NUTRIENT MANAGEMENT OPTIONS FOR IMPROVING GROWTH, YIELD AND QUALITY OF SNAP BEAN (*Phaseolus vulgaris* L.) IN EMBU COUNTY

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A THESIS SUBMITED TO GRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURAL RESOURCE MANAGEMENT

DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION

FACULTY OF AGRICULTURE

UNIVERSITY OF NAIROBI

2019

DECLARATION

This thesis is my original work and has not been presented for an award of a degree in any other university.

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DEDICATION

To my parents Mr. Isaiah Moturi and Mrs. Ann Ongoto and my siblings Eric, David, Winnie and Brian for their support and love just to see me succeed in my education.

and

To the University of Nairobi, Faculty of Agriculture, for the tutelage and mentorship.

ACKNOWLEDGEMENT

In the humblest manner, I want to thank the Almighty God that has brought me this far. Specifically, I am greatly indebted to my supervisors, Prof. George N. Chemining'wa, Prof. John H. Nderitu and Dr. John Busienei who walked with me through the most turbulent times and for their commitment to my study.

I thank the Kenya Agricultural Productivity and Agribusiness Project (KAPAP) and the University of Nairobi for supporting my research. I am also grateful to the farmers in Embu County for their support during the field trial.

Lastly, I greatly appreciate the support and love from my family; my parents Mr. Isaiah Moturi and Ann Ongoto and my siblings Eric Moturi, David Maranga, Winnie Kerubo and Brian Nyakundi. I have no way to thank you any better but to ask God to grant you peace to do this again to others.

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GENERAL ABSTRACT

Low soil fertility, especially deficiencies in nitrogen and phosphorous, is one of the key constraints to snap bean production in Kenya. An on farm trial was carried out in Karungua village in Kawanjara Sub-location, Runyenjes division, Embu East District. The first season trial was planted on 26th July 2014 and the second trial on 15th August 2014, respectively. The objectives of the study were: (1) to determine the effect of combining inorganic and organic fertilizers on growth, yield and quality of snap bean; and (2) to determine the cost effectiveness of various nutrient management options for snap bean production. The treatments comprised the following: (i) control (no fertilizers applied); (ii) farmyard manure (5 t/ha) and di-ammonium phosphate (50 kg N/ha) at planting and top dressing with calcium ammonium nitrate (50 kg N/ha) at 21 days after planting; (iii) di-ammonium phosphate (50 kg N/ha) at planting and top dressing with calcium ammonium nitrate (50 kg N/ha) at 21 days after planting; (iv) NPK (23:23:0) (50 kg N/ha) fertilizer at planting and top dressing with calcium ammonium nitrate (50 kg N/ha) at 21 days after planting (main farmer practice); (v) di-ammonium phosphate (50 kg N/ha) at planting, calcium ammonium nitrate (50 kg N/ha) at 21 days after planting and foliar feed spraying at pre- flowering stage; (vi) farmyard manure (5 t/ha), NPK (23:23:0) (50 kg N/ha) fertilizer at planting and top dressing with NPK (17:17:0) (50 kg N/ha) fertilizer at 21 days after planting; (vii) farmyard manure (5 t/ha) at planting and foliar feed spraying at pre- flowering stage; (viii) farmyard manure (5 t/ha) at planting; (ix) farmyard manure (5 t/ha), di-ammonium phosphate (50 kg N/ha), NPK (23:23:0) (50 kg N/ha) fertilizer at planting, top dressing with calcium ammonium nitrate (50 kg N/ha) at 21 days after planting and top dressing with NPK (17:17:0) (50 kg N/ha) fertilizer at 35 days after planting; (x) farmyard manure (5 t/ha) and calcium ammonium nitrate (50 kg N/ha) at planting and top dressing with calcium ammonium nitrate (60 kg N/ha) at 21 days after planting; (xi) farmyard manure (5 t/ha) at planting and top dressing with calcium ammonium nitrate (50 kg N/ha) at 21 days after planting. The trial was laid out in a randomized complete block design and replicated three times. The agronomic data collected included: 50% emergence, plant stand, days to 50% flowering, days to 50% podding, number of nodules per plant, shoot dry weight, pod yield and yield components, pest and disease infestation. Data for estimating cost effectiveness included the costs of inputs and revenue from the operations during the planting trial. Data were subjected to analysis of variance and mean separation was done using the least significant difference test at p=0.05.

The results of the study showed that nutrient management options did not significantly affect the number of days to 50% emergence and plant stand of snap bean. Application of farmyard manure (5 t/ha) alone and application of farmyard manure (5 t/ha) at planting plus foliar feed spraying at pre- flowering stage significantly took the shortest time to attain 50% flowering. Fertilizer application significantly depressed nodule number. Treatments with inorganic fertilizers alone had significantly fewer nodules than treatments with farmyard manure. Nutrient management options had no effect on 50% podding, extra-fine pod length, pest and disease infestation. Significantly higher extra-fine, fine and marketable pod yields were recorded in di-ammonium phosphate (50 kg N/ha) plus calcium ammonium nitrate (50 kg N/ha) treated plots than in plots with other nutrient management options. Economic analysis showed that application of di-ammonium phosphate (50 kg N/ha) at planting plus top dressing with calcium ammonium nitrate (50 kg N/ha) at 21 days after planting had the highest net benefit and marginal rate of return in both plantings compared to other nutrient management options. The control plots (no-fertilizer) had a higher net befit first planting compared to the fertilized treatments. The study has demonstrated that application of di-ammonium phosphate (50 kg N/ha) at planting plus top dressing with calcium ammonium nitrate (50 kg N/ha) at 21 days after planting can enhance yield and profitability of snap bean in Embu County.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Snap bean, commonly known as French bean or green bean, is a strain of common bean (*Phaseolus vulgaris* L.) commonly grown in Kenya for export mainly to the European market (CIAT, 2006). Over the years, the crop has gained popularity in the domestic market, especially in the supermarkets. Nevertheless, the consumption of French beans locally has increased hence a rise in demand at the domestic markets (HCDA, 2016). Its green pods are harvested for fresh, frozen and for canning purposes. Snap bean varieties vary in pod shape (flat, cylindrical or oval shape), color (green, light green, yellow, or purple) and length (Musaana *et al*., 2011). The crop is grown by both large scale farmers and small scale farmers. Even so, its production is mainly dominated by rural small-scale farmers. Snap bean pod yield varies from 2 to 8 tonnes ha^{-1} among the smallholder's farms compared to 14 t ha^{-1} for large-scale producers (Ndegwa, 2003). Depending on the total size of the farm, snap bean growers can be categorized as follows: small producers with less than 2.2 ha; medium scale producers with 2.2 to 4.4 ha; large scale producers with 4.4 to 44.0 ha; and plantations are those with more than 44.0 hectares (Mauch *et al*., 2006).

In the year 2009, snap bean was ranked first among horticultural export crops contributing to 20% of the total horticultural crop exports by Kenya. The total production was 30,000 metric tonnes valued at 4 billion shillings (HCDA, 2010). In contrast, in the year 2013 the total production of snap bean was 38,398 metric tonnes valued at Kshs 1.8 billion, consequently dropping to sixth place in value among the main vegetables, due mainly to challenges in meeting maximum residue limits. Despite the interceptions and rejections by the market of snap bean because of maximum residue levels (MRLs), the exports recovered from 22,553 MT in 2012 to 31,973 MT in 2013 (HCDA, 2013). This has been attributed to the integration of the traceability system in supply chains enabling exporters to monitor chemical use by farmers directly. Even though the French bean production has increased from 34,779 tons to 41,789 tons while the value has increased from Ksh 1.38 billion to Ksh 1.81billion representing 20 per cent and 31 per cent increase from 2015, the crop has also dropped to the eighth place in value among the main vegetables (HCDA, 2015). The leading counties were Kirinyaga, Machakos and Murang'a that accounted for 32, 20.7 and 13.5 per cent respectively of the countries value in 2016 (HCDA, 2016).

Snap bean has a potential to stimulate higher private sector investment in agro-processing and export, thus creating employment for young women and men (Lenne *et al.*, 2005). It requires less energy to cook and is a rich source of micronutrients (iron and zinc) thus is important where there is high prevalence of iron and zinc deficiencies (Broughton *et al*., 2003).

Despite its importance, snap bean production in small holders' farms is constrained by many biotic and abiotic stresses. In the tropics, pests and diseases present a major constraint to agricultural productivity of snap bean (Graham and Vance, 2003). In the whole world, yield losses caused by insect pests alone are estimated to vary from 35% to 100% annually (Sing *et al*., 2011). Key pests include aphids, thrips, whiteflies, caterpillars, nematodes and leafhoppers while diseases include bean rust, anthracnose, powdery mildew, angular leaf spot, common bacterial blight and common mosaic viruses (Kimani *et al*., 2004; Musaana *et al*., 2011). Therefore, farmers rely on costly pesticides to control pests and diseases thereby increasing the cost of production of snap bean (Nderitu *et al***.,** 2001: Musaana, 2002; Mwangi, 2008).

Low soil fertility is one of the major key challenges to the snap bean productivity in Kenya. Low nitrogen, potassium and calcium in the soils can cause bean yield loss equivalent to 744,900 metric tonnes in East Africa, because smallholder farms are usually cultivated continually without adequate replenishment of plant nutrients (Wortman *et al*.,1988).

Nitrogen is an important element in plant growth and in achieving high harvests. Nitrogen and phosphorus are identified as the major limiting nutrients for many cropping systems in Kenya (Kwambiah *et al*., 2003) and their application in form of inorganic and organic sources is essential to maximize and sustain snap bean yields (Hartemink *et al*., 2000). Inorganic sources of N and P are however not readily available to small-scale farmers (Smestad *et al*., 2002). It is therefore important for small holder farmers to use the available options to manage nitrogen and phosphorus in their fields. Therefore, chemical fertilizers are often considered a solution to the current nutrient deficiencies in the soils (Chemining'wa *et al*., 2004; Gentili *et al*., 2006). The high cost of inorganic fertilizers coupled with low returns and unreliable markets for agricultural produce have limited the use of fertilizers by the majority of smallholders in Kenya (Hassan *et al*., 1998). The common method of maintaining soil fertility is the application of farmyard manure, but its quality is usually low because of poor handling and poor quality feeds for livestock (Lekasi *et al*., 2003). In order to increase snap bean production, there is a need to consider an integrated approach to nutrient management which includes the use of affordable, easily accessible and environmentally friendly soil fertility management options.

1.2 Problem statement and justification

Low levels of nitrogen, potassium, organic carbon and micro-nutrients are a major constraint to rural small scale farmers in Embu County. Most of the soils in Embu County are deficient in nitrogen and phosphorous which are the key elements for crop growth and yield, therefore resulting in poor and low quality yield of snap bean (Wortman *et al*., 1998, Wangechi, 2009; Kamanu *et al*., 2012). Deterioration in soil fertility is as a result of smallholder farmers continually cultivating their lands without appropriate protection and amendments, hence leading to massive surface soil erosion and land degradation over time (Smaling, 1993).

Symbiotic nitrogen fixation by legumes plays an important role in sustaining crop production and maintaining the soil fertility. However, symbiotic nitrogen fixation is particularly sensitive to environmental stresses such as low levels of nitrogen, phosphorous and other nutrients in the soil therefore further constraining snap bean productivity (Serraj *et al*., 2004). Hence rural small scale farmers have to depend on the use of inorganic and organic fertilizers to be able to manage and supply the major nutrient deficiencies in their farms. Even though the use of inorganic fertilizers is recognized as the suitable way for rapid correction of nutrient deficiencies in the soils, its high cost limits its wide application by smallholder farmers in Embu County (Ibijben *et al*., 1996). As a result, small scale farmers use farmyard manure in their farms. The importance of farmyard manure is currently being recognized because of the high cost of commercial fertilizers and their associated long term adverse effects on soil chemical properties. Besides supplying macronutrients and micronutrients to the soil, (Negassa *et al*., 2001; Tirol-Padre *et al*., 2007), farmyard manure also improves the physico-chemical properties of the soil (Tirol-Padre *et al*., 2007). However, unless it is integrated with inorganic fertilizers, the use of farmyard manure alone may not fully satisfy crop nutrient demand, especially in the year of application (Patel *et al*., 2009). Animal manures are also useful in improving the efficiency of fertilizer recovery thereby resulting in higher crop yield (Gedam *et al*., 2008). Farmers in Embu County pay little attention to soil fertility management. They rarely apply organic fertilizers to their farms; however, they may use inorganic fertilizer but these are often not economically rationalized nor based on soil analysis (Wangechi *et al*., 2009; Kamanu *et al*., 2012). Since most of the small scale farmers do not carry out soil analysis, it is difficult for them to apply the appropriate rates and types of inorganic and organic fertilizers. Some studies have demonstrated that integrated nutrient management increases yield in snap bean as well as lowering the cost of production. This therefore calls for the need to identify fertilizer application regimes which enhance snap bean productivity and profitability.

1.3 Objectives of the study

The main objective of this study was to establish the appropriate nutrient management options for improving growth, yield and quality of snap bean in Embu County. The specific objectives of the study were:

1. To determine the effect of combining inorganic and organic fertilizers on the growth, yield and quality of snap bean.

2. To determine the cost effectiveness of various nutrient management options for snap bean production.

1.4 Hypotheses

1. A combination of inorganic and organic fertilizers improves growth, yield and quality of snap bean.
2. A combination of inorganic and organic fertilizers is more cost effective than application of inorganic or organic fertilizers alone.

CHAPTER TWO: LITERATURE REVIEW

1.1 Ecology and importance of snap bean

Snap bean grows best in lower midland and lower highland zones with the altitude range of 1000 - 2000 m above the sea level. It also does best under warm temperatures ranging between 15^0C and 34^0C (Pcarrd, 1989; Bay-an MC, 2002; KALRO, 2007). Snap bean is highly sensitive to temperature with temperatures below 12^0C being harmful to germination and cause damage due to frost. Temperatures above 34^0C destroy and damage the flowers leading to little or no yield at all. The crop grows best in well drained, sandy loam, silt loam or clay loam soils rich in organic matter content but sensitive to soil pH of 5.2. They do well in soils with a pH range of 5.5 to 6.5 (Kamanu *et al*., 2012). The rainfall should be well distributed throughout the growing season but too much rainfall causes disease and flower drops. The plant requires well distributed rainfall throughout the year, 600 -1500 mm, and the soil should be well drained; a waterlogged soil increases risk of root rot during seed germination. Snap bean is very sensitive to salinity; fertilizer applications should be applied in several instalments to avoid excess doses of salts (Infornet-biovision, 2012). This crop is also very susceptible to drought compared to other legumes (Pimentel *et al*., 2001). Drought causes abortions and abscission of buds and flower drops thus reducing the pod yield by 45% (Xial, 2009). Germination occurs four to ten days after sowing depending on the snap bean variety while flowering commences 28 to 35 days after sowing (Pesticides Initiative Programme, 2011). Harvesting of snap bean begins before the pods are fully grown, seven to eight weeks after sowing in early maturing varieties and continues for about three to five weeks depending on the altitude, variety and seasonal climate. The pods are picked every 2-3 days (Infornet-biovision, 2012).

In Kenya snap bean was initially grown exclusively for export market mainly to the European market, but over the years it has gained popularity in the local market and its consumption locally has also increase therefore a rise at the domestic markets (HCDA, 2016).

The area under snap bean production has increased from 5,671 ha^{-1} in 2015 to 5,983 ha^{-1} in 2016 which was 6 per cent increase compared to 2015also the production has increased from 34,779 tons to 41,789 tons while the value increased from Ksh1.38 billion to Ksh1.81billion representing 20 per cent and 31 per cent increase from 2015 (HCDA, 2015). Snap bean has recently gained importance as an export crop in Tanzania, Uganda, Rwanda and Sudan and is expected to play an enhanced role in the socio-economic systems of these countries. More than 90 per cent of the crop produced in Eastern Africa is exported to regional and internal markets. Round and thin types of snap bean pods are produced in Eastern Africa which is mainly preferred by Europe countries (CIAT, 2006).

The production of snap bean is mainly dominated by rural small scale farmers especially women and youths, and this forms their major source of income (Ndung'u *et al*., 2004; Monda *et al*., 2003). The main production areas of snap bean in Kenya are Kirinyanga, Athi River, Naivasha and Meru. The leading counties were Kirinyaga, Machakos and Murang'a that accounted for 32, 20.7 and 13.5 per cent respectively of the countries value in 2016 (HCDA, 2016). Snap bean production has created on-farm employment opportunities to rural farmers especially the women and the youths. It is estimated that more than 1 million people benefit from the snap bean sub-sector (CIAT, 2006).

Snap bean is a good substitute of major sources of protein products which have become very expensive. It requires less energy to cook, and is consumed as vegetable (Ndegwa *et al*., 2006). Snap bean is a nutritionally rich source of vitamin A, C, K and micro-nutrients (Fe and Zn). The micro- nutrients are important in the body because they play a part in cognitive development and fighting anemia among women, weaning children, the youth and other vulnerable populations as HIV& AIDs infected persons. The crop can also be used as green fodder for cattle and the pods are source of raw materials to the canning factories. Compared to dry beans, snap bean has a higher monetary value both in the local and export markets. Snap bean matures early and has a longer harvesting period than dry bean (Ugen *et al*., 2005).

2.2 Constraints to snap bean production

In spite of the results indicating that trade in snap bean production is highly profitable (Kamau, 2000), snap bean production is still being hindered by diseases and pests. The diseases include bean rust, anthracnose, angular leaf spot, common bacterial blight and common bean mosaic virus, while the bean stem maggot, aphids (*Aphis phabae*), thrips and nematodes are the major pests (Kimani *et al*., 2004; Musaana *et al*., 2011). Bean rust (*Uromyces appendiculatus)* is a major foliar disease of snap bean. According to a report by Wagacha et al., (2007) farmers incur losses of 25-100 per cent as a result of bean rust. Bean fly is a major pest of snap bean at seedling stage; yield losses of 30 to 100 per cent are associated with the pest during the dry season (Kaburu, 2011), while thrips at flowering and harvesting stage with a loss of more than 60% (Nderitu *et al*., 2010; Nyasani *et al*., 2012). Nderitu et al., (2007) reported that the yield reduction due to thrips could be as high as 40% at farm level and 20% at collection points thus leaving the small scale farmers with no option but to rely on costly pesticides to control diseases and pests (Nderitu *et al*., 2001; CIAT 2006; Mwangi, 2008).

Low soil fertility, especially low levels of nitrogen and phosphorous, is a key constraint to snap bean production. Nitrogen and phosphorus are the key elements vital for crop growth and yield production. According to Wortman et al., (1998) low nitrogen, phosphorous and potassium in the soils can cause bean yield loss equivalent to 744,900 MT per year in Eastern Africa. Other studies have proven that bean yield losses due to nitrogen and phosphorus deficiencies were estimated to be about 389,900 and 355,900 t/ha respectively (Wortman *et al*., 1998). Stresses such as poor soil fertility are long term and predictable (Lunze *et al*., 2011). Others like drought, some pests and diseases spurred by climate change could be short term but acute in nature (Katafiire *et al*., 2011). Smallholders can apply inorganic and organic fertilizers in their farmers to manage nitrogen and phosphorous deficiencies in their soils.

Snap bean farmers' production is further limited by lack of seeds and, if available, they are very costly (Ndegwa *et al*., 2009; CIAT 2006). Most of the snap bean varieties grown in Kenya are imported from Europe and are not adapted to the local climatic conditions (ASARECA, 2010). However, these imported varieties of snap bean seeds put the industry at a risk in case of outbreaks of new races of diseases and insect pests (Kweka, 2011). The few varieties developed by the public institutions are often susceptible to diseases and pests (CIAT, 2006). A report by Monda et al., (2003) reported that the use of own seed by farmers was a major means of transmission of seed borne pathogens like *Colletotrictum lindemuthianum* and *Phaeoisariopsis griseola*.

Post-harvest loss of snap bean at the farm level is another challenge to the small scale farmers (Katafiire *et al*., 2011). Snap bean is consumed fresh hence proper preservation in order to access the desired market is vital. Since consumption of fresh and frozen snap bean has been on the increase, thus, there is need for proper handling and management from harvest to export (Monda *et al*., 2003; Katafiire *et al*., 2011). Small scale farmers in Kenya lack proper post-harvest storage and handling facilities and technologies, leading to failure to meet the desired quantity and quality for the domestic and export markets (Ndegwa *et al*., 2010). To meet high quality of snap bean, smallholder farmers rely on fungicides and insecticides to reduce production and post-harvest losses associated with diseases and pests (CIAT, 2006), but this strategy is not sustainable in the face of tough maximum residue levels requirements in the export markets. Lack of value addition technologies in snap bean production is another challenge in snap bean production (Katafiire *et al*., 2011). Snap bean is categorized as a highly perishable vegetable that deteriorates quickly if not provided with proper temperature management. 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 production is also constrained by high cost of inputs especially the price of fertilizers and seeds. Kariuki (2012) reported that lack of credit to purchase inputs by small scale farmers has led to low usage of imported inorganic fertilizers. Price fluctuations and rejection of snap bean by the EU markets are the major marketing constraints that contribute to loss of income (Monda *et al*., 2003; Netherlands Development Organization, 2012). The EU regulations have forced small scale producers to change their pesticide application regimes and pesticide types (Muriithi, 2008). Most recently, the EU imposed 10% sampling per consignment of beans and peas from Kenya (KEPHIS, 2012). Increased controls and constant change in maximum residue levels (MRLs) and EU regulations on pesticides affected the Kenyan bean industry significantly, resulting in a 25% reduction in beans sales in January 2013 compared to January 2012 sales (PIP, 2013). Farmers need to adopt safer alternatives of pest control (Monda *et al*., 2003), and implement the requirements of the voluntary standards like Global G.A.P to be successful in the export markets (KEPHIS, 2012; Muriithi, 2008) which is a major challenge to small scale farmers in Kenya.

2.3 Effect of nitrogen fertilizer application on growth, yield and quality of snap bean

Nitrogen is a vital element for plant growth and is a constituent of nucleic acids and amino acids (Mala- kooti and Tabatabayee, 2005). Nitrogen is often provided to agricultural lands by the application of urea, ammonium nitrate and sulphate ammonium as well as livestock manure, but excess application of these chemicals can be harmful to the environment (Samavat *et al*., 2012). Minor sources of nitrogen input to the soil include deposition of nitrogen and ammonia from the atmosphere, nitrogen fixed biologically by legumes plants and sewage waste which is disposed of the farms. Therefore, the nitrogen requirement of the crop must be met through application of nitrogen fertilizers to improve growth, yield and quality of snap bean.

High rates of nitrogen fertilizers have been reported to increase snap bean growth and produce higher profits (Singh *et al*., 2011). According to Kamanu et al., (2012) application of 91 kg N /ha on variety Serengeti produced the highest yield. Hedge and Srinivas (1989) found that the highest green pod yield of snap bean were from the plants which were supplied with the highest nitrogen rate (120 kg N/ha). A similar report was made by Faizs et al., (2012) who observed that plots with nitrogen fertilizer application produced the highest yield of snap bean compared to the plots with no nitrogen fertilizer application.

Excessive application of N may also result in excessive vegetative growth leading to delayed flowering, reduced pod setting, lower seed yield and a greater risk of disease infestation (Nisar *et al*., 2002). Pick and Mac Donald (1984) evaluated the N content in snap bean pod at 0, 40, 80 and 120 kg N ha^{-1}, and reported that the highest N content was in 120 kg N ha^{-1}. These results show that bean responds positively to N fertilization and this response depends on availability of N in the soil. Delayed nitrogen fertilizer application to a later growth stage, leads to a greater proportion of N being utilized for seed production, producing more and or larger seeds, rather than vegetative growth (Davis and Brick, 2009). Ramesh et al., (2009) reported that application of 180 kg N ha^{-1} resulted in higher number of seeds per pod which significantly increased the pod length. A similar report was made by Amos et al., (2001) who found that nitrogen fertilizers only increased the number of seeds per plant, pod number and grain yield of common bean. Low N content in the soil can cause physiological disorders. Singh et al., (2003) stated that a low content of nitrogen (N) in the soil (45 kg ha^{-1}) affected growth rate and caused chlorosis in bean leaves.

Nitrogen fertilizers decrease nodulation and nodule dry weight. Based on extensive research conducted to test the effect of nitrogen fertilizers on nodulation and nitrogen fixation, it has generally been acknowledged that when sufficient levels of nitrogen are present in the soil, nodulation is inhibited (Gentill and Huss-Danell, 2003; 2006; Laws *et al*., 2005; Taylor *et al*., 2005; Chemining'wa and Vessey, 2006; Chemining'wa *et al*., 2011). Kamanu et al., (2012) reported that N fertilizer application significantly reduced the number of nodules and nodule dry weight per plant in snap bean.

2.4 Effect of phosphorus fertilizers on growth, yield and quality of snap bean

Phosphorus is required in large qualities for plant growth, and it is the most limiting nutrient factor after nitrogen. Phosphorus has an important role in energy transfer, photosynthesis, conversion of sugar to starch and carrying genetic traits (Kim *et al*., 1989). Nutrient balance studies indicate that soils in small scale farms in the tropics frequently lose fertility as a result of greater export than import of nutrients. Losses of phosphorous (P) can be particularly detrimental to plant growth due to the inherently low plant available P in tropical soils (Lunze *et al*., 2007). Furthermore, there is no biological process by which P is added to the soil comparable to nitrogen (N) fixation (Anonymous, 2000).

The nitrogen-fixing legume plants usually require more phosphorus than plants dependent on mineral nitrogen fertilizer (Serraj *et al*., 2004). Phosphorus is involved in reactions and processes required for accumulation and release of energy for cellular metabolism, seed formation and root development in crop plants (Terry and Ulrich, 1973; Kikby and Le Bot, 1994). Phosphorous fertilization contributes to early crop development, maturity and early flowering (Covarelli., 1977; Nassar *et al*., 2004; Muhammad *et al*., 2012). Phosphorous also increases the efficiency of nutrient uptake by plants and stimulates setting of pods, decreases the number of unfilled pods and hastens the maturity of crops (Gascho *et al*., 1990). Phosphorus has been reported to improve both the nodule number and nodule dry weight in snap bean (Floor, 1985; Ganeshamurthy *et al*., 2000). Meseret et al., (2014) found that the application of phosphorous fertilizer significantly increased growth and yield of common bean.

2.5 Effect of integrated nutrient management on growth, yield quality of snap bean

Declining soil fertility and high cost of inorganic fertilizers are major constraint to snap bean production in eastern Africa (Maobe *et al*., 2000; Chemining'wa *et al*., 2004; Kimani *et al*., 2007). Nitrogen and phosphorous are identified as the major limiting nutrients for many crops in Kenya (Kwambiah *et al*., 2003) and their applications from inorganic and organic sources is essential to maximize and sustain crop yield potentials (Hartemink *et al*., 2000).

Integrated nutrient management involves applications of combinations of both inorganic and organic fertilizers to increase crop and soil productivity (Janssen, 1993). It is achieved through efficient management of all nutrient sources (Singh *et al*., 2002). This involves the use of all natural and man-made sources of plant nutrients so that crop productivity increases in an efficient and environmentally benign manner without sacrificing soil fertility for the future generations (Gruhn *et al*., 2002). Application of excessive amount of inorganic and organic fertilizers does not substantially increase crop nutrient uptake and crop yields (Smaling *et al*., 1996). Instead, excessive nutrient application is economically wasteful and can damage the environment. Under application of nutrients can retard crop growth and lower yields in a short term and in the long run, jeopardize sustainability through soil mining and erosion (Smaling *et al*., 1996).

The performance of any crop depends not only on its genetic characteristic but also on the surrounding environmental conditions particularly the availability of nutrients in the soil hence integrated nutrient management is needed. Research shows that application of combined organic and inorganic fertilizers at only half the recommended rates offers a more economical option resulting in optimum crop production, compared to the use of either single source. Continuous use of organic manures stabilizes the soil structure and promotes buildup of microbial populations, some of which are essential in facilitating nutrient formation and transfer processes through rhizobial and mycorrhizal symbioses, enabling improved productivity (Ibijbijen *et al*., 1996). Besides supplying macronutrients and micronutrients to the soil (Negassa *et al*., 2001; Tirol-Padre *et al*., 2007), farmyard manure also improves the physico-chemical properties of the soil (Tirol-Padre *et al*., 2007). However, unless it is integrated with inorganic fertilizers, the use of farmyard manure alone may not fully satisfy crop nutrient demand, especially in the year of application (Patel *et al*., 2009). Animal manures are also useful in improving the efficiency of fertilizer recovery thereby resulting in higher crop yield (Gedam *et al*., 2008). According to Datt et al., (2003) integrated treatments were found to be better than organic ones in terms of pod yield in snap beans. Ramgopal et al., (2003) also reported that snap bean grain yields were increased with an increase in irrigation and nitrogen fertilizer rate along with farmyard manure.

2.6 Effect of foliar feed application on growth, yield and quality of snap bean

Crop plants require 17 nutrients to complete their life cycle. Essential plant nutrients are divided into macro and micronutrient groups (Brady *et al*., 2002). However, the essentiality of silicon (Si), sodium (Na), vanadium (V), and cobalt (Co) has been considered, but is not yet proven (Mengel *et al*., 2001; Fageria *et al*., 2002; Epstein and Bloom, 2005). Macronutrients are required in higher amounts compared to micronutrients. Though, from the plant essentiality point of view, all the nutrients are equally important for plant growth. Also, the first three macronutrients (C, H, and O) are supplied to plants by air and water. Hence, their supply to plants is not a problem. Therefore, the remaining 14 nutrients should be present in the plant growth medium in adequate amount and proportion for plant growth (Fageria, 2005; 2007; Baligar *et al*., 2005). Research on foliar fertilization was possibly started in the late 1940s and early 1950s (Fritz, 1978; Haq *et al*., 2000; Girma *et al*., 2007) but on selected crops including cereals (Girma *et al.*, 2007). However, in the 1970s, the research was restricted to micronutrients in high-value horticultural crops (Fritz, 1978) such as potato and tomatoes (Kaya *et al*., 2001).

Soil application is the most common method to supply essential nutrients to plants. In this case applied nutrients are absorbed by plant roots. Foliar fertilization is any nutrient supply substance applied to the leaves in liquid form. Foliar fertilization is increasing in practice because it is environmentally friendly, as the nutrients are directly delivered to the plant in limited amounts, thereby helping to reduce the environmental impacts associated with soil fertilization (Kuepper, 2003; Lovatt, 1999).

Foliar nutrients are mobilized directly into a plant leaf, resulting in increased rate of leaf photosynthesis in the leaves and enhanced nutrient absorption by plant roots (Barel *et al*., 1979). In recent years, there has been a steady trend to reduce the use of mineral fertilizers, especially soil applied nutrients such as nitrogen, phosphorus, and potassium (Kerin *et al*., 2003). 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.

Intensive farming, which produces high yields and quality, require the extensive use of chemical fertilizers that are both costly and create environmental problems. Hence, there has been a recent rebirth of interest in environmentally friendly, sustainable and organic agricultural practice (Orhan *et al*., 2006; Esitken *et al*., 2006). Therefore, it's necessary to supply the plant requirement to nutrient through proper procedure. One of the best methods is foliar application. Foliar feeding is an effective method for improving soil deficiencies and overcoming the soils inability to transfer nutrients to the plant. According to Fageria et al., (2009) interest in foliar sprays have increased because of the production of high concentration soluble fertilizers and the development of machinery for spraying fungicides, herbicides, and insecticides. Overhead irrigation further facilitates the application of nutrients to crops in the form of sprays. However, foliar sprays cannot substitute soil fertilization, but can be used to supplement soil applications in sustainable crop production. Garcia et al., (1976) reported that foliar feeding can be eight to ten times more effective than soil feeding and up to 90% of foliar fed nutrient solution can be found in the smallest root of a plant within 60 minutes of application. Liunsheng et al., (2015) observed that spraying snap bean with foliar feed which contains asparagine increased vegetative growth, total yield and quality of snap beans. According to Nderitu et al., (2001) foliar sprays-treated plots recorded the lowest infestation of beanfly level compared to plots where snap beans were seed dressed only. They considered foliar application as the most efficient way to increase yield and plant health. It is also recognized that supplementary foliar fertilization during crop growth can improve the mineral status of plants and increase the crop yield (Elayaraja and Angayarkanni, 2005). Ewais (2010) observed that foliar spray on snap bean increased yield, pod quality and protein content.

Foliar urea application provides an alternative fertilization strategy minimizing the potential risk of nutrient leaching loss compared with conventional soil fertilization (Gooding and Davies 1992; Dong *et al.*, 2005). Oko *et al*., (2003) reported that foliar fertilization of urea at an early reproductive stage increased soybean grain yield by 6% and 68% compared to the control. A study by Ranđelović *et al.*, (2009) demonstrated that foliar feeding is an effective tool for increasing grain yield in two soybean cultivars. In other studies, Sultan et al., (2003) showed that spraying with foliar fertilizers at 45 days after sowing increased grain yield of soybean. Previous studies have shown that supplementing soil potassium supply with foliar K applications during pod development can improve pod quality and that differences may exist among K compounds for foliar feeding (Lester *et al*., 2006).

Studies by Babar et al., (2011) and Iftikhar et al., (2010) reveal that applications of foliar N near flowering increased post flowering N uptake, grain protein content, and overall grain yield. Woolfolk et al., (2002) have demonstrated that foliar N applications are often associated with leaf burn when applications are made early in the morning when the dew is still on the crop. Foliar fertilization, does not totally replace soil fertilization on crops with large leaf area, but may improve the uptake and the efficiency of the nutrients applied to the soil (Kannan, 2010; Tejada and Gonzales, 2004). According to El-Habbasha (2007), increasing foliar nitrogen fertilizer increases bean pod weight per plant. Some studies have shown that the yield obtained from plants that have had foliar applications of molybdenum is higher than that obtained from plants that have not (Ide *et al*., 2011).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of the experiment site

The study was conducted at Karungua village, Kawanjara sub-location, Runyenjes Division, Embu County, which lies at -0° 28' 58.77", +37° 37' 40.16"(Google, 2012). The area falls under the main coffee agro ecological zone or upper midland zone two (UM2). The area receives a bimodal rainfall pattern with the long rain season stretching from March to July and the short rain season from October to December. It receives an average annual rainfall of 1400 mm with a mean temperature of 15.8^{0}C to 15.0^{0}C (Jaetzold *et al*., 2006a). The rainfall is unreliable for snap bean, therefore farmers irrigate their lands to supplement the uneven rainfall and as a result the soil nutrients especially N are lost through leaching. The soils are well drained, dusky reddish brown, with an acid humic top soil (Jaetzold *et al*., 2006b). The soil at the experimental site had an average pH of 5.93 with high P level of 95 ppm while N level was low at 0.19%, based on soil analysis tests carried out at the Kenya Agricultural and Livestock Research Organization (Appendix 1). The first trial was set up on 26th July 2014 and the second season was set up on 15th August 2014. Sprinkler irrigation was used to provide water to the crop when there was no rainfall to ensure that moisture content was maintained at the field capacity.

3.2 Experimental layout and design

Eleven treatments were laid out in a randomized complete block design and replicated three times. The following were the treatments tested in the study:

1. Control (no-fertilizers applied);
2. Farmyard manure (5 t/ha) + di-ammonium phosphate (50 kg N/ha) both applied during planting + calcium ammonium nitrate (50 kg N/ha) top dress at 21 days after planting;
3. Di-ammonium phosphate (50 kg N/ha) applied during planting + calcium ammonium nitrate (50 kg N/ha) top dress at 21 days after planting;

4. NPK (23:23:0) (50 kg N/ha) fertilizer applied during planting + calcium ammonium nitrate (50 kg N/ha) top dress at 21 days of planting (main farmers' practice);
5. Di-ammonium phosphate (50 kg N/ha) applied during planting + calcium ammonium nitrate (50 kg N/ha) top dress at 21 days after planting + foliar feed sprayed at pre-flowering stage;
6. Farmyard manure (5 t/ha) + NPK (23:23:0) (50 kg N/ha) fertilizer both applied during planting + NPK (17:17:17) (50 kg N/ha) fertilizer top dress after 21 days after planting;
7. Farmyard manure (5 t/ha) applied during planting + foliar feed sprayed at pre- flowering stage;
8. Farmyard manure (5 t/ha) alone applied during planting;
9. Farmyard manure (5 t/ha) + di-ammonium phosphate (50 kg N/ha) + NPK (23:23:0) (50 kg N/ha) fertilizer both applied during planting + calcium ammonium nitrate (50 kg N/ha) top dress at 21 days after planting + NPK (17:17:0) (50 kg N/ha) fertilizer top dress at 35 days after planting;
10. Farmyard manure (5 t/ha) + calcium ammonium nitrate (50 kg N/ha) both applied during planting + calcium ammonium nitrate (60 kg N/ha) top dress at 21 days after planting (Recommendation by the Kenya Agricultural and Livestock Research Organization based on soil tests);
11. Farmyard manure (5 t/ha) applied during planting + calcium ammonium nitrate (50 kg N/ha) top dressing after 21 days of planting.

Each experimental plot 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.

3.3 Crop husbandry practices

The plots were ploughed and harrowed to obtain a seedbed with a fine tilth. Irrigation was done before planting to ensure that the seedbed had adequate moisture. To prevent damage from bean fly and other soil borne pests, the snap bean variety Serengeti seeds were dressed with Monceren GTFS 390® (active ingredients Imidacloprid, Thiram and Pencycuron) at the rate of 8 ml/kg before planting. After seed dressing, the seeds were kept under the shade to dry before planting. The planting distance was 50 cm between rows and 10 cm within the rows. Sprinkle irrigation was generally applied thrice per week during the dry period to keep moisture levels at field capacity. Pesticides Confidor ® (active ingredient imidacloprid) and Duduthrine® (active ingredient lambdacyhalothrin) were applied at the rate of 30 ml/20 liters of water to control thrips, aphids, whiteflies, leafminers and mites. The pesticides were only sprayed whenever pest populations justified control. For the control of bacterial disease, angular leaf spot, rust, blights and anthracnose, 50 g/20 litres of water Isacop® (active ingredient copper oxychloride) were sprayed. The plots were kept weed free by regular weeding and the birds were controlled by using scarecrows.

3.4 Data collection

3.4.1 Agronomic data collection

The parameters measured included days to 50% emergence, plant stand, days to 50% flowering, days to 50% podding, number of nodules per plant, shoot dry weight, pod yield and yield components, pest and disease infestation.

The number of plants that had emerged was counted daily from 6 days after planting and days to 50% emergence estimated in each plot. To determine nodulation number and shoot dry weight, three plants in the middle rows were randomly uprooted at 21 days after plant emergence and this was done after irrigating the plots very early in the morning to loosen the soil in the root zone. A machete was used to lift up the soil around the selected plant without shaking it off the plant to ensure that the roots attached to the nodules were not lost. The three plants were then packed in khaki paper bags and transported to the laboratory where the nodules were counted. The roots were immersed in water to remove the soil and the shoots were cut off. Shoots of the three plants were packed in khaki papers bags and oven dried at 50 ^{0}C to constant weight then weighed. The number of plants that had flowered was counted daily in each plot to determine the number of days to 50% flowering. Fifty per cent podding was determined by counting the number of plants that had set pods in the middle five rows of each plot. Plant stand was determined at 50 days after emergence by counting the number of remaining plants in the experimental plots while taking into account the number of plants that had been uprooted for nodule count.

The crop was harvested from 40th day after planting and continued at two day intervals for six weeks in both plantings. Harvesting was done in the middle five rows of each plot. Harvested pods were immediately weighed under the shade to avoid loss of moisture and total fresh weight determined. Pods were sorted into marketable yield of extra fine and fine grade then weighed separately using an electronic weighing balance and total number of pods recorded. Extra fine pods were 8 cm in length but not exceeding 9 mm in diameter, while fine pods were 12 cm in length and 9-10 mm in diameter. Rejects grade were those beans that had the following defects; not straight, mechanical damage, fungal infection, insect contamination and excessive seed development (Kimani *et al*., 2004). Ten pods per class were sampled and their pod lengths recorded.

Severity of infestation of diseases like, anthracnose, rust and angular leaf spot was assessed using the CIAT scale (Schoonhoven and Corrales, 1987) where: 1, 2, 3 signified the absence of symptoms (resistance); 4, 5, 6 signified intermediate attack of diseases; and 7, 8, 9 signified susceptibility of the snap bean to diseases. The bean steam maggot (beanfly) incident was assessed by checking and sampling the plants showing infestation per plot at two, four and six weeks after emergence. Five plants from the outer rows of each plot showing beanfly attack symptoms were destructively sampled. The sampled plants were dissected and infested plants and the number of larvae and pupae of the beanfly were counted and recorded. The beanfly was identified by using morphological characteristics such as color, maggots yellow in color and pupae brown or black in color. The main symptoms of beanfly attack used to recognize infestation included punctures and scarification on the leaves, swelling at the base of the stem, development of longitudinal cracks on the stem and yellowing of the leaves that give a drought like appearance (Infornet- Biovision, 2012).

Scores for white flies and aphids were determined weekly on 20 random selected plants per plot during the vegetative stage. Severity of infestation by insect pests like white flies, aphids and bean steam maggot was assessed using the CIAT scale (Schoonhoven and Corrales, 2010) where: 1, 2, and 3 signified the absence of symptoms (resistance); 4, 5, 6 signified intermediate attack of insect pest; and 7, 8, 9 signified susceptibility of the snap bean to the insect.

3.4.2 Economic data collection

Primary data on inputs and outputs was obtained from the operations carried out during experimentation. Prices of fertilizers and pesticides were obtained from the local markets in Embu County. The actual sale price of snap bean seeds was obtained from Kenya Highland Seed Company, a major snap bean buyer and exporter in the area. The average price paid for extra fine and fine pod grades by the exporters was Ksh 55.00 per Kg during both first and the second season.

Detailed data on labour requirements were collected for every season during field trial operation. The fixed costs of various regimes consisted of land for hire 4 months, land preparations, costs of seeds, costs of pesticides and insecticides, irrigation cost and costs of labour (land preparation, planting, weeding, and harvesting). Non-fixed costs comprised costs of purchasing and applying fertilizer for each treatment. Average yields for each treatment was calculated and adjusted according to CIMMYT (1988). The prices of pesticides, insecticides, fertilizers, seeds, labour and irrigation used in the calculation were the prevailing prices in Embu during the four month period.

3.4.3 Agronomic data analysis

Agronomic data collected were subjected to analysis of variance using GenStat Discovery Edition 15th statistical package. Comparison of treatment means was done using the least significant difference (LSD) test at 5% probability level (Steel and Torrie, 1987).

3.4.4 Economic data analysis

The data was analyzed using excel computer program. Analysis performed included, net benefit, dominance and marginal rate of returns. Net benefit was computed as the difference between the gross field benefit and total variable cost for each variety. Gross field benefit was computed as the product of adjusted average snap bean yield (kg per hectare) by the field price according to Economic analysis of on-farm trials a review of approaches and implications for research program design (Duncan Boughton *et al.*,1990). The cost components included, land for hire (4 months), land preparation, purchase of seeds and pesticides, irrigation cost, cost of labour, costs of fertilizers and cost of applying fertilizers. Labour (planting, weeding, and harvesting) involved in carrying out each operation was taken into account. A mean field price of Ksh 55.00 per kg of snap bean was used. Dominance analysis is done by sorting the treatments on the basis of total variable cost listing them from the lowest to the highest together with their respective net benefit. Any treatment with net benefit less or equal to those treatments with lower cost is considered dominated or inferior hence it is excluded from further analysis. Un-dominated treatments imply that increase in total variable cost associated with the change from one treatment to another had a commensurate increase in the net benefit and hence decision on the best treatment to be adopted cannot be decided at this stage. This leads to analysis of marginal rate of return

(MRR) which throws more light on the relationship among the un-dominated treatments in terms of increasing costs and benefits.

Marginal rate of return (MRR) gives details on per cent return to additional investment as a farmer changes from one treatment to the other treatment. It is the ratio of net benefit to total variable costs expressed as a percentage or just as a ratio. The marginal rate of return and dominance were computed according to CIMMYT (1988).

$$\text{MRR (between treatments, a \& b)} = \frac{\text{Change in NB (NBb- NBa)}}{\text{Change in TCV (TCVb -TCVa)}} \times 100 \ldots\ldots\ldots\ldots\ldots(1)$$

Where:

- NB= net benefit.
- TVC= total variable cost.
- NBa= net benefit for treatment ‘a’.
- NBb= net benefit for treatment ‘b’.
- TVCa= total variable cost for treatment ‘a’.
- TVCb= total variable cost for treatment ‘b’.

Thus, a MRR of 100% implies a return of one Kenyan shilling on every shilling of expenditure in the given variable input.

CHAPTER FOUR: RESULTS

4.1 Effect of nutrient management options on the number of days to 50% emergence of snap bean

Nutrient management options had no significant ($p \leq 0.05$) effect on the number of days to 50% emergence in snap bean (Table 4.1). The number of days to 50% emergence ranged from 5.3 (fertilized plots) to 5.7 (control) and 5.6 (fertilized plots) to 5.9 (control) in the first and second planting, respectively.

Table 4. 1: Effect of nutrient management options on the number of days to 50% emergence of snap bean

	First planting	Second planting
Treatment		
1. Control (no fertilizer applied)	5.7 a	5.9 a
2. FYM + DAP + CAN top dress (21 DAE)	5.6 a	5.8 a
3. DAP + CAN top dress (21 DAE)	5.3 a	5.6 a
4. NPK (23:23:0) + CAN top dress (21 DAE) (famers' practice)	5.6 a	5.8 a
5. DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	5.3 a	5.6 a
6. FYM + NPK (23:23:0) + NPK (17:17:0) top dress (21DAE)	5.3 a	5.7 a
7. FYM + foliar (pre-flowering)	5.3 a	5.7 a
8. FYM	5.6 a	5.7 a
9. FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	5.6 a	5.8 a
10. FYM + CAN + CAN top dress (21 DAE)	5.4a	5.6 a
11. FYM + CAN (21 DAE)	5.4a	5.7 a
***P* value**	0.488	0.476
$LSD_{P=0.05}$	NS	NS
CV%	8.5	2.9

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; DAP=di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard Manure; DAE= days after emergence.

4.2 Effect of nutrient management options on the plant stand of snap beans at 50 days after emergence

Nutrient management options had no significant effect ($p \leq 0.05$) on the plant stand at 50 days after emergence in both plantings (Table 4.2). Plant stand ranged from 248.7 (no-fertilizer) to 303.3 (DAP + CAN) plants per plot in the first planting while in the second planting the plant stand ranged from 324 (no-fertilizer) to 333 (DAP + CAN) plants per plot.

Table 4. 2: Effect of nutrient management options on the plant stand (number of plants/plot) of snap beans at 50 days after emergence

	First planting	**Second planting**
Treatment		
1. Control (no fertilizer applied)	248.7 a	324.0 a
2. FYM + DAP + CAN top dress (21 DAE)	287.2 a	329.7 a
3. DAP + CAN top dress (21 DAE)	303.3 a	333.0 a
4. NPK (23:23:0) + CAN top dress (21 DAE) (famers' practice)	288.3 a	330.0 a
5. DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	282.7 a	329.0 a
6. FYM + NPK (23:23:0) + NPK (17:17:0) top dress (21 DAE)	282.2 a	327.7 a
7. FYM + foliar (pre-flowering)	281.7 a	325.2 a
8. FYM	249.3 a	325.0 a
9. FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	282.0 a	325.3 a
10. FYM + CAN + CAN top dress (21 DAE)	295.3 a	330.3 a
11. FYM + CAN (21 DAE)	255.3 a	325.1 a
***P* value**	0.516	0.695
LSD$_{P=0.05}$	NS	NS
CV%	11.8	1.8

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; DAP=di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard Manure; DAE= days after emergence.

4.3 Effect of nutrient management options on the number of days to 50% flowering of snap bean

In both plantings, there was a significant (p≤ 0.05) effect of nutrient management options on the number of days to 50% flowering (Table 4.3). In both plantings, FYM + foliar feed and FYM alone took fewer numbers of days to reach 50% flowering than all the other treatments. In the first planting, FYM + foliar feed took a shorter time than FYM alone to reach 50% flowering. No differences were noted among the rest of the treatments. The number of days to 50% flowering ranged from 31.3 to 32.0 in the first planting and 32.2 to 33.2 in the second planting.

Table 4.3: Effect of nutrient management options on the number of days to 50% flowering of snap bean

	First planting	**Second planting**
Treatment		
1. Control (no fertilizer applied)	32.0 a	33.2 a
2. FYM + DAP + CAN top dress (21 DAE)	32.0 a	33.0 a
3. DAP + CAN top dress (21 DAE)	32.0 a	33.0 a
4. NPK (23:23:0) + CAN top dress (21 DAE) (famers' practice)	32.0 a	33.0 a
5. DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	32.0 a	33.0 a
6. FYM + NPK (23:23:0) + NPK (17:17:0) top dress (21 DAE)	32.0 a	33.0 a
7. FYM + foliar (pre-flowering)	31.0 b	32.2 b
8. FYM	31.3 b	32.0 b
9. FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	32.0 a	33.0 a
10. FYM + CAN + CAN top dress (21 DAE)	32.0 a	33.0 a
11. FYM + CAN (21 DAE)	32.0 a	33.0 a
***P* value**	<.001	<.001
LSD$_{P=0.05}$	0.3	0.2
CV%	0.4	0.3

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; DAP=di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard Manure; DAE= days after emergence.

4.4 Effect of nutrient management options on the number of days to 50% podding of snap bean

Nutrient management options had no significant (p≤0.05) effect on the number of days to 50% podding in both plantings (Table 4.4). In the first planting, the number of days to 50% podding ranged from 46.0 (no-fertilizer) to 45.9 (FYM), while in the second planting the number of days to 50% podding ranged from 48.0 (no-fertilizer) to 47.7 (FYM and FYM + Foliar).

Table 4.4: Effect of nutrient management options on the number of days to 50% podding of snap bean

	First planting	Second planting
Treatments		
1. Control (no fertilizer applied)	46.0 a	48.0 a
2. FYM + DAP + CAN top dress (21 DAE)	46.0 a	48.0 a
3. DAP + CAN top dress (21 DAE)	46.0 a	48.0 a
4. NPK (23:23:0) + CAN top dress (21 DAE) (famers' practice)	46.0 a	48.0 a
5. DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	46.0 a	48.0 a
6. FYM + NPK (23:23:0) + NPK (17:17:0) top dress (21 DAE)	46.0 a	48.0 a
7. FYM + foliar (pre-flowering)	45.9 a	47.7 a
8. FYM	45.9 a	47.7 a
9. FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	46.0 a	48.0 a
10. FYM + CAN + CAN top dress (21 DAE)	46.0 a	48.0 a
11. FYM + CAN (21 DAE)	46.0 a	48.0 a
***P* value**	0.48	0.48
LSD$_{P=0.05}$	NS	NS
CV%	0.1	0.6

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; DAP=di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard Manure; DAE= days after emergence.

4.5 Effect of nutrient management options on the number of snap bean nodules per plant

Nutrient management options had a significant ($p \leq 0.05$) effect on the number of snap bean nodules per plant (Table 4.5). In both plantings, no-fertilizer plots had significantly ($p \leq 0.05$) more nodules per snap bean plant than all the nutrient management options. In the first planting, the number of nodules per plant ranged from 1.52 (FYM + CAN + CAN) to 19.67 (no-fertilizer), while in the second planting the number of nodules per plant ranged from 6.67 (FYM + CAN + CAN) to 47.67 (no-fertilizer). Application of farmyard manure alone had significantly higher number of nodules than all regimes that had inorganic fertilizers. Nutrient management options with CAN fertilizer top dress had significantly lower number of nodules than the other nutrient management regimes that had no CAN fertilizer.

Table 4. 5: Effect of nutrient management options on the number of snap bean nodules per plant

	First planting	Second planting
Treatment		
1. Control (no fertilizer applied)	19.7 a	47.7 a
2. FYM + DAP + CAN top dress (21 DAE)	11.0 e	19.6 g
3. DAP + CAN top dress (21 DAE)	2.4 h	17.7 h
4. NPK (23:23:0) + CAN top dress (21 DAE) (famers' practice)	3.0 g	15.4 i
5. DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	2.0 h	23.7 e
6. FYM + NPK (23:23:0) + NPK (17:17:0) top dress (21 DAE)	5.9 f	22.2 f
7. FYM + foliar (pre-flowering)	13.6 d	41.1 d
8. FYM	18.8 b	44.8 b
9. FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	2.9 g	9.6 j
10. FYM + CAN + CAN top dress (21 DAE)	1.5 i	6.7 k
11. FYM + CAN (21 DAE)	15.9 c	44.2 c
***P* value**	<.001	<.001
$LSD_{P=0.05}$	0.4	0.3
CV%	0.3	0.2

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; DAP=di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard Manure; DAE= days after emergence.

4.6 Effect of nutrient management options on shoot dry weight of snap bean per plant

Nutrient management options had a significant ($p \leq 0.05$) effect on shoot dry weight matter (Table 4.6). Applications of FYM + DAP + CAN and FYM + DAP + NPK + CAN + NPK had significantly higher shoot dry weight matter than application of FYM + NPK + NPK in the first planting; however, in the second planting these treatments had significantly higher shoot dry weight than all other nutrient management options except DAP + CAN. Generally, no-fertilizer control had significantly lower shoot dry weight that all the nutrient management options in both plantings. Shoot dry weight ranged from 133.3 g (no-fertilizer) to 188.9 g (FYM + NPK + NPK and FYM + DAP + NPK + CAN + NPK) per plant in the first planting and 155.6 g (no-fertilizer) to 255.6 g (FYM + DAP + NPK + CAN + NPK) per plant in the second planting.

Table 4. 6: Effect of nutrient management options on snap bean shoot dry weight per plant (grams)

	First planting	**Second planting**
Treatment		
1. Control (no fertilizer applied)	133.3 c	155.6 c
2. FYM + DAP + CAN top dress (21DAE)	188.9 a	251.0 a
3. DAP + CAN top dress (21 DAE)	179.5 ab	222.2 ab
4. NPK (23:23:0) + CAN top dress (21DAE) (famers' practise)	177.8 ab	211.1 b
5. DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	178.0 ab	206.6 b
6. FYM + NPK (23:23:0) + NPK (17:17:0) top dress (21 DAE)	155.6 bc	206.7 b
7. FYM + foliar (pre-flowering)	176.8 ab	188.9 bc
8. FYM	177.8 ab	200.0 b
9. FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	188.9 a	255.6 a
10. FYM + CAN + CAN top dress (21 DAE)	175.7 ab	203.4 b
11. FYM + CAN (21 DAE)	166.7 ab	188.9 bc
***P* value**	0.043	<.001
$LSD_{P=0.05}$	32.5	33.7
CV%	11.1	9.6

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; DAP=di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard Manure; DAE= days after emergence.

4.7 Effect of nutrient management options on snap bean extra-fine pod yield

Nutrient management options had a significant (p≤0.05) effect on extra-fine pod yield in both plantings (Table 4.7). In the first planting, application of DAP + CAN had significantly higher extra-fine pod yield in both plantings than most treatments. Application of FYM + CAN + CAN and DAP + CAN + foliar feed had higher extra-fine pod yield than famers' practice (NPK + CAN) and most of the other treatments. In the second planting, similar observations were made; however, application of DAP + CAN + foliar feed and DAP + CAN had the highest pod yield. In most cases, no-fertilizer plots had significantly the lowest extra-fine pod yield in both plantings. Farmyard manure alone and FYM + foliar feed had lower yield than most of the other treatments.

Table 4. 7: Effect of nutrient management options on snap bean extra-fine pod yield (kg/ha)

	First planting	**Second planting**
Treatment		
1. Control (no fertilizer applied)	422.8 f	5315 h
2. FYM + DAP + CAN top dress (21 DAE)	543.3 cd	6327 b
3. DAP + CAN top dress (21 DAE)	652.1 a	6481 a
4. NPK (23:23:0) + CAN top dress (21 DAE) (famers' practice)	558.8 c	6066 c
5. DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	623.5 b	6436 a
6. FYM + NPK (23:23:0) + NPK (17:17:0) top dress (21 DAE)	512.9 de	5890 d
7. FYM + foliar (pre-flowering)	507.7 de	5488 f
8. FYM	497.0 e	5315 h
9. FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	512.8 de	5727 e
10. FYM + CAN + CAN top dress (21 DAE)	605.7 b	6337 b
11. FYM + CAN (21 DAE)	488.5 e	5393 g
***P* value**	<.001	<.001
$LSD_{P=0.05}$	44.6	53.9
CV%	4.9	5.5

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; DAP=di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard Manure; DAE= days after emergence.

4.8 Effect of nutrient management options on snap bean fine pod yield

There were significant ($p \leq 0.05$) differences among nutrient management options in snap bean fine pod yield in both plantings (Table 4.8). Application of DAP + CAN and DAP + CAN + foliar feed had significantly higher fine pod yield than control in the first planting. In the second planting, DAP + CAN and DAP + CAN + foliar feed had significantly higher fine pod yield than most treatments. Application of FYM alone, FYM + CAN, FYM + NPK +NPK, FYM + foliar feed and FYM + NPK + CAN + NPK had no significant effect on fine pod yield.

Table 4. 8: Effect of nutrient management options on fine pod yield (kg/ha) in snap bean

	First planting	**Second planting**
Treatment		
1. Control (no fertilizer applied)	3382 c	3770 c
2. FYM + DAP + CAN top dress (21 DAE)	3750 ab	4484 ab
3. DAP + CAN top dress (21 DAE)	3829 a	4864 a
4. NPK (23:23:0) + CAN top dress (21 DAE) (famers' practise)	3712 ab	4575 ab
5. DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	3817 ab	4764 a
6. FYM + NPK (23:23:0) + NPK (17:17:0) top dress (21 DAE)	3573 ab	4154 bc
7. FYM + foliar (pre-flowering)	3488 ab	3963 c
8. FYM	3445 bc	4050 c
9. FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	3574 ab	4102 c
10. FYM + CAN + CAN top dress (21 DAE)	3793 ab	4666 ab
11. FYM + CAN (21 DAE)	3449 bc	4083 c
***P* value**	<.001	<.001
$LSD_{P=0.05}$	373.5	412.7
CV%	6.1	7.7

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; DAP=di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard Manure; DAE= days after emergence.

4.9 Effect of nutrient management options on snap bean marketable pod yield

Nutrient management options significantly ($p \leq 0.05$) affected the marketable pod yield produced in both plantings (Table 4.9). Application of DAP + CAN, DAP + CAN + foliar feed and FYM + CAN + CAN had significantly higher marketable pod yield than most treatments in both first and second planting. Plots treated with FYM alone, FYM + CAN and FYM + foliar feed were not significantly different from control plots. No-fertilizer plots had significantly lower marketable pod yield than most of the other treatments in both first and second planting. The marketable pod yield in the first planting ranged from 3805 kg/ha to 4481 kg/ha, while in the second planting it ranged from 9047 kg/ha to 11197 kg/ha.

Table 4. 9: Effect of nutrient management options on marketable pod yield (kg/ha)

	First planting	**Second planting**
Treatment		
1. Control (no fertilizer applied)	3805 d	9047 f
2. FYM + DAP + CAN top dress (21 DAE)	4312 ab	10634 b
3. DAP + CAN top dress (21 DAE)	4481 a	11345 a
4. NPK (23:23:0) + CAN top dress (21 DAE) (famers' practise)	4255 ab	10632 b
5. DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	4441 a	11197 a
6. FYM + NPK (23:23:0) + NPK (17:17:0) top dress (21 DAE)	4080 bc	10371 bc
7. FYM + foliar (pre-flowering)	3995 cd	9439 ef
8. FYM	3942 cd	9429 ef
9. FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	4087 bc	10024 cd
10. FYM + CAN + CAN top dress (21 DAE)	4399 ab	11001 a
11. FYM + CAN (21 DAE)	3938 cd	9819 dc
***P* value**	<.001	<.001
LSD$_{P=0.05}$	243.5	519
CV%	3.4	3.1

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; DAP=di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard Manure; DAE= days after emergence.

4.10 Effect of nutrient management options on length of extra-fine snap bean pods

Nutrient management options had no significant ($p \leq 0.05$) effect on length of extra-fine snap bean pods in the first and second planting (Table 4.10). The pod length ranged from 6.1 to 6.3 cm in the first planting, while in the second planting pod length ranged from 6.2 to 6.4 cm.

Table 4. 10: Effect of nutrient management options on length (cm) of extra fine snap bean pods

	First planting	**Second planting**
Treatment		
1. Control (no fertilizer applied)	6.3 a	6.2 a
2. FYM + DAP + CAN top dress (21 DAE)	6.1 a	6.2 a
3. DAP + CAN top dress (21 DAE)	6.2 a	6.3 a
4. NPK (23:23:0) + CAN top dress (21 DAE) (famers' practise)	6.1 a	6.3 a
5. DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	6.1 a	6.3 a
6. FYM + NPK (23:23:0) + NPK (17:17:0) top dress (21 DAE)	6.2 a	6.3a
7. FYM + foliar (pre-flowering)	6.2 a	6.2 a
8. FYM	6.1 a	6.2 a
9. FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	6.1 a	6.2 a
10. FYM + CAN + CAN top dress (21 DAE)	6.3 a	6.4 a
11. FYM + CAN (21 DAE)	6.1 a	6.2 a
***P* value**	0.48	0.42
$LSD_{P=0.05}$	NS	NS
CV%	0.2	0.4

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; DAP=di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard Manure; DAE= days after emergence.

4.11 Effect of nutrient management options on length of fine snap bean pods

There were significant ($p \leq 0.05$) differences among the nutrient management options in length of fine snap bean pods in both first and second planting (Table 4.11). Application of FYM + foliar, FYM alone, FYM + DAP + NPK + CAN + NPK had significantly higher pod length than all other treatments in the first planting and second planting. In the first planting pod length ranged from 6.5 cm (NPK + CAN) to 8.2 cm (FYM and FYM + foliar feed), while in the second planting ranged from 7.3 cm (FYM + DAP + CAN) to 8.9 cm (no-fertilizer).

Table 4. 11: Effect of nutrient management options on length (cm) of fine snap bean pods

	First planting	**Second planting**
Treatment		
1. Control (no fertilizer applied)	7.2 b	7.1 c
2. FYM + DAP + CAN top dress (21 DAE)	7.3 b	7.3 c
3. DAP + CAN top dress (21 DAE)	7.2 b	8.0 b
4. NPK (23:23:0) + CAN top dress (21 DAE) (famers' practise)	6.5 c	7.8 bc
5. DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	7.4 b	7.4 bc
6. FYM + NPK (23:23:0) + NPK (17:17:0) top dress (21 DAE)	7.4 b	7.6 bc
7. FYM + foliar (pre-flowering)	8.2 a	8.6 a
8. FYM	8.1 a	8.4 a
9. FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	8.2 a	8.7 a
10. FYM + CAN + CAN top dress (21 DAE)	7.4 b	7.6 bc
11. FYM + CAN (21 DAE)	7.4 b	7.4 bc
***P* value**	<.001	<.001
$LSD_{P=0.05}$	0.4	0.3
CV%	3.5	1.9

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; DAP=di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard Manure; DAE= days after emergence.

4.12 Effect of nutrient management options on pest (scores) infestation in snap bean

White flies, aphids and bean steam maggot were detected in snap bean plants in the first and second planting (Table 4.12). However, nutrient management options had no significant ($p \leq 0.05$) effect on the infestation of these pests in the first and second planting. Pest severity scores were 3.4 to 4.5 for white flies, 2.0 to 2.1 for aphids and 1.1 to 1.6 for bean steam maggot in the first planting. In the second planting pest severity scores ranged from 3.6 to 4.3 for white flies, 2.0 to 2.3 for aphids and 2.3 to 5.5 for bean steam maggots.

Table 4. 12: Effect of nutrient management options on pest (scores) infestation in snap bean

	First Planting			**Second Planting**		
Treatment	White flies	Aphid	BSM	White flies	Aphids	BSM
1. Control (no fertilizer applied)	4.2a	2.1a	2.1a	3.8a	2.0a	4.4a
2. FYM + DAP + CAN top dress (21 DAE)	3.9a	2.0a	1.1a	4.1a	2.1a	3.1a
3. DAP + CAN top dress (21 DAE)	3.7a	2.1a	1.6a	4.0a	2.6a	4.9a
4. NPK (23:23:0) + CAN top dress (21 DAE) (famers' practice)	4.1a	2.2a	1.4a	3.6a	2.1a	4.8a
5. DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	3.4a	2.0a	1.3a	4.0a	2.4a	3.0a
6. FYM + NPK (23:23:0) + NPK (17:17:17) top dress (21 DAE)	4.0a	2.3a	1.1a	4.2a	2.6a	2.6a
7. FYM + foliar (pre-flowering)	4.4a	2.1a	1.2a	3.9a	2.6a	2.3a
8. FYM	4.5a	2.1a	2.0a	4.1a	2.3a	3.9a
9. FYM + DAP + NPK (23:23:0)+ CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	4.4a	2.2a	1.4a	4.3a	2.3a	4.2a
10. FYM + CAN + CAN top dress (21 DAE)	4.5a	2.2a	1.6a	4.1a	2.3a	3.0a
11. FYM + CAN (21 DAE)	4.1a	2.0a	1.3a	3.9a	2.1a	4.6a
***P* value**	0.936	0.624	0.816	0.999	0.989	0.799
$LSD_{P=0.05}$	NS	NS	NS	NS	NS	NS
CV%	47.7	14.7	101.2	41.2	52.6	106.1

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; DAP=di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard Manure; DAE= days after emergence; White flies; Aphids and ;BSM= bean steam maggot scale used 1,2,3 absence of symptoms (resistance):4,5,6 intermediate attack of insects' pests and 7,8,9 susceptibilities to insect pest.

4.13 Effect of nutrient management options on diseases (scores) infestation in snap bean

Rust, anthracnose and angular leaf spot were detected in snap bean plants in the first and second planting (Table 4.13). There were no significant ($p \leq 0.05$) differences in disease severity among the nutrient management options. The average disease severity scores were 2.1 to 2.4 for rust 2.4 to 2.8 for anthracnose and 5.9 to 4.8 for angular leaf spot in the first planting. In the second planting the average disease severity scores were 2.1 to 2.7 for rust, 1.4 to 1.8 for anthracnose and 2.7 to 3.4 for angular leaf spot.

Table 4. 13: Effect of nutrient management options on disease (scores) infestation in snap bean

	First Planting			Second Planting		
Treatment	Rust	ANT	ALS	Rust	ANT	ALS
1. Control (no fertilizer applied)	2.4a	2.9a	4.8a	2.3a	1.6a	3.4a
2. FYM + DAP + CAN top dress (21 DAE)	2.3a	2.8a	4.7a	2.4a	1.4a	3.4a
3. DAP + CAN top dress (21 DAE)	2.0a	2.8a	4.5a	2.0a	1.6a	3.2a
4. NPK (23:23:0) + CAN top dress (21 DAE) (famers' practice)	2.2a	2.6a	5.9a	2.4a	1.5a	3.3a
5. DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	2.2a	2.6a	5.4a	2.3a	1.8a	3.4a
6. FYM + NPK (23:23:0) + NPK (17:17:17) top dress (21 DAE)	2.0a	2.4a	5.1a	2.7a	1.5a	3.3a
7. FYM + foliar (pre-flowering)	2.4a	2.9a	5.3a	2.3a	1.8a	2.9a
8. FYM	2.3a	2.6a	4.7a	2.7a	1.7a	3.5a
9. FYM + DAP + NPK (23:23:0)+ CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	2.1a	2.9a	4.0a	2.0a	1.6a	3.1a
10. FYM + CAN + CAN top dress (21 DAE)	2.0a	2.5a	5.3a	2.4a	1.6a	3.2a
11. FYM + CAN (21 DAE)	2.2a	2.7a	4.9a	2.1a	1.7a	3.3a
***P* value**	0.760	0.920	0.971	0.994	0.954	0.995
$LSD_{P=0.05}$	NS	NS	NS	NS	NS	NS
CV%	19.5	30.7	38.4	63.4	33.5	48.6

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; DAP=di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard Manure; DAE= days after emergence; Rust; ANT=anthracnose: ALS=angular leaf spot scale used 1,2,3 absence of symptoms (resistance): 4,5,6 intermediate attack of insects' diseases and 7,8,9 susceptibilities to diseases.

4.14 Total variable costs of various nutrient management options for snap bean

Table 4.14 (Appendix 4) shows total variable cost for each treatment. Control had the lowest total variable cost (TVC) of KES 145,600 while application of FYM + DAP + NPK + CAN + NPK had the highest total variable cost (TVC) of KES 202,200 in both plantings. The cost of purchase of fertilizers and the cost of fertilizer application varied across the treatments. The cost of fertilizer purchases per application regime ranged from KES 0 (no-fertilizer) to KES 54,500 (FYM + DAP + NPK + CAN + NPK) per ha, while the cost of fertilizer application per regime ranged from KES 0 in no-fertilizer plots to KES 2,100 per ha in plots supplied with FYM + DAP + NPK + CAN + NPK in Embu County. The cost of land for hire, land preparation, seeds, irrigation and labour did not vary across the treatments.

Table 4. 14: Total variable costs (Kenyan shillings) of various nutrient management options for snap bean (per ha)

Operational costs (KES)	Treatments									
Variable costs	Control	FYM+DAP+CAN	DAP + CAN	NPK(23:23:0) + CAN	DAP + CAN + foliar	FYM + NPK (23:23:0) + NPK(17:17:0)	FYM + foliar	FYM	FYM + DAP +NPK(23:23:0)+ CAN+NPK (17:17:0)	FYM+ CAN+ CAN	FYM+CAN
Land for hire 4 months	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
Land preparation	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
Cost of seeds	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000
Cost of pesticides	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800
Irrigation cost	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000
Cost of labour*	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800
Cost of fertilizers	0	32,250	22,250	18,500	23,000	32,250	10,750	10,000	54,500	29,250	18,750
Cost of labour for fertilizer applications	0	1,800	1,200	1,200	1,300	1,600	1,400	900	2,100	1,300	1,200
TOTAL VARIABLE COSTS	**145,600**	**179,650**	**169,050**	**165,300**	**169,900**	**179,450**	**157,750**	**156,500**	**202,200**	**176,150**	**165,550**

DAP=Di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard manure; DAE=days after emergence; KES= Kenyan shillings; *Cost of labour included the cost of planting, weeding and harvesting.

4.15 Net benefits of various nutrient management options for snap bean

In the first planting, control (no-fertilizer) had a higher net befit of KES of 42,747.5 Table 14:15 (Appendix 5a; 5b) compared to other treatments. The treatment supplied with DAP + CAN had the highest positive net benefit of KES 52,759.5, while application of FYM + DAP + NPK + CAN + NPK had the lowest positive net benefit of KES 106.5 in the first planting. In the second planting, there was a higher net befit incurred by the treatments compared to the first planting. In the second planting, application of DAP + CAN had the highest positive net benefit of KES 392,527.5 while application of FYM + DAP + NPK + CAN + NPK had the lowest positive net benefit of KES 293,988. In both plantings, application of DAP + CAN had the highest positive net benefit, followed by application of DAP + CAN + foliar feed with a net benefit of KES 384,351.5.

Table 4. 15: Net benefits of various nutrient management options for marketable snap bean (per ha) in the first planting

Operational costs (KES)	Treatments										
Variable costs	Control	FYM+DAP+ CAN	DAP + CAN	NPK(23:23:0) + CAN	DAP + CAN + foliar	FYM + NPK (23:23:0) + NPK(17:17:0)	FYM + foliar	FYM	FYM + DAP + NPK(23:23:0)+ CAN+NPK (17:17:0)	FYM+CAN + CAN	FYM+CAN
Land for hire 4 months	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
Land preparations	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
Cost of seeds	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000
Cost of pesticides	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800
Irrigation costs	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000
Cost of labour*	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800
Cost of fertilizers	0	32,250	22,250	18,500	23,000	32,250	10,750	10,000	54,500	29,250	18,750
Cost of labour for fertilizer applications	0	1,800	1,200	1,200	1,300	1,600	1,400	900	2,100	1,300	1,200
TOTAL VARIABLE COSTS (KES/ha)	**145,600**	**179,650**	**169,050**	**165,300**	**169,900**	**179,450**	**157,750**	**156,500**	**202,200**	**176,150**	**165,550**
Yield (Kg/ha)	3805	4312	4481	4255	4441	4080	3995	3942	4087	4399	3938
Adjusted yield	3424.5	3880.8	4032.9	3829.5	3996.5	3672	3595.5	3547.8	3678.3	3959.1	3544.2
Selling price per Kg	55	55	55	55	55	55	55	55	55	55	55
GROSS FIELD BENEFIT(KES/ha)	**188,347.5**	**213,444**	**221,809.5**	**210,622.5**	**219,807.5**	**201,960**	**197,725**	**195,129**	**202,306.5**	**217,750.5**	**194,931**
NET BENEFIT(KES/ha)	**42,747.5**	**33,794**	**52,759.5**	**45,322.5**	**49,907.5**	**22,510**	**39,975**	**38,629**	**106.5**	**41,600.5**	**29,381**

DAP=Di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard manure; DAE=days after emergence; KES= Kenyan shillings; *Cost of labour included the cost of planting, weeding and harvesting

Table 4. 16: Net benefits of various nutrient management options for marketable snap bean (per ha) in the second planting

Operational costs (KES)	Treatments									
Variable costs	Control	FYM+DAP+ CAN	DAP + CAN	NPK(23:23 :0) + CAN	DAP + CAN + foliar	FYM + NPK (23:23:0) + NPK(17:17 :0)	FYM + foliar	FYM	FYM+DAP+ NPK(23:23:0) +CAN+NPK (17:17:0)	FYM+CAN + CAN	FYM+CAN
Land for hire 4months	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
Land preparations	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
Cost of seeds	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000
Cost of pesticides	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800
Irrigation costs	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000
Cost of labour*	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800
Cost of fertilizers	0	32,250	22,250	18,500	23,000	32,250	10,750	10,000	54,500	29,250	18,750
Cost of labour for fertilizer applications	0	1,800	1,200	1,200	1,300	1,600	1,400	900	2,100	1,300	1,200
TOTAL VARIABLE COSTS	**145,600**	**179,650**	**169,050**	**165,300**	**169,900**	**179,450**	**157,750**	**156,500**	**202,200**	**176,150**	**165,550**
Yield Kg/ha	9047	10634	11345	10632	11197	10371	9439	9429	10024	11001	9819
Adjusted yield	8,142.3	9570.6	10210.5	9568.8	10077.3	9333.9	8495.1	84886.1	9021.6	9900.9	8837.1
Selling price per Kg	55	55	55	55	55	55	55	55	55	55	55
GROSS FIELD BENEFIT (KES/ha)	**447,826.5**	**526,383**	**561,577.5**	**526,284**	**554,251.5**	**513,364.5**	**467,230.5**	**466,735.5**	**496,188**	**544,549.5**	**486,040.5**
NET BENEFIT (KES/ha)	**302,226.5**	**346,733**	**392,527.5**	**360,984**	**384,351.5**	**333,914.5**	**309,480.5**	**310,235.5**	**293,988**	**368,399.5**	**320,490.5**

4.16 Dominance analysis of various nutrient management options for snap bean

In the first planting, Control and DAP + CAN were un-dominated while the rest were dominated (Appendix 6a:6b). In the second planting, application of FYM alone, NPK + CAN, DAP + CAN and the control (no-fertilizer) were un-dominated while the rest were dominated. The dominated treatments were excluded from further analysis.

Table 4.17: Dominance analysis for various nutrient management options for snap bean (per ha) in the first planting

Treatments	Total Variable Cost	Net Benefit	Dominance
Control (no fertilizer applied)	145,600	47,747.5	**Un dominated**
FYM	156,500	38,629	dominated
FYM + foliar (pre-flowering)	157,450	39,975	dominated
NPK (23:23:0) + CAN top dress (21 DAE) (famers' practice)	165,300	45,322.5	dominated
FYM + CAN (21 DAE)	165,550	29,381	dominated
DAP + CAN top dress (21 DAE)	169,050	52,759.5	**Un dominated**
DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	169,900	49,929.5	dominated
FYM + CAN + CAN top dress (21 DAE)	176,150	41,929.5	dominated
F YM + NPK (23:23:0) + NPK (17:17:0) top dress (21 DAE)	179,450	22,510	dominated
FYM + DAP + CAN top dress (21 DAE)	179,650	33,844	dominated
FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	202,200	106.5	dominated

DAP= Di-ammonium phosphate; CAN= calcium ammonium nitrate; NPK= nitrogen phosphorous potassium; FYM= farmyard manure; DAE= days after emergence.

Table 4. 18: Dominance analysis for various nutrient management options for snap bean (per ha) in the second planting.

Treatments	**Total variable cost**	**Net benefit**	**Dominance**
Control (no fertilizer applied)	145,600	302,226.5	**Un dominated**
FYM	156,500	310,235.5	**Un dominated**
FYM + foliar (pre-flowering)	157,750	309,480.5	dominated
NPK (23:23:0) + CAN top dress (21 DAE) (famers' practice)	165,300	360,984	**Un dominated**
FYM + CAN (21 DAE)	165,550	320,490.5	dominated
DAP + CAN top dress (21 DAE)	169,050	392,527.5	**Un dominated**
DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	169,900	384,351.5	dominated
FYM + CAN + CAN top dress (21 DAE)	176,150	368,399.5	dominated
F YM + NPK (23:23:0) + NPK (17:17:0) top dress (21 DAE)	179,450	333,914.5	dominated
FYM + DAP + CAN top dress (21 DAE)	179,650	346,783	dominated
FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	202,200	293,988	dominated

DAP=Di-ammonium phosphate; CAN=Calcium ammonium nitrate; NPK= nitrogen phosphorous potassium; FYM= farmyard manure; DAE= days after emergence.

4.17 Marginal rate of return of various nutrient management options for snap bean

After eliminating all the dominated treatments, the marginal rate of return between the un-dominated treatments was calculated. In the first planting marginal rate of return was 21.4% (Appendix 7a:7b). The highest marginal rate of return was obtained by switching from application of Control to application of DAP + CAN. In the second planting, the marginal rate of return ranged from 73.5% to 841.2%. The highest marginal rate of return was obtained by changing from application of NPK + CAN to application of DAP + CAN (Table 4.20).

The marginal rate of return of 21.4% was achieved in the first planting. In the second planting, the highest marginal rate of return was achieved by switching from application of NPK (23:23:0) (50 Kg N/ha) + CAN (50 Kg N/ha) (farmers' practice) to application of DAP (50 Kg N/ha) + CAN (50 Kg N/ha), while in the first plating was by switching from Control to application of DAP + CAN.

Table 4. 19: Marginal rate of return (per ha) of various nutrient management options for snap bean in the first planting

Treatment	Net benefits (KES)	Change in net benefit (KES)	Total variable cost (KES)	Change in total variable cost (KES)	MRR %(KES)
Control	47,747.5	-	145,600	-	-
DAP + CAN top dress (21 DAE)	52,759.5	5,012	169,050	23,450	21.4

DAP=Di-ammonium phosphate; CAN=calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM=farmyard manure; DAE=days after emergence; KES=Kenyan Shillings.

Table 4. 20: Marginal rate of return (per ha) of various nutrient management options for snap bean in the second planting

Treatment	Net Benefits (KES)	Change in net benefit (KES)	Total variable cost(KES)	Change in total variable cost (KES)	MRR % (KES)
Control	302,226.5	-	145,600	-	_
FYM	310,235.5	8,009	156,500	10,900	73.5
NPK(23;23;0) + CAN top dress (21 DAE) (famers' practice)	360,984	50,748.5	165,300	8,800	576.7
DAP + CAN top dress (21 DAE)	392,527.5	31,543.5	169,050	3,750	841.2

DAP=Di-ammonium phosphate; CAN= calcium ammonium nitrate; NPK=nitrogen phosphorous potassium; FYM= farmyard manure; DAE= days after emergence; KES= Kenya shilling.

CHAPTER FIVE: DISCUSION

5.1 Discussion

The study showed that none of the nutrient management options had a significant effect on the number of days to 50% emergence. Similar results were reported by Tesfaye (2015) who observed that inorganic fertilizers did not affect the time to emergence in common bean. The uniform emergence in all treatments might be attributed to the good viability of seeds, adequate moisture, proper temperature and good aeration at the time of planting (Dupont *et al*., 2012). Jan et al., (2002) similarly observed that the embryo in grams grows at the expense of stored food materials and did not require any external nutrition.

Application of FYM at the rate of (5 t/ha) and combined application of FYM (5 t/ha) + Foliar feed (pre flowering) reduced the number of days to 50% flowering in both the two plantings seasons. Foliar feed application improved plant growth and production of green bean relative to inorganic and organic fertilizer treated plots by supplying the plant with extra dose of necessary nutrients. According to Pradeep and Elamathi, (2007) additional foliar application during the growth and development of crops can improve their nutrient balance, which leads to development of leaves. Tesfaye (2015) observed a significant effect of phosphorus fertilizer application on days to 50% flowering in common bean supplied with phosphorus fertilizer. This is due to the fact that phosphorus fertilizer hastens flowering. Photosynthesis and assimilated partition of crop from source to sink is mainly determined by the ability of crop to utilize P (Iqbal *et al*., 2003). Adequate phosphorus enhances many aspects of plant physiology such as flowering, seed formation and maturation (Brady and Weil, 2002).

No-fertilizer (control) plots had the highest number of nodules per plant compared to fertilizer treated plots. This was an indication that inorganic N fertilizers depressed the number of nodules in snap beans per plant. Peck and Mackdonald (1984) similarly observed that snap plants grown without N fertilizers had many nodules in their roots. Others studies have similarly showed that application of nitrogen fertilizers remarkably reduced nodulation in snap and dry beans (Chemining'wa *et al*.,2007; Tarylor *et al*., 2005; Kamanu *et al*.,2012). Gentile et al., (2006) observed that high N levels inhibited early cell division in cortex of *Alnus Incana* there-by inhibiting nodulation. Reason for nitrate inhibition on nodulation is not well stated, though carbohydrate deprivation in the nodules as well as a result of energy required for nitrate reduction is one of the major explanatory hypotheses (Havelka *et al*., 1982; Chemining'wa, 2002). However, snap bean plants supplied with farmyard manure alone had significantly higher nodule number than plants that received inorganic fertilizer. This could be due to the slow mineralization of manure resulting in slow release of nitrogen leading to less effect on nodulation.

The results of the study showed that treatments supplied with FYM (5 t/ha) + DAP (50 Kg/ha) + CAN (50 Kg/ha) **+** CAN (50 Kg N/ha) and FYM (5 t/ha) + DAP (50 Kg/ha) + NPK (23:23:0) (50 Kg/ha) + CAN (50 Kg/ha) + NPK (17:17:0) (50 Kg/ha) had higher shoot dry matter than the no-fertilizer plots and other nutrient management options. Furtini et al., (2006) demonstrated that fertilizer application improved snap bean shoot dry matter. Bildrici et al., (2005) ascribe the improved biomass accumulation in snap bean to the increase availability of plant nutrients which enhances the photosynthetic capacity of the plants. It has been suggested that the inorganic fertilizers have a ''prime effect'' on N uptake by crops from the organic inputs resulting in increased yields. These findings are in line with those of Ogutu Philip. O (2013) who found that application of organic and inorganic fertilizer rates of 8 t/ha FYM, 100 Kg/ha NPK plus 4 t/ha chicken manure (CM), 200 Kg/ha NPK plus 4 t/ha

CM, and 200 Kg/ha NPK plus 4 t/ha FYM significantly increased shoot dry matter in navy bean. Bhaskarrao et al., (2015) also reported that application of manure and inorganic fertilizer increased shoot dry matter in faba bean (*Vica faba*). Wong and Ho (1991) showed that inorganic fertilizers are more efficient than the organic manures in supplying N, P and K in the short run, while the organic manure have the advantage in supplying other macro and micro nutrient elements not contained in inorganic fertilizers.

The DAP (50 Kg N/ha) + CAN (50 Kg N/ha) treated plots had higher extra-fine, fine and total marketable snap bean pod yields than other nutrient management options treatments and no-fertilizer treatment. Tesfaye (2017) reported that snap bean yields generally increased with increase in the rate of blended fertilizer with higher response attained at application rate of 92 Kg N/ha and 69 Kg N/ha. This is in agreement with studies done on snap bean which indicated that increasing NPK rates or increasing N: P fertilizer ratios increased yield of green beans (Abel-Mawgoud *et al*., 2005). Similar results were obtained by Hedge and Srinivas (2004), who applied N fertilizer at the rate of 100 Kg/ha to snap bean resulting in higher marketable yield. Snap bean plants will not grow well or produce the best yield with low soil nitrogen availability. Also Piha and Munnus (1987), reported that the N fertilizer requirement of snap bean plant is high, due to its week atmospheric N fixation capacity compared to other legumes.

A research recommended treatment which is application of FYM (5 t/ha) + CAN (50 Kg/ha) + CAN (60 Kg/ha) and FYM (5 t/ha) + DAP (50 Kg/ha) + CAN (50 Kg/ha) had more snap bean total marketable pod yield compared to farmers' practice and control (no-fertilizer). Though farmyard manure are a good source of N and P, they mineralize slowly compared to the inorganic fertilizers thus releasing nutrients gradually during early growth hence, slowing the growth rate of crops (Otieno *et al*.,2007). This slow release of nutrients by farmyard manure points to the need to integrate it with inorganic fertilizers for proper and early growth of beans (Gichangi *et al*., 2007). Saad et al., (2009) argued that combing inorganic fertilizer with organic resources improves fertilizer use efficiency. However, in the current study, farmyard manure supplemented with CAN or DAP did not perform well as the fertilizer application treated plots with higher rates of fast release inorganic fertilizers. Therefore, this calls for further studies to establish the optimal combination of inorganic and organic fertilizer application regimes for improving growth and yield of snap bean production.

FYM (5 t/ha) + Foliar feed, FYM (5 t/ha) and FYM (5 t/ha) + DAP (50 Kg/ha) + NPK (23:23:0) (50 Kg/ha) + CAN (50 Kg/ha) + NPK (17:17:0) (50 Kg/ha) had higher snap bean pod length compared to other nutrient management options and control treatment. According to Shafeek et al., (2017) cattle manure has a potential of increasing pod length of snap bean. The notable higher vegetative growth attained by higher level of organic manure might be related to its ability to improve the physical properties of soil (Marculescu *et al*., 2002 and Hampton *et al*., 2011). Amanullah et al., (2007) found that animal manure contributes higher N content to the soil and thus promotes the vegetative growth of plants.

Nutrient management options had no significant effect on disease severity and pest infestation on snap bean productivity. Severity scores of diseases like rust, anthracnose and angular leaf spot showed that snap bean variety Serengeti has some resistance to these diseases. Previous studies have shown rust to be a major disease affecting snap bean in farmer's field in Kenya (Bernard Ouma, 2013). Monda et al., (2003) explained the higher prevalence of rust in Kenya by the presence of *Uredospores* that are blown by wind from one farm to another.

Significant effects of Serengeti bean infestation by pests were recorded. Serengeti bean variety has been shown to be more susceptible to pests and diseases than variety Army (Ndegwa *et al*., 2009). There were a remarkable number of white flies observed on Serengeti variety. This was consistent to observations by Benard Ouma (2013) who reported that white flies are more destructive pests during the dry periods in Embu and Mwea East Counties.

As showed in the current study, marginal rate of return (MRR) analysis were done for the elven treatments under varying costs and prices (Appendix; 3) for each nutrient management options. In economic analysis, it is assumed that farmers require a minimal rate of return of 100% representing an increase in net return of at least 1KES for every 1KES invested to be sufficiently motivated to adopt a new agricultural technology (CIMMYT 1988).

Higher net margins were shown at application of DAP (50 kg N/ha) + CAN (50 kg N/ha) with a net benefit of 52,759.5 first plating to 392,527.5 second planting respectively. This gave a marginal rate of return of MRR=198.3 and 841.2 % per 1KES invested for DAP (50 kg N/ha) + CAN (50 kg N/ha). In both plantings, the highest marginal rate of return was achieved by switching from application of NPK (23:23:0) (50 Kg N/ha) + CAN (50 kg N/ha) to application of DAP (50 kg N/ha) + CAN (50 kg N/ha). Therefore, application of DAP (50 kg N/ha) + CAN (50 kg N/ha) yielded better economical return with maximum pod yield production for Serengeti variety of snap bean in the study area. Similar observations were made by Kamanu et al., (2012) who reported that application of DAP plus CAN on Serengeti variety of snap bean gave the highest pod yield and a cumulative net profit.

The identification of a recommendation is based on the change from one treatment to another if the marginal rate of return of that change is greater than the minimum rate of return (CIMMYT, 1988). Since the assumption was that the minimum level of return (100%), indicated that application of fertilizer at any level can benefit the producer even if the return amount varies. According to the manual for economic analysis of CIMMYT (1988) the recommendation is not necessarily based on the treatment with the highest marginal rate of return. However, define recommendation may not be drawn from this research result since the maximum yield response of nutrient management options was not obtained with the current levels of fertilizer. This study was besides conducted only for two seasons under irrigation. Therefore is; however; need to optimize nutrient application regimes and rates for snap bean production.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study shows that planting snap bean with application of DAP (50 kg N/ha) + CAN (50 kg N/ha) and DAP (50 kg N/ha) + CAN (50 kg N/ha) + Foliar feed has a potential to increase plant growth and yield parameters of snap bean. The use of DAP (50 kg N/ha) + CAN (50 kg N/ha) + Foliar feed had however significantly higher marketable pod yields compared to other nutrient management options. Farmers who apply foliar feed thus may realize higher marketable pod yield. There is however need to evaluate the optimal foliar feed rates for snap bean production.

Application of DAP (50 kg N/ha) + CAN (50 kg N/ha) recorded significantly higher snap bean productivity resulting into better economical return. Economic analysis showed that, higher net margins were obtained by application of DAP (50 kg N/ha) + CAN (50 kg N/ha) with a net benefit ranging between KES 52,759.5 and KES 392,527.5. This gave a marginal rate of return (MRR) of 21.4% and 841.2%. Further trials are required to establish optimal nutrient management options rates under farmers' field conditions.

6. 2 Recommendations

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

1. Farmers in Embu County should plant Serengeti snap bean variety and apply 50 Kg N/ha of di-ammonium phosphate (DAP) at planting and the top dress with 50 Kg N/ha calcium ammonium (CAN) at 21 days after planting (DAP + CAN).

2. Further studies should be carried out to evaluate the optimal foliar feed rate involving various nutrient management options that can enhance snap bean productivity and profitability.

3. Field trials involving a wide a range of snap bean commercial varieties and various nutrient management options should be conducted to improve productivity in a more cost effective way.

4. A study should be carried out to evaluate the optimal combination of inorganic and organic fertilizers application regimes that can improve growth, yield and quality of snap bean.

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APPENDICES

Appendix 1a: Soil test result (first planting).

Soil depth (cm)	**0-30**	
Fertility results	Value	class
Soil pH	5.86	Medium acid
Total nitrogen (%)	0.19	low
Total Organic Carbon (%)	1.78	moderate
Phosphorous (ppm)	40	moderate
Potassium (me%)	0.62	adequate
Calcium (me%)	2.5	adequate
Magnesium (me%)	2.93	adequate
Manganese (me%)	0.43	adequate
Copper (ppm)	1.89	adequate
Iron (ppm)	13.6	adequate
Zinc (ppm)	31.0	adequate
Sodium (me%)	0.16	Adequate

Appendix 1b: Soil test result (Second planting).

Soil depth (cm)	**0-30**	
Fertility results	Value	class
Soil pH	5.95	Medium acid
Total nitrogen (%)	0.21	adequate
Total Organic Carbon (%)	2.01	moderate
Phosphorous (ppm)	95	high
Potassium (me%)	0.87	adequate
Calcium (me%)	3.9	adequate
Magnesium (me%)	3.60	high
Manganese (me%)	0.68	adequate
Copper (ppm)	8.76	adequate
Iron (ppm)	16.8	adequate
Zinc (ppm)	33.7	adequate
Sodium (me%)	0.22	Adequate

Appendix 2: Table showing variable cost Ksh/ha (Non- fertilizer production cost)

Input	Production cost Ksh (Embu)
Land for hire (4months)	16,000
Land preparations	6,000
Cost of Serengeti seeds	44,000
Pesticides costs	6,800
Irrigation costs	34,000
Cost of Labour	38,800
Total	**145,600**

Appendix 3: Table showing Cost of fertilizer and fertilizer application per regime Ksh/ha

	Ksh/ha
Treatment	
Control (no fertilizer applied)	0
F YM + DAP + CAN top dress (21 DAE)	34,050
DAP + CAN top dress (21 DAE)	23,450
NPK (23:23:0) + CAN top dress (21 DAE) (famers practice)	18,700
DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	24,300
FYM + NPK (23:23:0) + NPK (17:17:0) top dress (21 DAE)	33,850
FYM + foliar (pre-flowering)	12,150
FYM	10,900
FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	56,600
FYM + CAN + CAN top dress (21 DAE)	30,550
FYM + CAN	19,950

Appendix 4: Table showing Total variable cost (KES)

Operational costs	Treatments									
Variable costs	Control	FYM+DAP+CAN	DAP + CAN	NPK(23:23:0) + CAN	DAP + CAN + foliar	FYM + NPK (23:23:0) + NPK(17:17:0)	FYM + foliar	FYM	FYM + DAP + NPK(23:23:0)+ CAN+NPK (17:17:0)	FYM+CAN+ CAN	FYM+CAN
Land for hire 4months	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
Land preparations	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
Costs of seeds	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000
Costs of pesticides	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800
Irrigation costs	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000
Costs of labour	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800
Costs of fertilizers	0	32,250	22,250	18,500	23,000	32,250	10,750	10,000	54,500	29,250	18,750
Costs of fertilizers applications	0	1,800	1,200	1,200	1,300	1,600	1,400	900	2,100	1,300	1,200
TOTAL VARIABLE COSTS	**145,600**	**179,650**	**169,050**	**165,300**	**169,900**	**179,450**	**157,750**	**156,500**	**202,200**	**176,150**	**165,550**

Appendix 5a: Table showing Net Benefit Cost (KES) (first planting)

Operational costs (KES)	Treatments									
Variable costs	Control	FYM+DAP+ CAN	DAP + CAN	NPK(23:23:0) + CAN	DAP + CAN + foliar	FYM + NPK (23:23:0) + NPK(17:17:0)	FYM + foliar	FYM	FYM + DAP + NPK(23:23:0)+ CAN+NPK (17:17:0)	FYM+CAN + CAN	FYM+CAN
Land for hire 4months	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
Land preparations	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
Costs of seeds	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000
Costs of pesticides	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800
Irrigation costs	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000
Costs of labour*	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800
Costs of fertilizers	0	32,250	22,250	18,500	23,000	32,250	10,750	10,000	54,500	29,250	18,750
Costs of fertilizers applications	0	1,800	1,200	1,200	1,300	1,600	1,400	900	2,100	1,300	1,200
TOTAL VARIABLE COSTS (Ksh/ha)	**145,600**	**179,650**	**169,050**	**165,300**	**169,900**	**179,450**	**157,750**	**156,500**	**202,200**	**176,150**	**165,550**
Yield (Kg/ha)	3805	4312	4481	4255	4441	4080	3995	3942	4087	4399	3938
Adjusted yield	3424.5	3880.8	4032.9	3829.5	3996.5	3672	3595.5	3547.8	3678.3	3959.1	3544.2
Selling price per Kg	55	55	55	55	55	55	55	55	55	55	55
GROSS FIELD BENEFIT(Ksh/ha)	**108,347.5**	**213,444**	**221,809.5**	**210,622.5**	**219,829.5**	**201,960**	**197,725**	**195,129**	**202,306.5**	**217,750.5**	**194,931**
NET BENEFIT(Ksh/ha)	**42,747.5**	**33,794**	**52,759.5**	**45,322.5**	**49,929.5**	**22,510**	**39,975**	**38,629**	**106.5**	**41,600.5**	**29,381**

Appendix 5b: Table showing Net Benefit Cost(KES) (second planting)

Operational costs (KES)	Treatments										
Variable costs	Control	FYM+DAP +CAN	DAP + CAN	NPK(23:23:0) + CAN	DAP + CAN + foliar	FYM + NPK (23:23:0) + NPK(17:17:0)	FYM + foliar	FYM	FYM+DAP+ NPK(23:23:0) +CAN+NPK (17:17:0)	FYM+CAN + CAN	FYM+CAN
Land for hire 4months	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
Land preparations	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
Costs of seeds	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000	44,000
Costs of pesticides	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800	6,800
Irrigation costs	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000	34,000
Costs of labour*	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800	38,800
Costs of fertilizers	0	32,250	22,250	18,500	23,000	32,250	10,750	10,000	54,500	29,250	18,750
Costs of fertilizers applications	0	1,800	1,200	1,200	1,300	1,600	1,400	900	2,100	1,300	1,200
TOTAL VARIABLE COSTS	**145,600**	**179,600**	**169,050**	**165,300**	**169,900**	**179,450**	**157,750**	**156,500**	**202,200**	**176,150**	**165,550**
Yield (Kg/ha)	9047	10634	11345	10632	11197	10371	9439	9429	10024	11001	9819
Adjusted yield	8,142.3	9570.6	10210.5	9568.8	10077.3	9333.9	8495.1	84886.1	9021.6	9900.9	8837.1
Selling price per Kg	55	55	55	55	55	55	55	55	55	55	55
GROSS FIELD BENEFIT (Ksh/ha)	**447,826.5**	**526,383**	**561,577.5**	**526,284**	**554,251.5**	**513,364.5**	**467,230.5**	**466,735.5**	**496,188**	**544,549.5**	**486,040.5**
NET BENEFIT (Ksh/ha)	**302,226.5**	**346,733**	**392,527.5**	**360,984**	**384,351.5**	**333,914.5**	**309,480.5**	**310,235.5**	**293,988**	**368,399.5**	**320,490.5**

Appendix 6a: Table showing Dominance analysis (first planting)

Treatments	**Total Cost that vary (KES)**	**Net Benefit (KES)**	**Dominance**
Control (no fertilizer applied)	145,600	47,747.5	**Un dominated**
FYM	156,500	38,629	dominated
FYM + foliar (pre-flowering)	157,450	39,975	dominated
NPK (23:23:0) + CAN top dress (21 DAE) (famers' practice)	165,300	45,322.5	dominated
FYM + CAN	165,550	29,381	dominated
DAP + CAN top dress(21 DAE)	169,050	52,759.5	**Un dominated**
DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	169,900	49,929.5	dominated
FYM + CAN + CAN top dress (21 DAE)	176,150	41,929.5	dominated
F YM + NPK (23:23:0) + NPK (17:17:0) top dress (21 DAE)	179,450	22,510	dominated
FYM + DAP + CAN top dress(21 DAE)	179,650	33,794	dominated
FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	202,200	106.5	dominated

Appendix 6b: Table showing Dominance analysis (second planting)

Treatments	**Total Cost that vary (KES)**	**Net Benefit (KES)**	**Dominance**
Control (no fertilizer applied)	145,600	302,226.5	**Un dominated**
FYM	156,500	310,235.5	**Un dominated**
FYM + foliar (pre-flowering)	157,750	309,480.5	dominated
NPK (23:23:0) + CAN top dress (21 DAE) (famers' practice)	165,300	360,984	**Un dominated**
FYM + CAN	165,550	320,490.5	dominated
DAP + CAN top dress (21 DAE)	169,050	392,527.5	**Un dominated**
DAP + CAN top dress (21 DAE) + foliar (pre-flowering)	169,900	384,351.5	dominated
FYM + CAN + CAN top dress (21 DAE)	176,150	368,399.5	dominated
F YM + NPK(23:23:0) + NPK(17:17:0) top dress (21 DAE)	179,450	333,914.5	dominated
FYM + DAP + CAN top dress(21 DAE)	179,650	346,733	dominated
FYM + DAP + NPK (23:23:0) + CAN top dress (21 DAE) + NPK (17:17:0) top dress (35 DAE)	202,200	293,988	dominated

Appendix 7a: Table showing marginal analysis (first planting)

Treatment	**Net benefits (KES)**	**Change in net benefit (KES)**	**Total variable cost (KES)**	**Change in total variable cost (KES)**	**MRR %(KES)**
Control	47,747.5	-	145,600	-	-
DAP + CAN top dress (21 DAE)	52,759.5	5,012	169,050	23,450	21.4

Appendix 7b: Table showing marginal analysis (second planting)

Treatment	**Net Benefits (KES)**	**Change in net benefit (KES)**	**Total variable cost(KES)**	**Change in total variable cost (KES)**	**MRR % (KES)**
Control	302,226.5	-	145,600	-	_
FYM	310,235.5	8,009	156,500	10,900	73.5
NPK(23;23;0) + CAN top dress (21 DAE) (famers' practice)	360,984	50,748.5	165,300	8,800	576.7
DAP + CAN top dress (21 DAE)	392,527.5	31,543.5	169,050	3,750	841.2