4% higher yield than plots with the control (no ridges + no mulch), tied ridges + no mulch, untied ridges + no mulch and mulch + no ridges treatments, respectively. Relative to the control (no ridges + no mulch), tied ridges + no mulch and mulch + no ridges had no effect on snap bean extra fine pod yield.

Table 4.6: Effect of moisture conservation practices on extra fine pod yield production (kg/ha) in snap beans

Treatment	Mwea	Embu
Control (no ridges + no mulch)	2576 c	2803 a
Tied ridges + no mulch	2674 bc	2925 a
Untied ridges + no mulch	2919 abs	3411 a
Mulch + no ridges	2347 c	2253 a
Mulch + tied ridges	3489 a	3249 a
Mulch + untied ridges	3553 a	3840 a
P value	0.015	0.09
LSD $_{p=0.05}$	671.0	NS
CV %	11	11.2

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05; NS= not significant; CV= coefficient of variation

There were significant differences in the production of fine pod yield among the various moisture conservation practices in both Mwea and Embu sites (Table 4.7). In Mwea, mulched plots with tied or untied ridges and unmulched plots with untied ridges had significantly higher fine pod yield than unmulched plots with tied ridges, mulched plots with no ridges and control plots (no ridges + no mulch). Mulched plots with untied ridges had 90.6, 39.5 and 45.1% higher fine pod yield than control plots (no ridges + no mulch), unmulched plots with tied ridges, and mulched plots with no ridges, respectively. The control plots had significantly the lowest fine pod yield.

In Embu, tied ridges with or without mulch and untied ridges with mulch had significantly higher fine pod yield than all the other treatments. Mulched plots with tied ridges had 100.8, 34.1 and 55.6 % higher fine pod yield than the control (no ridges + no mulch), unmulched plots with untied ridges and mulched plots with no ridges respectively. The control plot had the lowest fine pod yield.

Table 4.7: Effect of moisture conservation practices on fine pod yield production (kg/ha) in snap bean

Treatment	Mwea	Embu
Control (no ridges + no mulch)	4444 c	7223 c
Tied ridges + no mulch	6072 b	13773 a
Untied ridges + no mulch	8099 a	10815 b
Mulch + no ridges	5838 b	9317 bc
Mulch + tied ridges	8429 a	14501 a
Mulch + untied ridges	8469 a	14499 a
P value	<.001	<.001
LSD $_{p=0.05}$	1394.0	2202.0
CV %	4.1	8.4

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05; CV= coefficient of variation

There were significant differences in the amount of reject pod yield produced among the various moisture conservation practices in Mwea site (Table 4.8). The use of mulch + tied ridges produced higher reject pod than all the other treatments except for mulch + untied ridges. Untied ridges + no mulch produced higher reject yield than mulch + no ridges and tied ridges + no mulch. The control (no ridges + no mulch) had the lowest reject pod yield.

Table 4.8: Effect of moisture conservation practices on reject pod yield (kg/ha) in snap bean

Treatment	Mwea	Embu
Control (no ridges + no mulch)	986 d	1767
Tied ridges + no mulch	1110 cd	2880
Untied ridges + no mulch	1351 bc	4030
Mulch + no ridges	1198 cd	2120
Mulch + tied ridges	1693 a	2384
Mulch + untied ridges	1583 ab	2273
P value	0.001	0.08
LSD $_{p=0.05}$	274.0	NS
CV %	4.6	9.4

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05; NS= not significant; CV= coefficient of variation

In both Mwea and Embu sites, there were significant differences among the various moisture conservation practices on total marketable pod yield produced (Table 4.9). In both sites, plots with mulch + untied ridges and mulch + tied ridges produced higher marketable pod yield than the other treatments while the control (no ridges + no mulch) had generally the lowest marketable pod yield. In Mwea, unmulched plots with untied ridges, mulched plots with tied or untied ridges had significantly higher total marketable pod yield than all other treatments. Unmulched plots with tied ridges had higher marketable pod yield than the control (no ridges + no mulch). Mulched plots with untied ridges had 37.5, 9.1 and 46.9% higher total marketable pod yield than unmulched plots with tied ridges, unmulched plots with untied ridges and mulched plots with no ridges, respectively.

In Embu, mulched plots with tied and untied ridges, and unmulched plots with tied ridges had significantly higher total marketable pod yield than all the other treatments. Mulched plots with untied ridges had 9.8, 28.9 and 58.5 % higher marketable pod yield than unmulched plots with tied ridges, unmulched plots with untied ridges and mulched plots with no ridges, respectively.

Table 4.9: Effect of moisture conservation practices on total marketable pod yield (kg/ha) in snap bean

Treatment	Mwea	Embu
Control (no ridges + no mulch)	7020 c	10026 c
Tied ridges + no mulch	8746 b	16698 a
Untied ridges + no mulch	11018 a	14226 b
Mulch + no ridges	8185 bc	11571 c
Mulch + tied ridges	11918 a	17750 a
Mulch + untied ridges	12022 a	18339 a
P value	<.001	<.001
LSD $_{p=0.05}$	1625.0	2056.0
CV %	2.6	5

Figures followed by the same letter (s) within a column are not significantly different according to LSD at *P*=0.05; CV= coefficient of variation

4.4.6 Effect of moisture conservation practices on profitability in snap bean production

The non-treatment cost includes cost of land hire, irrigation, Serengeti seeds, fertilizers, rice straw mulch and pesticides per hectare (Table 4.10). The treatment cost which comprised the cost of labour (plus material in the case of rice straw mulch treatment) used in applying each treatment, ranged from ksh. 19,600/ ha (control) to ksh. 55,600/ ha (mulch + tied ridges) in Mwea and ksh. 34,500/ ha (control) to ksh. 70,000 ksh/ ha (mulch + tied ridges) in Embu (Table 4.11, Appendix 7 and Appendix 8). Total cost of each moisture conservation practice, determined by addition of non-treatment and treatment costs for each moisture conservation practice treatment, varied from ksh. 149,051 (control) to ksh. 185,051 (mulch + tied ridges) in Mwea and 150,051 (control) to 185,551 (mulch + tied ridges) in Embu (Table 4.12, Appendix 7 and Appendix 8)

Table 4.10: Non treatment costs (ksh/ha)

Input	Production costs (Mwea)	Production costs (Embu)
Pesticides	5,700.00	5,700.00
Serengeti seeds	40,000.00	40,000.00
Cost of DAP + CAN	29,251.40	29,251.40
Irrigation	34,500.00	20,600.00
Rice straw mulch	20, 000.00	20, 000.00
Land hire for 6 months	20,000.00	20,000.00

Table 4.11: Treatment costs for each moisture conservation practice (ksh/ha)

Treatment	Mwea	Embu
Control (no ridges + no mulch)	19,600	34,500
Tied ridges + no mulch	35,600	50,000
Untied ridges + no mulch	25,600	40,500
Mulch + no ridges	39,600	54,500
Mulch + tied ridges	55,600	70,000
Mulch + untied ridges	45,600	60,500

Table 4.12: Total cost for each moisture conservation practice (ksh/ha)

Treatment	Mwea	Embu
Control (no ridges + no mulch)	149,051	150,051
Tied ridges + no mulch	165,051	165,551
Untied ridges + no mulch	155,051	156,051
Mulch + no ridges	169,051	170,051
Mulch + tied ridges	185,051	185,551
Mulch + untied ridges	175,051	176,051

Net profit ranged from ksh 103,729/ ha (control) to ksh 231,339/ ha (mulch + untied ridges) in Mwea and ksh 184,689/ ha (control) to ksh 397,624/ ha (mulch +untied ridges) in Embu. In Mwea, untied ridges + no mulch, mulch + tied ridges and mulch + untied ridges had 24.7%, 30.5% and 38.7% higher net profit, respectively, than the average for all the treatments while the use of no ridges + mulch (control), mulch + no ridges and tied ridges + no mulch had 37.8%, 36.4% and 19.7% lower net profit than the average for all the treatments, respectively (Table 4.13). In Embu, untied ridges + no mulch, tied ridges + no mulch, mulch + tied ridges and mulch + untied ridges had 2.6%, 15.4%, 20.8% and 35.1% higher net profit, respectively, than the average for all treatment while no ridges + no mulch (control) and mulch + no ridges had 37.3% and 36.6% lower net profit than the average for all the treatments, respectively (Table 4.14) Mulch + tied ridges and mulch + untied ridges had 109.7% and 123.0%, respectively, higher net profit than the control (no ridges + no mulch) in Mwea. In Embu, the former two treatments had 92.6% and 115.3%, respectively, higher net profit than the control (no ridges + no mulch).

Table 4.13: Effect of moisture conservation practices on profit/ ha (ksh) in Mwea.

Treatment	Extra fine (kg/ ha)	Fine (kg/ ha)	Income (ksh/ ha)	Cost (ksh/ ha)	Profit (ksh/ ha)
Control (no ridges + no mulch)	2576	4444	252780	149,051	103,729
Tied ridges + no mulch	2674	6072	298870	165,051	133,819
Untied ridges + no mulch	2919	8099	363020	155,051	207,969
Mulch + no ridges	2347	5838	275035	169,051	105,984
Mulch + tied ridges	3489	8429	402,620	185,051	217,569
Mulch + untied ridges	3553	8439	406,390	175,051	231,339
Mean	2926	6886	333119	166,384	166735

Income (Ksh/ha) = (Extra fine yield (kg) * price /kg) + (fine yield (kg) * price/ kg). Profit= Income–cost; Extra fine price ksh. 55 per kg of pods, Fine price ksh. 25 per kg of pods.

Table 4.14: Effect of moisture conservation practices on profit/ ha (ksh) in Embu.

Treatment	Extra fine (kg/ ha)	Fine (kg/ ha)	Income (ksh/ ha)	Cost (ksh/ ha)	Profit (ksh/ ha)
Control (no ridges + no mulch)	2803	7223	334740	150,051	184,689
Tied ridges + no mulch	2925	13773	505200	165,551	339,649
Untied ridges + no mulch	3411	10815	457980	156,051	301,929
Mulch + no ridges	2253	9317	356840	170,051	186,789
Mulch + tied ridges	3249	14501	541220	185,551	355,669
Mulch + untied ridges	3840	14499	573675	176,051	397,624
Mean	3080	11688	461609	167,218	294,392

Income (Ksh/ha) = (Extra fine yield (kg) * price /kg) + (fine yield (kg) * price/ kg). Profit= Income–cost; Extra fine price ksh. 55 per kg of pods, Fine price ksh. 25 per kg of pods.

4.5 Discussion

Tied and untied ridges with or without mulching accelerated the time to 50% pod formation of snap beans in Embu. Studies done by Shuhuai Jiang et al., (2012) showed that ridges are able to improve soil moisture of beans thereby exerting influence on the growth and development stages. Ren et al., (2008) showed that the use of ridges enabled crops begin their growth and development earlier.

Snap bean plants reached 50% flowering and 50% pod formation earlier in Mwea than in Embu. This could be attributed to the higher mean monthly temperature of 33.3^{o}c in Mwea than mean monthly temperature of 28.8^{o}c in Embu (Appendix 3 and 4). Studies done by Baker and Reddy (2001) showed that temperature is one of the main environmental variables that determines the time to flowering. Shiringani (2007) reported a significant earliness of plant flowering and podding with an increase of temperature. The results of the current study also concur with the findings of Munyasa (2013) and Kabutbei (2014) who found out that higher temperatures accelerated time to flowering and maturity in common bean genotypes.

Unmulched plots with tied ridges and untied ridges led to a significant increase in plant vigor, number of pods per snap bean plant, extra fine, fine and total marketable pod yield relative to the control (no-ridges and no-mulch). This finding is in agreement with studies done by Mulungu et al., (2006) which showed that the use of ridges increased number of pods per plant, pod length and yield per plant in beans. Ridges have been reported to increase number of grains per pod, pod weight, number of pods and grain yield of cowpea (Mehrpooyan et al., 2010; Karimvand, 2013). Elwell et al., (1974) reported an increase in yields and significant reductions in soil and runoff losses were achieved through ridging. Similarly, Kaluli et al., (2005) reported that ridges preserve soil moisture which leads to improved crop yields. Smith (1988) reported an increase in yields with the use of tied ridging compared to conventional tillage.

There were no significant differences between the use of tied and untied ridges in the time to 50% pod formation, disease and pest infestation and plant vigor. However, tied ridges produced more pods per plant than untied ridges. In Mwea, untied ridges produced higher total marketable pod yield than the control (no-ridges + no-mulch) while in Embu, tied ridges produced higher total marketable pod yield than the control (no-ridges + no-mulch). Previous reports demonstrated that yield responded significantly to tied and untied ridges but the magnitude of the yield response and relative efficiency of the tied ridges varied with soil type, the total amount of rainfall, distribution of rainfall during the cropping season and fertilization (Gebrekidan, 2003; Bayu et al., 2012). Miriti et al., (2007) reported that cowpea yields were not significantly affected by tied ridges and the use of tied ridges gave superior yields for different crops (Miriti et al., 2003; Kipserem, 1996). However, tied ridging is also reported to give contradictory results as the net effects of tied ridging can be both positive and negative partly because of variation in soil and climatic characteristics among sites and between years (Lal, 1995).

Mulching with rice straw (with no ridges) out-performed the control (no-mulch and no-ridges) only in the number of pods and fine pod yield in Mwea. Singh et al., (2011) reported that mulching of french bean led to higher single pod weight, pod length, pod weight per plant and pod yield. Zhang et al., (2005) and Mchugh et al., (2007) reported that straw mulch reduced soil evaporation and increased plant water use efficiency, hence improved growth and development. However, combination of mulch + ridges (tied or untied) led to an increase in plant vigor, higher number of pods per plant, higher extra fine, fine and total marketable pod yields than the other treatments. Combination of mulch + ridges resulted in higher total marketable pod yield than the use of either ridges or mulch alone possibly because the combined use offered a more effective control of evaporation losses hence, conservation of more moisture. Shuhuai Jiang (2012) reported that a combination of mulching and ridging improved soil moisture thereby significantly improving the growth, development and yield of beans. Reiz et al., (1988) concluded that the use of mulched ridge technology had significant yield-increasing effects as compared to planting with no ridges.

Mulched plots with untied ridges had the highest net profit followed by mulched plots with tied ridges. Un-mulched plots with no ridges (control) had the lowest net profit. The results of this study indicated that whereas growing of snap beans in mulched and ridged (tied and untied) plots produced higher total marketable pod yield than the other treatment, the use of mulch + untied ridges resulted to higher net profits.

4.6 Conclusion

According to the results of the study, ridging is an important moisture conservation practice in snap bean production. Combination of mulch + ridges (tied or untied) led to increases in plant vigor, number of pods per plant, extra fine, fine and total marketable pod yields. The use of mulch + untied ridges had higher net profit than all the other treatments, hence, planting snap beans with mulch + untied ridges may be recommended for farmers both in Mwea and Embu.

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 General discussion

In the first experiment, the no-fertilizer control snap bean plot took significantly longer days to achieve 50 % pod formation than fertilizer treated plots. Studies have shown that applications of phosphorus fertilizer accelerate crop development and maturity and deficiencies of nutrients such as nitrogen result in stunted growth. The time to 50% flowering and 50% podding in snap beans was observed earlier in Mwea than in Embu. This is attributed to the higher mean temperature in Mwea than in Embu. DAP (43.2 kg N/ha + 48.2 kg P/ha) + CAN (46.8 kg N/ha) + foliar feed and DAP (43.2 kg N/ha + 48.2 kg/ha) + CAN (46.8 kg N/ha) produced more vigorous snap bean plants, higher number of pods per plant, higher extra fine, fine and marketable pod yield than the other treatments. This could be attributed to the higher N and P nutrients contained in the two treatments. Snap beans grown in Embu were more vigorous, produced higher number of pods per snap bean plant, higher average pod length and higher marketable pod yield than the snap beans in Mwea. This could probably be due to the differences in soil nutrients and climatic conditions. There were no significant differences between DAP (43.2 kg N/ha + 48.2 kg P/ha) + CAN (46.8 kg N/ha) + foliar feed and DAP (43.2 kg N/ha + 48.2 kg P/ha) + CAN (46.8 kg N/ha) in growth and yield parameters. This could probably be due to inadequate doses of foliar feed or the foliar feed had no significant effect on the growth and yield parameters. DAP (43.2 kg N/ha + 48.2 kg P/ha) + CAN (46.8 kg N/ha) + foliar feed had significantly higher net profit than the other treatments, hence, optimal foliar feed rates may be recommended for farmers' adoption after further trials.

In the second experiment, tied and untied ridges with or without mulching accelerated the time to 50% pod formation of snap bean in Embu. Studies have shown that ridging results to conservation of soil moisture which may have enabled crops begin their growth and development earlier. Ridges (tied or untied) led to production of higher number of pods per snap bean plant and higher extra fine, fine and marketable pod yields. Studies have shown that ridging showed superiority in number of pods per plant, pod length and yield per plant. This could be due to conservation of water in the soil leading to better crop growth and yield production. The use of ridges in growth of snap bean plants produced higher pod yield than no ridges. This could probably be due to the significant reduction in water losses leading to higher pod yield.

Combination of mulch + ridges (tied or untied) led to increases in plant vigor, higher number of pods per plant, higher extra fine, fine and total marketable pod yields than the other treatments. This could be due to combined use of both mulch and ridges offered a more effective control of evaporation losses hence, more conservation of moisture improving growth and yield of beans. Mulching without ridging had no significant effect on the yield and yield components.

There were no significant differences between tied ridges + mulch and untied ridges + mulch in growth and yield parameters. Mulched plots with untied ridges had significantly higher net profit than the other treatments. Hence, the use of mulch + untied ridges may be recommended to farmers in Mwea and Embu

5.2 Conclusions

Planting snap beans with DAP (43.2 kg N/ha + 48.2 kg P/ha) + CAN (46.8 kg N/ha) + foliar feed and DAP (43.2 kg N/ha + 48.2 kg P/ha) + CAN (46.8 kg N/ha) produced vigorous snap beans with higher pods per plant and total marketable pod yield, but the use of DAP + CAN + foliar feed had significantly higher net profit than the other treatments. Hence, farmers who apply foliar feed may have higher profit, though the optimal foliar feed rates may be recommended after further trials.

Ridging is important in planting of snap beans. Growing of snap beans with the use of mulched or un-mulched plots with ridges (tied and untied) produced a higher total marketable pod yield than growing with no ridges. The use of mulch + untied ridges had higher net profit than all the other treatments, hence, planting snap beans with mulch + untied ridges may be recommended for farmers in Mwea and Embu.

5.3 Recommendations

As a result of the findings reported in this study, it is recommended that:

1. Farmers in Mwea and Embu should use DAP (43.2 kg N/ha + 48.2 kg P/ha) at planting + CAN (46.8 kg N/ha) at 21 days after planting or DAP (43.2 kg N/ha + 48.2 kg P/ha) at planting + CAN (46.8 kg N/ha) at 21 days after planting + foliar feed. The use of DAP + CAN + foliar feed produces significantly higher net profit, hence, farmers who apply foliar feed may have higher profit, though the optimal foliar feed rates may be recommended after further trials.
2. Farmers in Mwea and Embu should use mulch and untied ridges in snap bean production to achieve higher net profits.
3. A study should be carried out to assess the optimal foliar feed rates that can enhance maximum snap bean productivity and profitability.

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CHAPTER SEVEN: APPENDICES

Appendix 1: Soil test results for Kimbimbi site in Mwea division, Kirinyaga South district and Kawanjara site in Runyenjes division, Embu East district.

	Mwea		Embu	
	Value	Class	Value	Class
Soil pH	4.85	Strong acid	5.95	Medium acid
Total nitrogen %	0.15	Low	0.20	Adequate
Total organic carbon %	1.53	Moderate	2.00	Moderate
Phosphorous ppm	25	Low	30	Adequate
Potassium me %	0.76	Adequate	0.88	Adequate
Calcium me %	6.7	Adequate	3.9	Adequate
Magnesium me %	3.00	Adequate	3.59	High
Manganese me %	0.29	Adequate	0.43	Adequate
Copper ppm	4.02	Adequate	8.80	Adequate
Iron ppm	24.8	Adequate	11.5	Adequate
Zinc ppm	4.13	Low	31.6	Adequate
Sodium me %	0.24	Adequate	0.22	Adequate

Appendix 2: Farmyard manure analysis results for Kimbimbi site in Mwea division, Kirinyaga South district and Kawanjara site in Runyenjes division, Embu East district.

	Mwea	Embu
	Value	Value
Nitrogen%	1.4	0.70
Phosphorous%	0.48	0.39
Potassium %	1.60	1.00
Calcium %	1.20	0.54
Magnesium %	0.05	0.01
Iron mg/kg	2223	1285
Copper mg/ kg	13.7	3.33
Manganese mg/ kg	942	210
Zinc mg/kg	32.5	13.2

Appendix 3: Weather data for Kimbimbi site in Mwea division, Kirinyaga South district during the experimental period.

Month	Average total rainfall (mm)	Temperature ^{0}c(Maximum)	Temperature ^{0}c(Minimum)
January 2013	13	32	11
February 2013	24	34	12
March 2013	72	37	12
April 2013	294	34	12
May 2013	139	34	11
June 2013	23	32	10
July 2013	7	31	10
August 2013	11	31	10
September 2013	12	34	11
October 2013	108	36	11
November 2013	158	33	11
December 2013	59	32	10

Appendix 4: Weather data for Kawanjara site in Runyenjes division, Embu East district during the experimental period.

Month	Average total rainfall (mm)	Temperature ^{0}c (Maximum)	Temperature ^{0}c (Minimum)
January 2013	27	29	10
February 2013	26	30	10
March 2013	113	32	11
April 2013	278	31	10
May 2013	164	29	10
June 2013	32	27	9
July 2013	29	26	9
August 2013	38	26	9
September 2013	41	29	10
October 2013	171	30	10
November 2013	234	29	10
December 2013	53	28	9

Appendix 5: Calculation of cost of inputs per hectare in Mwea

Input	Quantity	Rate (Ksh)	Total cost (Ksh/ha)
Pesticides: (insecticides)			
Moncerene	1 No x 500 ml	750.00	750.00
Fastac	3 No x 50 ml	200.00	600.00
(Fungicide)			
Ortiva	20 No x 50 ml	180.00	3,600.00
Mancozeb	1 No x 1 kg	750.00	750.00
Snap bean seed –Serengeti	1 No x 50 kg	800.00	40000.00
Labour:			
For land preparation, ridging, fertilizer application and weeding			25,600.00
Irrigation:			
Cost of water and labour for application	1 unit	34,500.00	34,500.00
Cost of fertilizer per application regime:			
FYM + MPR	5000 kg FYM + 235 kg MPR	3.30 + 52.00	28,720.00
FYM + DAP	5000 kg FYM + 151.5 kg DAP	3.30 + 80.00	28,620.00
FYM + CAN	5000 kg FYM + 222 kg CAN	3.30 + 58.00	29,376.00
DAP + CAN	240 kg DAP + 173.3 kg CAN	80.00 + 58.00	29,251.40
Farmer practice	166.7 kg DAP + 148.1 kg CAN	80.00 + 58.00	21,925.80
DAP + CAN + Foliar feed	240 kg DAP + 173.3 kg CAN + 4 liters	80.00 + 58.00+ 1300.00	34, 451.40
Total cost of each fertilizer regime:			
FYM + MPR + seeds + pesticides + labour + irrigation + land hire	28,720.00 + 40000.00 + 5700.00 + 25,600.00 + 34,500.00 + 20,000.00	-	154,520.00
FYM + DAP + seeds + pesticides + labour + irrigation+ land hire	28,620.00 + 40000.00 + 5700.00 + 25,600.00 + 34,500.00 + 20,000.00	-	154,420.00
FYM + CAN + seeds + pesticides + labour + irrigation+ land hire	29,376.00 + 40000.00 + 5700.00 + 25,600.00 + 34,500.00 + 20,000.00	-	155,176.00
DAP + CAN + seeds + pesticides + labour + irrigation+ land hire	29,251.00 + 40000.00 + 5700.00 + 25,600.00 + 34,500.00 + 20,000.00	-	155,051.40

Farmer practice + seeds + pesticides + labour + irrigation+ land hire	21,925.80 + 40000.00 + 5700.00 + 25,600.00 + 34,500.00 + 20,000.00	-	147,725.00
DAP + CAN + Foliar feed + seeds + pesticides + labour + irrigation+ land hire	34, 451.40 + 40000.00 + 5700.00 + 25,600.00 + 34,500.00 + 20,000.00	-	160251.40
Control (No fertilizer) + seeds + pesticides + labour + irrigation+ land hire	0+40000.00 +5700.00 + 26,600.00 +34500.00 +20,000.00	-	125,800.00

Farmyard manure (5 t/ha) + mining phosphate rock (30 kg P/ha); farmyard manure (5 t/ha) + DAP (30 kg P/ha); Farmyard manure (5 t/ha) + CAN (60 kg N/ha); DAP (43.2 kg N/ha) + CAN(46.8 kg N/ha) ; Farmer practice [DAP (30 kg N/ha) + CAN (40 kg N/ha); DAP (43.2 kg/ha) +CAN (46.8 kg/ha) + foliar feed

Appendix 6: Calculation of cost of inputs per hectare in Embu

Input	Quantity	Rate (Ksh)	Total cost (Ksh/ha)
Pesticides: (Insecticides)			
Moncerene	1 No x 500 ml	750.00	750.00
Fastac	3 No x 50 ml	200.00	600.00
(Fungicide)			
Ortiva	20 No x 50 ml	180.00	3,600.00
Mancozeb	1 No x 1 kg	750.00	750.00
Snap bean seed -Serengeti	1 No x 50 kg	800.00	40000.00
Labour:			
For land preparation, ridging, fertilizer application and weeding			40,500.00
Irrigation:			
Cost of water and labour for application	1 unit	34,500.00	20,600.00
Cost of fertilizer per application regime:			
FYM + MPR	5000 kg FYM + 235 kg MPR	3.30 + 52.00	28,720.00
FYM + DAP	5000 kg FYM + 151.5 kg DAP	3.30 + 80.00	28,620.00
FYM + CAN	5000 kg FYM + 222 kg CAN	3.30 + 58.00	29,376.00
DAP + CAN	240 kg DAP + 173.3 kg CAN	80.00 + 58.00	29,251.40
Farmer practice	166.7 kg DAP + 148.1 kg CAN	80.00 + 58.00	21,925.80
DAP + CAN + Foliar feed	240 kg DAP + 173.3 kg CAN + 4 liters	80.00 + 58.00+ 1300.00	34, 451.40
Total cost of each fertilizer regime:			
FYM + MPR + seeds + pesticides + labour + irrigation + land hire	28,720.00 + 40000.00 + 5700.00 + 40,500.00 + 20,600.00 + 20,000.00	-	155,520.00
FYM + DAP + seeds + pesticides + labour + irrigation+ land hire	28,620.00 + 40000.00 + 5700.00 + 40,500.00 + 20,600.00 + 20,000.00	-	155,420.00
FYM + CAN + seeds + pesticides + labour + irrigation+ land hire	29,376.00 + 40000.00 + 5700.00 + 40,500.00 + 20,600.00 + 20,000.00	-	156,176.00
DAP + CAN + seeds + pesticides + labour + irrigation+ land hire	29,251.00 + 40000.00 + 5700.00 + 40,500.00 + 20,600.00 + 20,000.00	-	156,051.00

Farmer practice + seeds + pesticides + labour + irrigation+ land hire	21,925.80+ 40000.00 + 5700.00 + 40,500.00 + 20,600.00 + 20,000.00	-	148,725.80
DAP + CAN + Foliar feed + seeds + pesticides + labour + irrigation+ land hire	34, 451.40+ 40000.00 + 5700.00 + 40,500.00 + 20,600.00 + 20,000.00	-	161,251.40
Control (No fertilizer) + seeds + pesticides + labour + irrigation+ land hire	40,000.00 + 5700.00 + 40,500.00 + 20,600.00 + 20,000.00	-	126,800.00

Farmyard manure (5 t/ha) + mining phosphate rock (30 kg P/ha); farmyard manure (5 t/ha) + DAP (30 kg P/ha); Farmyard manure (5 t/ha) + CAN (60 kg N/ha); DAP (43.2 kg N/ha) + CAN(46.8 kg N/ha) ; Farmer practice [DAP (30 kg N/ha) + CAN (40 kg N/ha); DAP (43.2 kg/ha) +CAN (46.8 kg/ha) + foliar feed

Appendix 7: Calculation of cost of inputs per hectare in Mwea (moisture conservation practices)

Input	Quantity	Rate (Ksh)	Total cost (Ksh)
Pesticides: (Insecticides)			
Moncerene	1 No x 500 ml	750.00	750.00
Fastac	3 No x 50 ml	200.00	600.00
(Fungicide)			
Ortiva	20 No x 50 ml	180.00	3,600.00
Mancozeb	1 No x 1 kg	750.00	750.00
Snap bean seed -Serengeti	1 No x 50 kg	800.00	40000.00
DAP + CAN	240 kg DAP + 173.3 kg CAN	80.00 + 58.00	29,251.40
Irrigation:			
Cost of irrigation and application labour	1 unit	34,500.00	34,500.00
Labour cost of each moisture conservation practice			
Control (no ridges + no mulch)	19,600.00		19,600.00
Tied ridges + no mulch	35,600.00 + 0		35,600.00
Untied ridges + no mulch	25,600.00 + 0		25,600.00
Mulch + no ridges	20,000.00 + 19600.00		39,600.00
Mulch + tied ridges	20,000.00 + 35,600.00		55,600.00
Mulch + untied ridges	20,000.00 + 25,600.00		45,600.00
Total cost of each moisture conservation practice:			
Control + seeds + pesticides + labour + irrigation + land hire	19,600.00 + 40000.00 + 5700.00 + 29251.00 + 34,500.00 + 20,000.00	-	149,051.00
(Tied ridges + no mulch) + seeds + pesticides + labour + irrigation+ land hire	35,600.00 + 40000.00 + 5700.00 + 29251.00 + 34,500.00 + 20,000.00	-	165,051.00
(Untied ridges + no mulch) + seeds + pesticides + labour + irrigation+ land hire	25,600.00 + 40000.00 + 5700.00 + 29251.00 + 34,500.00 + 20,000.00	-	155,051.00
(Mulch + no ridges) + seeds + pesticides + fertilizer + irrigation + land hire	39,600.00 + 40000.00 + 5700.00 + 29251.00 + 34,500.00 + 20,000.00	-	169,051.00
(Mulch + tied ridges) + seeds + pesticides + fertilizer + irrigation+ land hire	55,600.00 + 40000.00 + 5700.00 + 29,251.00 + 34,500.00 + 20,000.00	-	185,051.00
(Mulch + untied ridges) + seeds + pesticides + fertilizer + irrigation +land hire	45,600.00 + 40000.00 + 5700.00 + 29251.00 + 34,500.00 + 20,000.00	-	175,051.00

Appendix 8: Calculation of cost of inputs per hectare in Embu (moisture conservation practices)

Input	Quantity	Rate (Ksh)	Total cost (Ksh)
Pesticides: (Insecticides)			
Moncerene	1 No x 500 ml	750.00	750.00
Fastac	3 No x 50 ml	200.00	600.00
(Fungicide)			
Ortiva	20 No x 50 ml	180.00	3,600.00
Mancozeb	1 No x 1 kg	750.00	750.00
Snap bean seed -Serengeti	1 No x 50 kg	800.00	40000.00
DAP + CAN	240 kg DAP + 173.3 kg CAN	80.00 + 58.00	29,251.40
Irrigation:			
Cost of water and labour for application	1 unit	20,600.00	20,600.00
Labour cost of each moisture conservation practice			
Control (no ridges + no mulch)	34,500.00		34,500.00
Tied ridges + no mulch	50,000.00 + 0		50,000.00
Untied ridges + no mulch	40,500.00 +0		40,500.00
Mulch + no ridges	20,000.00 + 34,500.00		54,500.00
Mulch + tied ridges	20,000.00 + 50,000.00		70,000.00
Mulch+ untied ridges	20,000.00 + 40,500.00		60,500.00
Total cost of each moisture conservation practice:			
Control + seeds + pesticides + irrigation + land hire	34,500.00 + 40000.00 + 5700.00 + 29251.00 + 20,600.00 + 20,000.00	-	150,051.00
(Tied ridges + no mulch) + seeds + pesticides + irrigation+ land hire	50,000.00 + 40000.00 + 5700.00 + 29251.00 + 20,600.00 + 20,000.00	-	165,551.00
(Untied ridges + no mulch) + seeds + pesticides + irrigation+ land hire	40,500.00 + 40000.00 + 5700.00 + 29251.00 + 20,600.00 + 20,000.00	-	156,051.00
(Mulch+ no ridges) + seeds + pesticides + fertilizer + irrigation+ land hire	54,500.00 + 40000.00 + 5700.00 + 29251.00 + 20,600.00 + 20,000.00	-	170,051.00
(Mulch + tied ridges) + seeds + pesticides + fertilizer + irrigation+ land hire	70,000.00 + 40000.00 + 5700.00 + 29,251.00 + 20,600.00 + 20,000.00	-	185,551.00
(Mulch+ untied ridges) + seeds + pesticides + fertilizer + irrigation+ land hire	60,500.00 + 40000.00 + 5700.00 + 29251.00 + 20,600.00 + 20,000.00	-	176,051.00