EFFECT OF INTEGRATED NUTRIENT MANAGEMENT ON GROWTH AND YIELD OF NAVY BEAN (*Phaseolus vulgaris* L.)

By

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DECLARATION

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

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LIST OF ABBREVIATIONS

AGRA	–	Alliance for a Green Revolution in Africa
ANOVA	–	Analysis of Variance
ATP	–	Adenosine Tri-phosphate
ATTRA	–	Appropriate Technology Transfer for Rural Areas
CGR	_	Crop Growth Rate
CIAT	–	International Centre for Tropical Agriculture
EDTA	–	Chemical Reagent
FAO	–	Food and Agriculture Organization
IPCC	–	Intergovernmental Panel on Climate Change
KARI	–	Kenya Agricultural Research Institute
LSD	–	Least Significant Difference
MC	–	Moisture Content
PER	–	Protein Efficiency Ratio
RCBD	–	Randomized Complete Block Design
SAT	–	Semi-arid Tropics
SNF	–	Symbiotic Nitrogen Fixation
SOM	–	Soil Organic Matter
UoN	–	University of Nairobi
USA	–	United States of America

GENERAL ABSTRACT

Low soil fertility and pests are the major constraints to Navy bean (*Phaseolus vulgaris* L.) production in Kenya. A study consisting of two experiments was therefore conducted in Mwea and Kabete during the 2009 short rains and 2010. The overall objective of the study was to develop integrated nutrient management options for improving productivity of canning Navy bean. The specific objectives were: (i) to determine the effect of varying combinations of organic and inorganic fertilizers on the growth and yield of canning Navy bean; (ii) to determine the interactive effects of fertilizer application and pesticide sprays on the growth and yield of canning Navy bean; and (iii) to determine the cost-effectiveness of the various fertilizer and chemical spray options in the production of canning navy bean. In the first experiment, the treatments comprised: a control with no fertilizer application, NPK (17:17:17) fertilizer at rates of 50 kg/ha, 100 kg/ha and 200 kg/ha, chicken and cattle manure each at 4 t/ha and 8 t/ha, and combinations of the three rates of fertilizer with the two rates of chicken and cattle manure respectively. The treatments were laid out in a randomized complete block design with three replications. In the second experiment, the treatments comprised fertilizer applications and pesticide sprays. The fertilizer treatments were full dose farmyard manure (8 t/ha), half dose farmyard manure (4 t/ha) plus half dose NPK (100 kg/ha), full dose NPK (200 kg/ha), *Rhizobium* inoculation, and a control (no fertilizer), while the pesticide treatments were fungicide spray (Ortiva^{R}), insecticide spray (Actara^{R}), fungicide spray (Ortiva^{R}) plus insecticide spray (Actara^{R}) and a control (no spray). The experimental design was a randomized complete block design laid out in a split plot arrangement with three replications. In both experiments Mexican 142 variety was used.

The data collected in the two experiments included: plant count, shoot biomass, root biomass, nodule number, number of pods, grain yield and 100 seed weight. Data generated were subjected to analysis of variance (ANOVA) and treatment means compared using Genstat statistical programme. A partial economic analysis was done for the various fertilizer and chemical spray options in the production.

In the first experiment, combinations of 100 kg/ha NPK and above with chicken manure and farm yard manure each at the rate of 4 or 8 t/ha generally had significantly higher nodule number, root biomass, shoot biomass and grain yield than the untreated control and other treatments. Each of these fertilizer combinations as well as application of 200 kg/ha NPK had cost-to-benefit ratio of about 1:2. In the second experiment, all the pesticide spray treatments had significantly higher grain yield in plots supplied with 4 t/ha farm yard manure plus 100 kg/ha NPK than in unsprayed plots. Combined fungicide and insecticide sprays had higher grain yield than insecticide or fungicide alone treatment. In the *Rhizobium* treated plots only a combination of fungicide and insecticide significantly increased grain yield relative to the unsprayed control. Fertilizer application increased the number of nodules but pesticide application had no effect. Fertilizer application increased grain yield significantly relative to the non-fertilizer control in pesticide sprayed plots, but had no effect in unsprayed plots. Applications of 200 kg/ha NPK and half dose farmyard manure (4 t/ha) plus half dose NPK (100 Kg/ha) in combination with insecticide or insecticide/fungicide sprays were the most cost-effective treatment regimes with cost-benefit ratio of about 1:2. In conclusion, pesticide sprays, *Rhizobium* inoculation, application of 200 kg/ha NPK and combined moderate doses of organic and inorganic fertilizers have the potential to improve Navy bean productivity in central Kenya.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Common bean (*Phaseolus vulgaris* L.) is a herbaceous annual plant grown worldwide for its edible grain, green leaves and green pods. However, the dry seeds are the ultimate economic product (CIAT, 2001). Common bean is native to the highland regions of Mesoamerica and Andean South America and in both areas it has been domesticated for more than 7,000 years (Gepts and Bliss, 1988; Gepts, 1990 and 1998). It is widely regarded as a crop adapted to cooler, less humid highland regions of 1000 m above sea level or more. In eastern, central and southern Africa, 90% of production comes from highland agro-ecological zones (CIAT, 2006).

Beans are the most important grain legumes for direct human consumption in the world. Total production exceeds 23 million metric tonnes (MT) of which 7 million MT are produced in Latin America and Africa (Broughton et al., 2003). Common bean production is almost twice that of chickpea, the second most important grain legume. Social factors and ecological constraints determine the particular regions beans are grown in (Broughton et al., 2003). Across the African continent over 4 million hectares of beans are grown annually giving an estimated production of over 2.5 million MT, providing dietary protein for over 100 million people in rural and urban communities and accounting for about 25% of the global production of the dry beans (Pachico, 1993; PABRA, 2005). As in Latin America, resource-poor farmers with few inputs grow beans primarily on small scale, marginal farms. In Africa, women farmers, who have little access to fertilizer compared to men, more often grow beans (Broughton et al., 2003; Wortmann et al., 1995). Intercropping of beans with cereals (maize, millet or sorghum), bananas and plantains or root and tuber crops is a common practice (Broughton et al., 2003).

Common bean is one of the 11 primary pulses recognized by FAO. The bean has a high production potential of more than 1000 kg/ha in the temperate regions, but in the tropical and subtropical regions of Latin America and Africa, more than 90% is produced under stressed conditions where average yields are below 600 kg/ha. According to Abate and Ampofo (1996), farmers realize yields of 300-700 kg/ha, although the crop has the capacity of producing up to 3,000 kg/ha. In Africa, bean production is often constrained by low availability of soil nitrogen (N), phosphorus (P), and potassium (K) and the toxicity complex of aluminium (Al) and manganese (Mn) resulting in annual losses of production estimated at 1.2, 1.0, 0.3 and 0.5 million MT respectively (Wortmann and Allen, 1994).

Beans play an essential role in human nutrition by complementing other foods (e.g., maize in the Latin American highlands and Eastern Africa and rice in Brazil) that are primarily sources of carbohydrates. The high nutritional quality of beans in terms of percentage protein is an important complement to starchy foods (Broughton et al., 2003). In Africa, East Africa has the highest per capita consumption of beans (50-60 kg per person per year) in general. A combination of maize and beans is a major traditional food in many cultures in Kenya. Further, different preparations of beans are a major dietary component of many other cultures in East Africa, and play a major role in the control of malnutrition especially in children. The high mineral content of beans, especially of iron and zinc, is advantageous in regions where there is high prevalence of micronutrient deficiencies such as iron deficiency anaemia (Broughton et al., 2003).

In Kenya beans are grown usually as an intercrop with maize, and are an increasingly important commodity in the cropping systems of small scale producers for improving food security and household incomes. In high rainfall regions where the security of staple foods is not a major concern the monocrop is common in the short rains while in more arid regions a bean monocrop is an option when anticipated rains may not be enough for crops with longer growing cycle. The dry grains of beans are especially important because they are nutritious, store easily for long, and cook fast with little energy. Bean production falls far short of consumption in Kenya. The total consumption of beans in Kenya is 450,000 MT per year, while only between 150,000 and 200,000 MT are produced from some 800,000 hectares (AGRA, 2008). The deficit is filled by imported beans from Uganda, Tanzania and Central Africa. Because of this deficit local and regional research institutions and universities are actively engaged in research for improving bean productivity. Worldwide, continued increases in human population and affluence will sustain the increasing demand for grain legumes to feed animals and for direct human consumption (e.g. Ali and Gupta, 2012).

Canning navy bean is one of the common dry beans and is a small, white, dry, oval (pea-shaped) haricot bean type grown mainly for the canning industry. It derives its name from having been widely used by the US navy in the 18th century. The dried bean kept for long and provided excellent nutrition thus it comprised staple supplies to the navy vessels (Chemining'wa et al., 2011).

The main markets for the canned/baked beans locally are the affluent populations particularly the Asians, who are the major consumers, educational institutions and hotels, while the main export markets are United States of America, Canada and the European Union (Chemining'wa et al., 2011). Thus the crop offers an opportunity for farmers to enter the high returns European market, vital for improving their livelihoods. However, production is currently very low and there is critical need to boost its potential for production to exploit the opportunity it offers for improvement of farm income (Chemining'wa et al., 2011).

1.2 Statement of the problem and justification

Low soil fertility, especially of nitrogen and phosphorus, and pests are major constraints in smallholder Navy bean production. Most of the soils in the country are deficient in nitrogen and phosphorus, which are the key elements vital for crop growth and yield. The decline in soil fertility is a result of soils having been cultivated for decades without appropriate protection and use of amendments, leading to massive surface soil erosion and land degradation over time. The production of Navy bean in the country has since dropped and, where grown, only less than ½ acre is put under the crop (Chemining'wa et al., 2011). The cost of inorganic fertilizers is also prohibitive and the majority of farmers cannot afford adequate amounts for Navy bean production.

For legumes symbiotic nitrogen fixation plays an important role in sustaining crop productivity and maintaining soil fertility. However, symbiotic nitrogen fixation is particularly sensitive to biotic and abiotic stresses hence further constraining bean productivity (Serraj et al., 2004). Pests and diseases aggravate bean production situation through their direct effects on the crop. They cause grain quality reduction which leads to rejection due to stringent quality standards required for grain canning and therefore lowering the value of the farmers' produce after sorting. This situation is aggravated by over-reliance on one variety Mexican 142 which is susceptible to bean pests and diseases. The major diseases are angular leaf spot (*Phaeoisariopsis griseola*), anthracnose (*Colletotrichum lindemuthianum*), leaf rust (*Uromyces appendiculatus* var. *appendiculatus*), common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*) and bean common mosaic virus (Nkalubo et al. (2007), while the major pests are bean stem maggot (*Ophiomyia* spp.), aphids (*Aphis fabae* and *Aphis craccivora*), whiteflies (*Bemisia tabaci* and *Trialeurodes vaporariorum*), foliage beetles (*Oortheca* spp.), thrips (*Frankliniella* spp. and *Megalurotrhips sjostedti*) and pod/seed feeders which include boll worms (*Helicorverpa armigera*), and bugs (*Clavigralla tomentosicolis*) (Wortmann et al., 1995 and Ojwang', 2010).

To effectively increase Navy bean productivity and grain quality per unit area under smallholder systems, efficient use of fertilizer and control of pest-damage is critical. This is important in minimizing production costs, especially because smallholder farmers are resource poor and the costs of fertilizers and pesticides are high. Although the use of inorganic fertilizers is recognized as a convenient way for rapid correction of nutrient deficiencies in soils, its high cost limits its wide application by farmers Ibijbijen et al. (1996). Farmers are unable to apply the needed quantities of mineral fertilizers to replace that removed by crop harvest. Given the high cost and uncertain accessibility of inorganic fertilizers, the use of locally available forms of organic nutrient sources like livestock manures, green manures, composted materials, household wastes and crop residues is an all important way of improving soil fertility. Reducing crop yields suggest that organic sources have low nutrient concentrations with limited potential to improve crop yields when applied as sole source of nutrients. There is therefore need to improve their quality if maximum benefits are to be derived from their usage by resource poor farmers (Fening et al., 2010).

Cattle manure and other livestock manures could supply an estimated 30% of N needs for crop production (Jokela, 1992). The chemical composition of cattle manures is influenced by diet, storage and handling practices. But the average content of N, P and K in most manure is 1.9, 0.6 and 1.2 (%) respectively. This shows that manures can have nutrient imbalance especially for P and this may require correction through soil supplementation with inorganic P (Brady, 1984). Nevertheless it remains a most valuable soil organic resource especially for resource poor farmers (Kipkosgei, 2004). Farmyard manure improves the physical and chemical properties of soil (Smaling, 1993), example, base saturation of cation exchange capacity, with added advantages of improving the soil structure, organic matter content, microbial environment, and water retention capacity. They also last long in the soil as they release nutrients slowly, which are then available for crops in the subsequent seasons. These properties of manures when combined with small amounts of inorganic fertilizers give more sustainable crop yields than the use of any one single source since adequate quantities of manures are not easily obtainable on-farm. Their use would enable farmers to offer consistent production that meets market and processing demand in terms of quality and quantity, and imports of beans would drastically reduce, saving foreign exchange.

1.3 Objectives

1.3.1 Broad objective:

To develop integrated crop management options for improving productivity of canning navy bean.

1.3.2 Specific objectives:

1. To determine the effect of various combinations of organic and inorganic fertilizers on the growth and yield of canning navy bean.
2. To determine the interactive effects of fertilizer application and pesticide sprays on the growth and yield of canning navy bean.
3. To determine the cost-effectiveness of the various fertilizer and chemical spray options in the production of canning navy bean.

1.3.3 Hypotheses

1. Combinations of organic and inorganic fertilizers will improve growth and yield of canning navy bean.
2. Fertilizer application and chemical spraying will have synergistic effects on the growth and yield of canning navy bean.
3. Some of the fertilizer and chemical spray treatments will be cost-effective in the production of navy bean.

CHAPTER TWO: LITERATURE REVIEW

2.1 Production and importance of Navy bean in Kenya

Canning navy bean is one of the common dry beans (*Phaseolus vulgaris* L.) grown in the country exclusively for the canning industry; although small quantities are consumed at household levels. Many varieties exist including Great Northern, Rainy River, Robust, Michelite and Sanilac, but the variety mostly grown is Mexican 142 because of its resilience to diseases (Chemining'wa et al., 2011).

In East Africa it was introduced in Tanzania in 1937 during the colonial times, and later to Kenya and Uganda from Tanzania by Arusha Co. Ltd. This was mainly in Rift valley, especially in Nakuru district in Rongai in the late 1990's where it was grown by farmers under contractual agreement with processing companies, although it is known to have been grown in Subukia, Kutus, Mwea and Meru in the 80's under similar arrangements (Chemining'wa et al., 2011). The recent survey indicates that major growing areas now are the new Rongai and Nakuru north districts, especially Solai (30%), Ndungiri (30%), Ngata (20%) areas in Rongai, and Bahati and Kabazi divisions in Nakuru north. The two main processing companies which are the main consumers of the locally produced bean are Njoro Canning Factory Ltd. and Kabazi Canners Ltd. (Chemining'wa et al., 2011). To meet their demand these companies now import Navy bean mainly from Ethiopia. In Ethiopia the crop earned 60 million US dollars in 2008 and has been labeled the 'white gold' of Ethiopia (Kimani et al., 2009). In Kenya the production slump has been due to the breakdown in the contractual agreement with the companies.

Navy bean has a fairly mild flavour and a texture that tends to be dense. It is nutritionally rich, having 22% protein. It provides 10% of the dietary proteins (contains 2-3 times that of cereal grains), starch, fibre and essential mineral nutrients (Pachico, 1993; Kibiego et al., 1993). In eastern and southern Africa, beans are the second most important protein source and the third most important caloric source after cassava and maize (Pachico, 1993; Kibiego et al., 1993). It is especially rich in low cholesterol fibre with high digestibility, making it good for diabetics. It is also one of the best non-meat sources of iron (Fe), a vital component of hemoglobin, providing 23-30% of daily-recommended levels from a single serving (Schwarz et al., 1996). Its content of the trace elements molybdenum (Mo), magnesium (Mg), sodium (Na), and zinc (Zn) makes it useful in the oxidation of sulfites consumed in food preservatives as Mo is an integral part of the enzyme sulfitase; Mg is beneficial for its cardio-vascular effects enhancing blood flow and supply of oxygen (O_2) to the brain; while Zn and Fe play an important role in child mental development. When combined with other whole grains, it provides virtually fat-free high quality proteins. Replacing animal foods in the diet with legumes reduces saturated fat intake without compromising overall protein intake. Beans are also superior sources of folate and potassium, among other nutrients (Messina, 2009).

Although they have high carbohydrate content, beans have a low glycemic index, attributable in part to their high content of both fiber and resistant starch. As a result, the glycemic load of beans is actually quite modest. Resistant starch is the sum of starch and products of starch degradation that are not absorbed in the small intestine of healthy individuals. Foods with a high concentration of resistant starch may improve digestive health and glycemic control, and possibly reduce colon cancer risk and increase calcium absorption (Messina, 2009). Finally, beans are high in antioxidants, providing amounts that are equal to those found in foods such as strawberries and blueberries. Antioxidants protect against the oxidative damage to biological molecules such as proteins, lipids, and DNA that is thought to increase the risk of certain forms of cancer, heart disease, and possibly even diseases such as Alzheimer's, and contribute to the aging process. Exposure to free radicals that cause this damage comes in many forms such as environmental pollutants, but they are also generated endogenously. Although the human body has an elaborate system to defend against free radicals, it is not 100% successful. Therefore, consuming foods that are high in antioxidants is thought to reduce the risk of a variety of diseases (Messina, 2009).

As the effects of climate change become pronounced, the duration of rains in the growing season is becoming shorter and occasionally torrential, and in many seasons when the maize harvest falls below the requirement, beans always bridge the gap, making it not a total crop failure. In such instances of food shortage, beans always come in handy providing an emergency food well before the maize crop matures, as it matures much earlier and is ready for consumption, almost as green beans (MOA, 2004).

The potential of beans as a key source of farm income is immense, since the continued shortfalls in production lead to high stable market prices which can be exploited by the producers. Being mainly produced by women farmers who comprise the majority in Africa it is an opportune crop with the potential for improving their income and livelihood. Wortmann et al. (1995) confirm that women are primarily responsible for the decisions and labour in smallholder bean production in most sub-Saharan countries. In Ethiopia, beans are among the main export crops and evolving as an important source of foreign currency and cash income for smallholder farmers (Asfaw et al., 2002).

2.2 Ecology of Navy bean

Common bean is adapted to a wide range of growing conditions, but requires 300-500 mm of rainfall well distributed over the growing season/crop cycle (Broughton et al., 2003). They observed that one of the strengths of beans is their ability to adapt to a variety of niches. In some important agricultural settings, the environment is so harsh that few crops are productive. As a result of its adaptable physiology and its indeterminate flowering pattern, beans still produce (albeit 400 kg ha^{-1} or less) in environments where other crops like maize fail completely. It is a warm season crop usually not affected by high temperatures if adequate soil moisture is present. It is susceptible to drought, especially during flowering and pod-formation, and heavy rains (extreme wetness/waterlogging) or prolonged dry conditions at harvest cause heavy losses of grains due to rotting or splitting of pods. Moisture deficits severely constrain production in some areas, frequently resulting in complete loss. Grain losses attributable to moisture deficits were estimated for annual rainfall ranges of less than 300, 300-375, 375-450, and above 450 mm per season for sole crop at 1,000, 600, 400, and 0 kg/ha respectively (Wortmann, 1998). Similarly, dry bean crop growth requires soil water to be at field capacity. The water requirement for maximum crop growth is similar during much of the growing period but varies during ripening. Peak water use by dry bean coincides with the critical growth stages (flowering and pod development) and periods of highest evapotranspiration. The crop is most sensitive to water stress during these periods when it utilizes approximately 0.30 inches of water per day. It also depends on whether the pod is harvested wet or dry. When grown for its fresh product, the total growing period of the crop is relatively short, and during the ripening, which is about 10 days long, the crop evapotranspiration is relatively small because of the drying of the leaves. When the crop is grown for seed, the ripening period is longer and the decrease in evapotranspiration rate is relatively greater (FAO STAT, 2001).

Rainfed cultivation is however possible in areas with well distributed medium to high annual rainfall of 900-1200 mm (Wortmann, 1998). To maintain continuous production especially during the dry season irrigation is essential. During the dry season up to 50 mm of water per week is required. This could be applied through furrow or overhead irrigation. The altitude range suitable for beans is 600 to 1950 m above sea level (Wortmann, 1998).

Germination requires a temperature of 15 ^{o}C or more and optimum soil moisture (100% field capacity); at 18 ^{o}C germination occurs in about 12 days while at 25 ^{o}C about 7 days. The appropriate growing temperature range is 17.5-27 ^{o}C; the minimum mean daily temperature being 10 ^{o}C and the maximum 27 ^{o}C. High temperatures increase fibre content in the pods and excessive rains or hot weather cause flower and pod drop and increase the incidence of diseases. Flower buds are likely to fall at temperatures above 30 °C and seeds are rarely formed above 35 °C. Common bean is also sensitive to night frost. Most bean varieties are not affected by day length. The length of the total growing period varies with the use of the product; it is 60-90 days for green beans and 90-120 days for dry beans (FAOSTAT, 2001).

The crop does not have specific soil requirements but friable deep soils with pH 5.5 to 6.0 are preferred, and especially suitable are light to moderately heavy to peaty soils, with organic matter, and near neutral pH, with good drainage (Salcedo, 2008). Orthic Ferralsol is the major soil type in bean production areas of eastern and southern Africa, but is generally low in nutrients. Beans are produced primarily in four areas where median soil pH is between 5.0 and 6.0, with 23% and 20% of production in areas where soil pH is either below or equal to 5.0 in eastern and southern Africa, respectively (Wortmann, 1998). Common bean is susceptible to soil salinity.

2.3 Biological nitrogen fixation by beans

Beans get near sufficient quantities of nitrogen from symbiotic nitrogen fixation, but in the absence of essential nutrients this process is constrained. Plants relying on fixed N for growth may achieve only 80-90% of the yield possible with N fertilization (Silsbury, 1977; Ryle et al., 1979; Thies et al., 1991). For legumes symbiotic nitrogen fixation plays an important role in sustaining crop productivity and maintaining the fertility of marginal lands particularly in the smallholder systems (Serraj et al., 2004). Major grain legumes are estimated to fix approximately 11.1 million MT of N per annum from the atmosphere in developing countries (FAO and IAEA, 2003-2012). Symbiotic nitrogen fixation is particularly sensitive to environmental stresses such as drought, waterlogging, soil salinity or acidity, temperature, insect pests, diseases, low phosphorus (P), and other nutrient limitations. Nutrients that affect SNF include high nitrates (NO_3^-), nitrogen (N), phosphorus (P), boron (B), zinc (Zn), sulphur (S), molybdenum (Mo), and cobalt (Co). Consequently legume productivity is greatly stressed if subjected to these constraints (Serraj et al., 2004).

Bean N fertilizer requirement depends on soil fertility levels; for low soil nitrogen levels (below 34 kg/ha or 300 ppm) it is generally recommended that 34 kg N/ha should be applied in order for deficiency symptoms not to manifest and for full development up to production. However, up to 60 kg/ha N also promotes increased nodule number, mass and size, giving highest yields. Higher amounts result in a decline in these parameters. Applying all required N at seeding may inhibit N fixation. Early application may also result in excessive vegetative growth leading to delayed flowering, reduced pod set, lower seed yield and a greater risk of disease infestation. Delayed N 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).

Most stress factors influence all physiological processes in plants as the stress develops. They influence all aspects of nodulation and symbiotic N_2-fixation, in some cases reducing rhizobial survival and diversity in soil, in others essentially affecting nodulation and nitrogenase activity. It is often difficult to isolate the effects of the stress factors on the success of inoculation from their effects on symbiosis functioning and nitrogen-fixation (Serraj et al., 2004).

Phosphorus is the second most important element limiting crop growth. The nitrogen-fixing legume plants usually require more phosphorus than plants dependent on mineral nitrogen fertilizer (Serraj et al., 2004). They quoted that nodule establishment and function are important sinks for phosphorus, and nodules usually have the highest phosphorus content in the plant. Therefore, P deficiency conditions result in reduced symbiotic nitrogen fixation potential. P fertilization will usually result in enhanced nodule number and mass, as well as greater nitrogen-fixation activity per plant. P is also required particularly to support energy transfer within cells. Much of the phosphorus in the plant is in inorganic form and readily reacts in the sequence of events resulting in energy transfer (Sinclair and Vadez, 2012). Phosphorus requirements are generally higher for N-fixation than for shoot growth and mineral N assimilation since nodules are important sinks for P (Adu-Gyamfi et al., 1989). Efficient P utilization in N-fixing symbioses may be closely related to an adequate P partitioning between shoot and nodulated roots, and between roots and nodules (Cassman et al., 1981). P fertilization contributes to early crop development and maturity, N is an essential constituent of protein and chlorophyll, while K influences both yield and pod quality (Abdel-Mawgoud et al., 2005). When soil P levels are low (below 20 ppm), 45 kg/ha P should be applied. This meets the minimal bean requirement, although other studies indicate that 45-60 kg/ha P are sufficient for maximum yields after which there is decline in yield and even grain quality (Davis and Brick, 2009).

Acid soils in Kenya pose a major challenge to the establishment of N-fixing symbioses. Symbiotic nitrogen fixation can be seriously reduced in such soils, due to the effects of high H^+ concentration, toxic levels of Al and Mn, and induced deficiencies of calcium (Ca), phosphorus (P), and molybdenum (Mo). Soil acidity limits *Rhizobial* growth and survival in the soils, as well as root nodule development (Serraj et al., 2004). Acidity affects several steps in the development of the symbiosis, including the exchange of molecular signals between the legume and the micro-symbiont (Hungria and Vargas, 2000). Therefore, nodule formation in many legumes is delayed or inhibited by low pH, lack of calcium, and the presence of dissolved Al, (Serraj et al., 2004).

Past research show that lack of *Rhizobia* in soils may occur in areas where indigenous related legumes are absent or where levels of pH, osmotic stress, temperatures and heavy metals are detrimental to *Rhizobial* populations (Catroux et al., 2001; Hansen, 1994; Chemining'wa et al., 2006). Inoculation of legumes is also found to be especially critical when compatible *Rhizobia* are absent, when population densities are low, or when native *Rhizobia* are not effective (Catroux et al., 2001; Brockwell et al., 1995; Giller and Cadisch, 1995).

2.4 Effects of pests and diseases on phenology, growth and yield of beans

Pests and diseases are major causes of yield losses in bean production and bean yield losses of 37% up to 90% have been reported (Karel and Autrique, 1989). The major diseases are angular leaf spot, anthracnose, leafrust, common bacterial blight and bean common mosaic virus. Nkalubo et al. (2007) reported that anthracnose reduced the potential yield of susceptible bean cultivars by about 30-45%. Anthracnose destroys plant photosynthetic tissue causing premature defoliation and early maturation thus lowering yields, they quoted. Although susceptible cultivars can be infected at any stage, yield loss depends on the crop stage when infection occurs. The most important crop stages determining yield loss are between early flowering through pod fill to the end of seed development, they quoted Bassanezi et al. (2001), and that significant disease development and yield loss occurs if the weather conditions are prolonged throughout the pod formation and pod filling stages, Peloso (1992). Economic losses are aggravated when late planting is done to avoid foliar diseases. These diseases have similar physiological effects on the phenological stages of beans and cause significant yield losses. In the market class varieties higher yield losses of 39-44% occur, but the percentage marketable yield loss is almost double the percentage yield loss, about 63-73% (Nkalubo et al., 2007).

The major pests affecting common bean on the other hand are: aphids, whiteflies, thrips, pod and seed borers, and bean stem maggot which is of greatest concern and widespread and is especially serious during late planting, and when conditions for seedling growth are not favourable. Whiteflies and thrips are important pests in some instances. Important pod and seed feeders include:

Bollworrms and bugs, while foliage beetles are destructive on foliage (Wortmann et al., 1995 and Ojwang', 2010). In a study by Mwang'ombe et al. (2007) pests (black bean aphid and bean stem maggot) and diseases (anthracnose and angular leaf spot) of beans were found to be rampant in farmers' fields. They attributed this to biophysical factors such as nutrient deficiencies and imbalances and low standards of husbandry compounded by the succulent nature of the plant.

2.5 Effects of *Rhizobium* inoculation on bean yield

In a study by Otieno et al. (2007) inoculation with *Rhizobium* increased the number of nodules and nodule dry weight in beans and other legume species under study, but this did not translate into increased shoot or root dry matter and yield. They attributed this to the possible existence of more effective indigenous *Rhizobium* in the soil than the inoculants strains. While a study by Rabbani et al. (2005) on the effect of *Rhizobium* inoculation, N, P and Mn on nodulation, yield, and seed protein in pea showed that inoculated plants added 80 kg N/ha, and the average dry matter yield increased in pea plants over uninoculated control. Other studies have also reported that significant increases in pod yield, seed yield and protein content were obtained by *Rhizobium* inoculation (Feng et al., 1997; Tolkachev et al., 1994). However, plants relying on fixed N for growth may achieve only 80-90% of the yield possible with N fertilization (Silsbury, 1977; Ryle et al., 1979; Thies et al., 1991). Also according to Chemining'wa et al., (2007), *Rhizobia* inoculation and starter-N did not significantly improve shoot biomass per plant in common bean. However, under soils low in mineral N a moderate dose of starter N has been demonstrated to stimulate seedling growth and subsequently N-fixation. Inorganic-N is required by legume plants during N-hunger period for their nodule development, shoot and root growth before the onset of N-fixation process (Giller, 2001).

2.6 Effects of combined organic and inorganic fertilizers on growth and yield of Navy bean

Low soil fertility due to decades of land cultivation is a major factor in the decline of bean productivity. lt is aggravated by high costs of fertilizers and their low use in smallholder farming systems. Cultural practices like the use of crop residues from legumes which is a potential source of plant nutrients that may complement/supplement inorganic fertilizers, can foster sustainable, environmentally friendly sound agricultural systems in subtropical semi-arid soils low in organic matter (Mwangi, 2010; ATTRA 2003). Integration of small amounts of inorganic fertilizer nitrogen along with nitrogen fixed by the legumes may offer a strategy to meet nitrogen needs of smallholder farmers (Mwangi, 2010).

Other studies (Reddy et al., 1986, and Kimenju et al., 2008) indicate that long term use of green manure with crotalaria and mucuna reduces soil populations of root knot nematodes. The impact of rainfall irregularity and poor distribution, reducing season length leading to prolonged periods of drought during the growing season of the crop, may combine with soil nutrient limitations and aggravate the decline in bean yields in the foreseeable future. It is well established that combining mineral fertilizer with organic resources improves fertilizer use efficiency (Wangechi, 2009). 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 build up 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) state that the important role of arbuscular mycorrhizas in the uptake by plants of nutrients of low solubility especially P is well recognized. Application of inorganic fertilizers also provides a ready nutrient supply at the early growth phases of the young crop (Chemining'wa et al., 2007; Bildiricci et al., 2005; Thies et al., 1991), and coupled with the property of organic manure of moisture storage and slow release of nutrients, therefore sustain crop development cushioning against adverse conditions.

Past research has also shown that continuous use of green manures is an alternative method for improving and maintaining the fertility of most soils, and with the applied nutrients stored in the matrix of organic manure, ensures adequate nutrient availability for full production, being cushioned from rapid leaching. After continued compost application total and available phosphorus and potassium concentration respectively in the soil are increased. But in contrast to nitrogen P, K and Mg show in principle higher plant availability (Seminar proceedings - Brussels, 2001).

Nutrient management is thus useful in correcting and maintaining soil conditions suitable for nutrient availability and sustaining a fertile environment that ensures improved crop productivity. Nutrient management therefore conserves soil fertility, and improves the economy of crop production. A combination of organic and inorganic fertilizers has also been shown to benefit a bean crop more than any single one alone. Studies by Bildirici et al., (2005) showed that the combination of N, P and rhizobia gave the highest yield in bean.

2.7 Effect of combined chemical sprays and fertilizers on growth and yield of Navy bean

Application of pesticides during crop development minimizes the damage by pests and diseases on the growing parts of the plant enabling full development and proper physiological functions of nutrient accumulation and biomass formation. However, only moderate amounts should be applied as higher amounts interfere with the physiological functioning of the plant systems. Similarly, nutrients N and P are only assimilated when availed in moderate quantities and excess quantities may either retard growth and dry matter formation or fatally scorch the plant (McCauley, Jones, and Jacobsen, 2009).

2.7.1 Effects of pesticides on growth, yield and yield components of beans

Schnelle and Hensley (2006) in a study on the effect of pesticide application on nitrogen fixation and nodulation of the dry bean, observed that all pesticides examined were found innocuous to nitrogen fixation (acetylene reduction) except bentazone, a post-emergence herbicide. Bentazone at 6.7 kg ha^{-1} consistently depressed nitrogen fixation rates within 48 hours after application. However, fixation rates recovered and were comparable to those of control plants after 6 days. No effects were observed on nodulation from any of the pesticides applied.

Siddiqui and Ahmed (2006) also observed that past studies indicated that higher concentrations of pesticides had harmful effects on various growth parameters of plants. The adverse effect of pesticide residues on proteins, lipids and carbohydrates metabolism may cause the lowering of Net Assimilation Rate (NAR) values and there is a possibility of the inhibition of protein and carbohydrate synthesis. They quoted further that pesticides initiate some kind of abiotic stress (chemical stress) in plants triggering formation of phenolic compounds which are potential inhibitors of germination and plant growth. They concluded that these effects depend on the concentration of compounds produced by the plants in response to pesticide application, which determines if the application is going to prove beneficial or disruptive for plant growth.

In a study on combined effects of pesticides on growth and nutritive composition of soybean plants Siddiqui and Ahmed (2006), however, found that the pesticides - Topsin M^R, Benlate^R (benomyl), Demacron^R (phosphomedon), and chlorosuphuron, Cypermethrin and Cypermethrin dimethride (Lazer^R) had significant positive effects on leaf growth components e.g. leaf area ratio (LAR), leaf area index (LAI), leaf weight ratio (LWR), specific leaf area (SLA), relative growth rate (RGR), leaf area duration (LAD), net assimilation rate (NAR) crop growth rate (CGR), and seed nutritive composition. Application of 0.25 g L^{-1} of a concentration of pesticide increased these parameters between flowering and early fruiting stages, but a decline was observed towards late fruiting in some of them. On the other hand, higher concentrations of 0.5 g L^{-1} and 0.75 g L^{-1} led to a reduction in these parameters. Pesticides have been reported to have an effect on nutrient composition of bean seed. High pesticide concentrations significantly reduce protein content. However, seed lipids produced in plants grown in 0.25 g L^{-1} treated soil, were in significant excess compared to the seed lipids at control and high concentration sites. A decrease of 32.04% in lipids was observed at a concentration 0.75 g L^{-1} of pesticides and of 48.4% at higher concentrations (Schnelle and Hensley, 2006).

Phosphorus fertilizer application is effective in root development in the first stages of growth and in improving grain yield and quality. The requirement of N can be quite high in the early stages of growth when nodules and symbiosis are not fully functional. In the later stages of development the plant fulfils its requirement from nitrogen fixation by the bacteria, thus it does not need any fertilization based on N. However, N fertilizers in the scale of 20-60 kg/ha were found to positively affect yield, but generally decreased nodule weight, number and size, (Bildirici and Yilmaz, 2005). They observed that N applications in increasing amounts up to 60 kg/ha increased number of pods per plant. Similarly, P increased number of pods per plant up to 60 kg/ha. The study also found no significant effect of both N and P on number of seeds per pod and 1000 seed weight, which they concluded were related to the genetic structure of the plant (Bildirici and Yilmaz, 2005). The effects of N also increased grain yield/ha compared with the control. 60 kg/ha N gave an increase of 503 kg/ha from 3151 to 3654 kg/ha. Whereas P was only effective on grain yield up to 40 kg/ha, and subsequently yield decreased. Application of N also increased raw protein. They concluded that only N had a significant effect while P had no significant effect on the factors investigated.

In another study, Furtini et al. (2006) evaluated 100 bean lines in the presence and absence of N and observed that the lines differed in their response to N. In order to identify the strategy that the bean lines adopted in their divergent responses they used six genotypes and tested them at three N levels: 0, 60, and 120 kg/ha N. As expected, higher grain yield, pod number, and total dry matter were obtained with the increase in the N level. For grain yield, the increase was 16% when 60 kg/ha N was used and 31% with 120 kg/ha N, in relation to the absence of this nutrient at planting and at top dressing stages. An average increase of 6.75 kg/ha in grains was observed per kg/ha N used.

Smallholder farming systems widely use manure to increase the productivity of soils that contain inadequate levels of organic carbon. The organic amendments used (FYM and compost) have a pH of about 7.4 to 8.4, and high levels of exchangeable bases such as calcium, phosphorus and potassium that have amending effect on soil acidity in addition to improving the physical, biological and other chemical properties of soil (Saad et al., 2009). They also reported that previous studies on the effects of manure on P availability in various soils show that it is a source of P; interacts with soil components in a manner that increases P recovery by crops; and enhances the effectiveness of inorganic P fertilizer. Most of the soils that have low cation exchange capacity with an acid reaction (average pH range of 5.1 to 5.5) usually have nutrients adsorbed in the surfaces of soil particles and is unavailable to crops; a situation that is corrected by the application of manure.

According to Mengel and Kirkby, (2001) lack of P in the soil may prevent other nutrients from being acquired by plants. Circumstances that influence P availability in the soil are soil properties such as soil pH, organic carbon and clay content (Dodor and Oya, 2000; Hinsinger, 2001). Mengel and Kirkby (2001) reported that the decrease in P occurred due to the shift in the HPO_4^{2-}/H_2PO_4 ratio in the nutrient solution. On the other hand, increasing the clay composition of several soils was reflected in a higher capacity for adsorbing phosphate (Toreu et al., 1988), while high C/N ratio or low N content is insufficient for supplementing the existing organisms to decompose the cereal material (i.e. the narrower C/N ratio, the higher effect of FYM) (Aikman, 2008). Although organic manures have the ability of improving bean productivity, their on-farm availability is a major limitation to achieving this. Any substantial effect of organic amendments requires very large quantities that are not readily accessible to the majority of bean growers who are smallholder farmers (Thung and Rao, 1999).

The results obtained in the study by Sulieman and Haag, (2009) on the effect of supplying different levels of P and FYM on the various bean parameters demonstrated that plants provided with manure nodulated more than the unfertilized controls but had no effect on shoot biomass, grain yield and yield components. The insignificant shoot and grain yield response to FYM application may have been related to the nature of this organic fertilizer which commonly contains about 75% water and relatively low concentration of nutrients (Tolessa and Friesen, 2001; Sulieman and Hago, 2009).

The study also shows that neither phosphorus nor FYM significantly affected yield and yield components. In contrast Cheminingwa et al., **(**2007) reported that FYM significantly increased yield and yield components of beans. The report on soil management research project in Western Kenya (1994-2002) (not published) states that integrated nutrient management, which seeks to maximise the complementary effects of inorganic fertilisers and organic nutrient sources, is one of the options that hold much promise in increasing crop productivity on smallholder farms. In the study, application of farmyard manure (FYM) or compost alone (5 or 10 t/ha) or in combination with low levels of inorganic fertilisers (30 kg P_2O_5 + 30 kg N/ha or 15 kg P_2O_5 + 15 kg N/ha) increased yields of important crops in the region compared to when no fertilizer was applied and farmers' practice.

In a study by Chemining'wa et al., (2007) and Sulieman and Hago, (2009) investigating the effect of inoculation, **N** fertilizer and manure application on nodulation, dry matter accumulation, yield and yield components of beans, manure application and rhizobia inoculation significantly increased number of nodules per plant in all legume species except one bean variety. While an experiment studying the effect of integrated nutrient management on growth, yield, nutrient uptake and economics of French bean (*Phaseolus vulgaris*), (Kumar et al., 2004) showed that gross and net returns were higher with a combination of 100% NPK+50% N organic fertility level, but benefits to cost ratio (B:C) was higher under 100% NPK+25% N organic level. The combined effect of biofertilizers and micronutrients (biofertilizer+Zn+Fe treatment) was significantly better than their individual effects as this treatment significantly improved growth characters, yield attributes, yield, harvest index, nutrient uptake and B:C ratio. Furthermore, they also concluded that integration of 100% NPK+25% N organic and biofertilizer+Zn+Fe was conducive for getting optimum yield.

Adequate levels of P in the leaf are needed for normal metabolic processes since it is a constituent of ATP and intermediary organic compounds. In a study on effects of pruning Tughutu (*Vernonia subligera O.* Hoffn) in combination with Minjingu phosphate rock (MPR) or triple super phosphate (TSP) supply on the concentration of P in the tissues and seed yields of common bean, and the economic returns of these different technologies, it was observed that addition of MPR or TSP alone significantly raised P concentration in bean shoots, and combining MPR or TSP with Tughutu increased P concentration above the proposed deficiency level of 2 mg g^{-1}. The relative agronomic effectiveness (RAE) of MPR ranged from 12.5% to 45.0% and seed yields were markedly increased by 28%-104% from MPR or TSP supply alone, and 148%-219% from Tughutu application combined with 26 kg P ha^{-1} of MPR or TSP relative to the control. With Tughutu alone, seed yield increased by 53%. From economic analysis, the increase in seed yield with the supply of any one combined with Tughutu translated into a significantly ($P \leq 0.001$) higher marginal rate of return and profit for common bean farmers.

CHAPTER THREE: EFFECT OF VARYING COMBINATIONS OF ORGANIC AND INORGANIC FERTILIZERS ON THE GROWTH AND YIELD OF NAVY BEAN

3.1 Abstract

Low soil fertility especially of nitrogen and phosphorus is a constraint to Navy bean production in Kenya. A study was carried out in Mwea in 2009 short rains and 2010 long rains to determine the effect of varying combinations of organic and inorganic fertilizers on growth and yield of canning bean. The treatments comprised: a control with no fertilizer application, NPK (17:17:17) fertilizer at rates of 50 kg/ha, 100 kg/ha and 200 kg/ha, chicken and cattle manure each at 4 t/ha and 8 t/ha, and combinations of the three rates of NPK with the two rates of chicken and cattle manure respectively. The treatments were laid out in a randomized complete block design with three replications. Data collected included: number of days to 50% germination, 50% flowering, 50% podding, and 50% maturity, plant height, shoot biomass, root biomass, nodule count, yield at harvest and yield components. Data was subjected to analysis of variance using the GENSTAT statistical package and treatment means compared using the least significant difference test at $p \leq 0.05$. A partial economic analysis was conducted for the various treatments. Results showed that the fertilizer and manure treatments had highly significant effect ($p<0.01$) on shoot biomass, and in both seasons on root biomass. The treatments significantly ($p<0.001$) increased nodule development in both seasons and grain yield in the second season. A partial economic analysis showed that although 200 kg/ha NPK plus 8t/ha FYM had higher yield than 100kg/ha NPK plus 4t/ha FYM, the latter was more profitable per unit of expenditure. It can be concluded that application of fertilizer and manure improved vegetative growth of beans, increased nodule development and grain yield of beans, and there was reduced cost of production that led to increased profits.

3.2 Introduction

Beans are an important source of affordable proteins, help to control malnutrition in children, and complement other foods therefore reducing food insecurity, in addition to other health advantages (Pachico, 1993; Kibiego, 2003; Broughton et al., 2003). Navy bean is mainly produced for processing although it is also locally consumed by households in small quantities. It attracts high demand in the local and export market when canned (Chemining'wa et al., 2011). Navy bean production is mainly done by women farmers in African countries where they are the decision makers and main source of labour (Wortman et al., 1995). Navy bean production in Kenya has declined to very low levels and can be found only in small pockets in smallholdings (Chemining'wa et al., 2011). Major constraints attributed to this decline are low soil fertility, pest and disease problems (Serraj et al., 2004). Lack of N and P in most soils is aggravated by low fertilizer use because fertilizers are prohibitively expensive particularly for smallholder farmers (Gerner et al., 1995). As a result yields are low, mainly between 300 and 700 t/ha (Abate and Ampofo, 1996). There is a need to develop an appropriate fertilization strategy for farmers to increase Navy bean productivity. One such strategy is integrated use of organic and inorganic fertilizers and nutrient management. Combining mineral fertilizer with organic resources improves fertilizer use efficiency (Saad et al., 2009) as lower rates of these have cost reduction effects on production offering more economical options resulting in optimum crop production, compared to the use of either single source alone, and this has also been shown in previous studies to benefit a bean crop more.

Continuous use of organic manures stabilizes the soil structure promoting build up of microbial populations (Smaling, 1993). This enhances soil properties such as increased populations of beneficial micro-flora, increased aeration, decomposition of vegetative material into organic matter, increased water-holding capacity and promotion of micorrhizal-crop root symbioses which improve soil nutrient uptake ((Smaling, 1993; Ibijbijen et al., 1996). Manure also corrects soil acidity that leads to nutrient adsorption in the surfaces of soil particles becoming unavailable to crops, a situation common in most soils that have low cation exchange capacity with an acid reaction (average pH range of 5.1 to 5.5) (Smaling, 1993). Manure also interacts with soil components in a manner that increases P recovery by crops; and enhances the effectiveness of inorganic P fertilizer (Saad et al., 2009; Seminar proceedings – Brussels, 2001). While application of inorganic fertilizers provides a ready nutrient supply at the early growth phase of the young crop in soils low in fertility (Chemining'wa et al., 2011; Thies et al., 1991). Inorganic fertilizers are also a quick way of correcting the poor fertility status of the soil for immediate crop production, and improved yields (Gerner et al., 1995). Lack of P in the soil may prevent other nutrients from being acquired by plants and circumstances that influence P availability in the soil are soil properties such as soil pH, organic carbon and clay content which are improved by addition of manures (Saad et al., 2009, Dodors and Oya, 2000; Hinsinger, 2001; Toreau et al., 1998).

Phosphate fertilizer is useful in root development, increased production of pods, grain yield and quality. P fertilization also contributes to early crop development and maturity, while the requirement of N is quite high during the emergence of nodules and build-up of symbiotic N fixation in the first stage of development (Bildirici and Yilmaz, 2005). Nitrogen fertilizers increase nodulation, yield and raw protein content, but high amounts decrease nodule weight and number (Furtini, 2006). Inorganic fertilizers are, however, easily removed into the lower soil levels beneath the root zone rendering them unavailable to crops. This is alleviated when manure is applied because they store inorganic nutrients in their matrix, reducing their rapid leaching and consequently prolonging their availability to crops. The objective of the study was to develop integrated nutrient options that can give optimum yields.

3.3 Materials and methods

3.3.1 Experimental sites

The study was carried out on a farm in Kirinyaga South at latitude 0^{o} 36’20.89’’S and longitude 37^{o} 22’0.94’’E, at an altitude of 1214 m above sea level. This area receives an annual rainfall of 400-1200 mm and has mean monthly minimum and maximum temperatures of 20.1 to 24 ^{o}C. The rainfall is bimodal, with the long and short rain seasons occurring in the months of March to May and October to December, respectively. The area is in agro-ecological zone UM4 and has soil types which are predominantly clay/loam, with a suitable pH of 5.9 satisfactory for crop growth. Soil was analyzed for pH, macronutrients and micronutrients. The soil was low in organic matter, deficient in nitrogen (0.11%) and organic carbon (0.92%) but adequate in phosphorus (52%) and potassium (0.96%). The second site had a pH of 4.97, 0.12% N, 57% P, 0.67% K, 8.71 ppm Cu, 36.3 ppm Fe and 3.36 ppm Zn. The experiment was carried out between December 2009 and March 2010 in season one and from April to July 2010 for the second season. The average monthly rainfall up to the end of December was 159 mm but this dropped to 51 mm in January-February period. Irrigation was done twice weekly during this dry spell until the rains resumed in March. As a result there was more insect infestation in the long rains. Average monthly temperatures during this period were 17.5 ^{o}C minimum and 28.6 ^{o}C maximum. The second season was planted with the continuing rains which on average was around 168.3 mm/month between March and May. There was a dry spell again in June and irrigation was done twice a week until the crop matured. Irrigation was carried out for an average of two hours each time, giving an average water infiltration of less than 70 mm per week into the soil (the average nozzle discharge rate being below 35 mm per hour considering irrigation losses) (Fig. 3.1 and Appendix 1).

3.3.2 Experimental designs, treatments and crop husbandry

The treatments consisted of a control with no fertilizer application and no seed dressing, NPK

(17:17:17) fertilizer at rates of 50 kg/ha, 100 kg/ha and 200 kg/ha, chicken and cattle manure each at 4 t/ha and 8 t/ha, and combinations of the three rates of NPK with the two rates of chicken and cattle manure respectively. The cattle manure had a pH of 8.28 and contained 0.94% N, 1.12% P, 0.91% K and 1.76% organic C, while chicken manure had a pH of 8.24 and contained 1.46% N, 1.21% P, 1.35% K and 1.79% organic C. The treatments were laid out in a randomized complete block design and replicated three times. The plots were of size 3 m x 2 m.

At planting seed was dressed with a Moncerene^{R} solution containing the active ingredients – imidacloprid (systemic insecticide) 233 g/l; pencycuron (non-systemic fungicide) 50 g/l; and thiram (contact fungicide) 107 g/l. The solution was mixed with water in a ratio of 1:3 and used at 6 ml/kg seed. Spraying started one week after emergence against major insect pests like beanfly using the insecticide Actara^{R} with respective active ingredients of thiamethoxan 252 g/kg solution diluted to 20 g/100 l of water per ha (4 g/20 l). At the third week, fungicide Ortiva^{R} was sprayed against fungal diseases with azoxystrobin 250 g/l at a rate of 6 ml/20 l of water. Planting was done in December during the short rains after land had been prepared and harrowed to a fine tilth and in the April 2010 long rains. The inter-row spacing was 50 cm and two seeds were planted per hill, spaced 10 cm apart. Plots were thinned to one plant per hill after emergence and weeding was done by hand to ensure weed-free conditions.

3.3.3 Data collection:

The data collected were: days to 50% emergence, days to 50% flowering, days to 50% podding, days to 50% maturity, plant height; weekly plant count, biomass and nodule count at two weeks up to flowering, number of pods per plant, number of grains per pod, 100 seed weight and yield at harvest. Plant counts involved actual counting of all the plants in each plot every week. Biomass sampling and nodule count were done weekly until maturity. Five plants were randomly selected from the inner rows and harvested together with the roots. The root nodules were counted and the roots separated from the shoots and oven dried at temperatures of 50-60 ^{o}C until constant weight was reached. The final biomass sampling at harvest determined total plot biomass yield when all the dry biomass including seed were weighed. This comprised total grain yield, and 100 seed weight and combined with foliage the total biomass was obtained for each plot.

3.3.4 Data Analysis

Data collected were subjected to analysis of variance (ANOVA) using Genstat statistical package and the means were compared using the least significant difference test (LSD) at 5% probability level (Steel and Torrie, 1987). A cost/benefit analysis was carried out using the approach of Siddiqui et al., (2004).

The procedure adopted by Siddiqui et al., (2004) was used to evaluate the economics of bean production under the fertilizer application treatments. It involved calculation of average value of yield (gross returns), yield increment above or below recommended input level, and value of yield increment (profit or net returns). The average yield was determined as the average of all the plots with the same treatment in the three blocks. The value of yield (gross returns) was obtained by multiplying the average yield by the market value of 1 kg of beans while the yield increment was the difference in yield between a given treatment input and that obtained with the recommended 200 kg/ha NPK. The value of yield increment (net returns or profit) is the yield increment multiplied by the market value of 1 kg of beans and was calculated as the difference between total variable costs (TVC) and the gross returns (NR=GR-TVC), where the total variable costs was the sum of all the production costs (namely: costs of land clearing, ploughing, harrowing, planting, weeding, fertilizers and pesticides, application and spraying labour, harvesting labour, drying and packaging). The cost benefit ratio was calculated as the total value of yield divided by the sum of the costs of production (GR/TVC) and it defines the returns on every shilling invested.

The rates and costs of inputs used are shown in Table 3.1. In the economic evaluation of treatment effects, the recommended rate of fertilizer application for beans (200 kg/ha NPK) was adopted.

Table 3.1 Rates and costs of inputs used in the treatments

Pesticide	**Recommended rate/ha per spray**	**No. of sprays done**	**Amount used**	**Unit price**	**Cost of pesticide**
Fungicide	300-500 ml	4	1200-2000 ml	100 ml @ 750/=	15,000/=
Insecticide	200 g	4	800 g	40 g @ 600/=	12,000/=
Seed dressing	6-8 ml/kg seed	4.8 kg seed	72-120 ml	50 ml @ 250/=	1,200/=
Fertilizer	200 kg/ha	-	200 kg/ha	50 kg bag @ 2700/=	10,800/=
Manure	8 T/ha	-	8 T/ha	1 tonne @ 2000/=	16,000/=

3.4 Results

3.4.1 Effects of fertilizer and manure treatment on shoot biomass

At 4 weeks after emergence fertilizer treatments had significant effect ($p \leq 0.05$) on shoot biomass during the long rains while they had no significant effect during the short rains (Tables 3.2 and 3.3) In the long rains, application of 8 t/ha FYM, 100 kg/ha NPK plus 4 t/ha CM, 200 kg/ha NPK plus 4 t/ha CM, and 200 kg/ha NPK plus 4 t/ha FYM significantly increased shoot biomass compared to the untreated control. At 8 and 10 weeks after emergence fertilizer application significantly ($p<0.05$) increased shoot biomass during both the long and short rains relative to the untreated control (Tables 3.2 and 3.3). Combination of 200 kg/ha NPK with 8 t/ha chicken manure had higher shoot biomass than most of the other treatments.

Table 3.2: Mean shoot biomass (g/m^2) of beans in plots subjected to different fertilizer and manure treatments in weeks after emergence in long rains season 2010

	Weeks after emergence		
	4	8	10
Control	2.20	14.96	77.70
4t/ha CM	3.64	18.36	97.70
4 t/ha FYM	4.38	19.20	147.56
8t/ha CM	7.11	30.16	191.40
8 t/ha FYM	3.76	28.20	188.16
50kg/ha NPK	3.13	25.53	123.33
100kg/ha NPK	3.76	18.58	168.44
200kg/ha NPK	3.69	25.11	214.44
50kg/ha NPK x 4t/ha CM	3.53	19.84	159.56
50kg/ha NPK x 4t/ha FYM	1.96	19.64	157.04
50kg/ha NPK x 8t/ha CM	2.98	22.69	172.00
50kg/ha NPK x 8t/ha FYM	3.33	21.64	166.51
100kg/ha NPK x 4t/ha CM	5.22	24.49	185.04
100kg/ha NPK x 4t/ha FYM	2.42[j]	21.29	181.49
100kg/ha NPK x 8t/ha CM	3.56	26.29	194.60
100kg/ha NPK x 8t/ha FYM	2.20	16.36	190.51
200kg/ha NPK x 4t/ha CM	4.67	27.87	218.29
200kg/ha NPK x 4t/ha FYM	6.27	27.09	220.00
200kg/ha NPK x 8t/ha CM	4.04	32.96	268.22
200kg/ha NPK x 8t/ha FYM	3.56	31.13	252.67
Mean	3.77	23.57	178.73
LSD(p=0.05)	2.28	1.4	10.18
CV%	15.2	1.3	3.4

Table 3.3: Mean shoot biomass (g/m^2) of beans in plots subjected to different fertilizer and manure treatments at 4, 8 and 10 weeks after emergence in short rains season of 2010

	Weeks after emergence		
	4	8	10
Control	60.44	73.27	87.00
4t/ha CM	65.33	80.49	131.78
4 t/ha FYM	64.44	79.91	88.73
8t/ha CM	60.22	106.80	133.56
8 t/ha FYM	60.89	87.84	106.44
50kg/ha NPK	61.78	108.98	129.93
100kg/ha NPK	56.44	145.62	163.58
200kg/ha NPK	56.67	166.51	188.89
50kg/ha NPK x 4t/ha CM	59.56	109.91	117.44
50kg/ha NPK x 4t/ha FYM	70.00	109.51	117.11
50kg/ha NPK x 8t/ha CM	57.78	140.76	145.93
50kg/ha NPK x 8t/ha FYM	77.56	123.64	127.42
100kg/ha NPK x 4t/ha CM	64.89	157.04	166.47
100kg/ha NPK x 4t/ha FYM	49.56	154.96	190.56
100kg/ha NPK x 8t/ha CM	48.89	161.16	170.96
100kg/ha NPK x 8t/ha FYM	88.67	159.69	173.11
200kg/ha NPK x 4t/ha CM	49.78	261.56	276.73
200kg/ha NPK x 4t/ha FYM	87.56	220.24	250.78
200kg/ha NPK x 8t/ha CM	80.89	283.13	306.20
200kg/ha NPK x 8t/ha FYM	62.89	267.00	288.49
Mean	64.22	149.90	165.62
LSD(p=0.05)	NS	27.93	27.76
CV%	8.44	3.33	3.33

3.4.2 Effects of fertilizer and manure treatment on root biomass

Fertilizer treatments had significant effects ($p<0.05$) on root biomass at 4, 8 and 10 weeks after emergence during the short rains (Tables 3.4 and 3.5). Similar results were observed in the long rains except that treatments had no effect on root biomass at 4 weeks after emergence. In the short rains most fertilizer treatments increased root biomass relative to the untreated control.

At 8 and 10 weeks after emergence, all the fertilizer treatments had higher root biomass than the untreated control.

Table 3.4: Mean root biomass (g/m^2) of beans in plots subjected to different fertilizer treatments at 4, 8 and 10 weeks after emergence during the long rains of 2010

	Weeks after emergence		
	4	**8**	**10**
Control	0.69	1.76	1.20
4t/ha CM	0.67	2.69	1.51
4t/ha FYM	0.67	2.27	1.38
8t/ha CM	1.00	3.31	1.64
8t/ha FYM	0.62	2.87	1.56
50kg/ha NPK	0.58	2.31	1.31
100kg/ha NPK	0.62	2.76	2.27
200kg/ha NPK	0.67	2.96	2.78
50kg/ha NPK x 4t/ha CM	2.16	2.47	2.58
50kg/ha NPK x 4t/ha FYM	0.76	2.02	1.82
50kg/ha NPK x 8t/ha CM	0.76	2.20	2.11
50kg/ha NPK x 8t/ha FYM	0.93	2.40	1.87
100kg/ha NPK x 4t/ha CM	1.31	3.02	2.53
100kg/ha NPK x 4t/ha FYM	0.51	2.78	2.51
100kg/ha NPK x 8t/ha CM	1.29	3.24	2.40
100kg/ha NPK x 8t/ha FYM	0.53	3.22	2.33
200kg/ha NPK x 4t/ha CM	0.53	3.07	2.67
200kg/ha NPK x 4t/ha FYM	0.89	3.22	2.60
200kg/ha NPK x 8t/ha CM	0.40	3.60	2.87
200kg/ha NPK x 8t/ha FYM	0.89	3.49	2.87
Mean	0.82	2.78	2.13
LSD	NS	0.34	0.06
CV%	18.7	10.3	3.9

Table 3.5: Mean root biomass (g/m^2) of beans in plots subjected to different fertilizer and manure treatments in weeks in short rains of 2010

	Weeks after emergence		
	4	**8**	**10**
Control	1.22	3.44	4.36
4t/ha CM	5.38	6.42	7.07
4t/ha FYM	2.44	4.18	4.24
8t/ha CM	5.04	5.67	6.80
8t/ha FYM	3.00	3.96	4.09
50kg/ha NPK	3.20	4.13	4.96
100kg/ha NPK	3.89	4.71	5.27
200kg/ha NPK	3.53	4.49	5.67
50kg/ha NPK x 4t/ha CM	5.73	6.82	7.69
50kg/ha NPK x 4t/ha FYM	6.09	6.49	7.33
50kg/ha NPK x 8t/ha CM	2.96^j	3.67	4.62
50kg/ha NPK x 8t/ha FYM	3.87	5.60	6.56
100kg/ha NPK x 4t/ha CM	5.40	7.78	8.78
100kg/ha NPK x 4t/ha FYM	2.31	3.53	4.56
100kg/ha NPK x 8t/ha CM	3.29	5.04^j	5.73
100kg/ha NPK x 8t/ha FYM	4.16	6.98	7.82
200kg/ha NPK x 4t/ha CM	2.78	7.24	7.58
200kg/ha NPK x 4t/ha FYM	3.31	4.78	5.44
200kg/ha NPK x 8t/ha CM	3.33	4.40	5.00
200kg/ha NPK x 8t/ha FYM	4.22	5.22	5.93
Mean	3.76	5.23	5.97
LSD	1.47	1.29	1.80
CV%	17.11	6.00	3.33

3.4.3 Effects of fertilizer and manure treatment on nodule count in the long rain season

The fertilizer treatments had highly significant ($p \leq 0.01$) effects on nodule count at 4, 8 and 10 weeks after emergence. Application of combinations of 100 kg/ha NPK with chicken and farm yard manure each at 4 and 8 t/ha had higher nodule number than the untreated control (Tables 3.6 and 3.7). Nodules number declined progressively after 4 weeks after emergence, a period which coincided with flowering and pod development.

Table 3.6: Mean nodule count of beans in plots subjected to different fertilizer and manure treatments at 4, 8 and 10 weeks after emergence, in the long rains of 2010

	Weeks after emergence		
	4	**8**	**10**
Control	44.3	27.2	17.0
4t/ha CM	30.3	27.0	15.3
4t/ha FYM	54.3	38.3	24.0
8t/ha CM	75.7	49.27	24.0
8t/ha FYM	64.0	52.0	32.7
50kg/ha NPK	53.7	61.3	36.7
100kg/ha NPK	41.7	33.0	24.3
200kg/ha NPK	60.3	43.7	23.3
50kg/ha NPK x 4t/ha CM	34.7	28.0	19.0
50kg/ha NPK x 4t/ha FYM	62.0	50.0	23.7
50kg/ha NPK x 8t/ha CM	31.0	35.7	24.0
50kg/ha NPK x 8t/ha FYM	85.0	45.0	29.7
100kg/ha NPK x 4t/ha CM	56.7	62.0	40.0
100kg/ha NPK x 4t/ha FYM	67.7	54.3	26.7
100kg/ha NPK x 8t/ha CM	45.7	46.0	28.7
100kg/ha NPK x 8t/ha FYM	34.4	25.0	15.3
200kg/ha NPK x 4kg/ha CM	78.3	55.3	36.0
200kg/ha NPK x 4t/ha FYM	117.7	74.3	29.7
200kg/ha NPK x 8t/ha CM	130.0	89.3	48.7
200kg/ha NPK x 8t/ha FYM	117.3	107.7	47.0
Mean	64.24	50.22	28.29
LSD	44.84	23.52	17.0
CV%	13.5	6.5	4.5

Table 3.7: Mean nodule count of beans in plots subjected to different fertilizer and manure treatments in weeks after emergence in the short rains of 2010

	Weeks after emergence		
	4	8	10
Control	24.0	21.3	8.0
4t/ha CM	33.0	19.3	9.67
4t/ha FYM	29.3	18.0	9.67
8t/ha CM	49.0	39.3	10.0
8t/ha FYM	34.0	25.3	9.67
50kg/ha NPK	39.0	32.0	11.0
100kg/ha NPK	53.3	42.7	18.0
200kg/ha NPK	71.0	56.0	29.0
50kg/ha NPK x 4t/ha CM	38.0	26.0	15.7
50kg/ha NPK x 4t/ha FYM	43.0	24.0	11.0
50kg/ha NPK x 8t/ha CM	51.0	44.7	18.0
50kg/ha NPK x 8t/ha FYM	49.7	38.7	17.0
100kg/ha NPK x 4t/ha CM	39.0	47.3	22.0
100kg/ha NPK x 4t/ha FYM	55.3	42.0	19.0
100kg/ha NPK x 8t/ha CM	32.3	25.3	28.0
100kg/ha NPK x 8t/ha FYM	67.0	55.3	23.0
200kg/ha NPK x 4t/ha CM	79.7	62.0	34.0
200kg/ha NPK x 4t/ha FYM	77.0	54.7	32.0
200kg/ha NPK x 8t/ha CM	139.3	111.7	54.0
200kg/ha NPK x 8t/ha FYM	103.3	60.3	46.0
Mean	55.4	42.3	21.2
LSD	33.6	27.9	12.6
CV%	1.3	20.6	11.0

3.4.4 Effects of fertilizer and manure treatment on yield and weight of 100 seeds in the long and short rain seasons

In the long rains season all the fertilizer treatments increased yield relative to the control except 4 t/ha chicken manure, 50 kg/ha NPK, 100 kg/ha NPK, 50 kg/ha NPK plus 4 t/ha FYM. Generally, combinations of NPK at 100 kg/ha and above with chicken manure and farm yard manure each at 4 and 8 t/ha significantly outperformed most of the other treatments. Similar observations were made in the second season, however, application of FYM and chicken manure each at 4 and 8 t/ha had no effect on grain yield relative to the control.

In the short rains yields were drastically lower than in the long rains, having been due to the prolonged dry weather in the season with more intense insect damage. The reduction in yields was also due to the reduced soil moisture limiting nutrient uptake and consequently affecting the physiological processes of the plant and hence physical development. This implies that the amount of water (less than 70 mm) that infiltrated into the soil every week during irrigation was not adequate for nutrient uptake by the plant for sustained metabolic processes as this was lost through evapotranspiration due to high daily temperatures and very low relative humidity during subsequent dry days (Fig. 3.1 and Appendix 1).

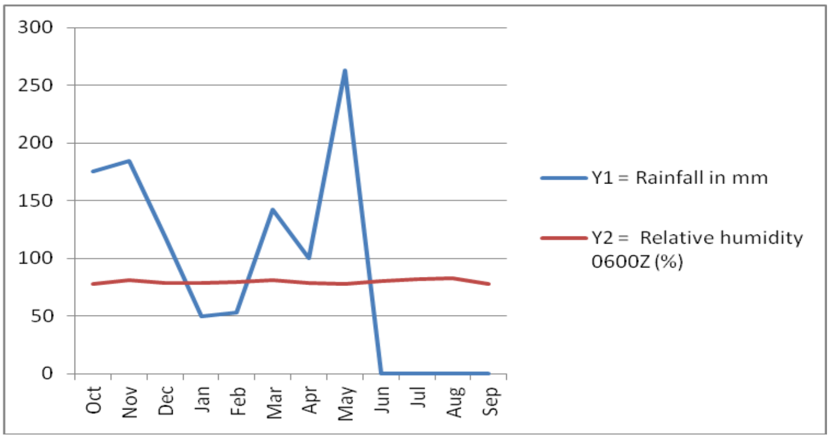

Fig 3.1: Monthly rainfall and relative humidity at Mwea during the experimental period

Table 3.8: Mean yields (t/ha) of beans in plots subjected to various levels of fertilizer and manure treatments in the long and short rains of 2010

	Yield t/ha	
	Long rains	**Short rains**
Control	0.05	0.38
4t/ha CM	0.05	0.46
4t/ha FYM	0.76	0.41
8t/ha CM	1.16	0.55
8t/ha FYM	1.34	0.53
50kg/ha NPK	0.05	0.57
100kg/ha NPK	0.08	0.70
200kg/ha NPK	1.92	0.72
50kg/ha NPK x 4t/ha CM	1.09	0.66
50kg/ha NPK x 4t/ha FYM	0.40	0.58
50kg/ha NPK x 8t/ha CM	1.18	0.66
50kf/ha NPK x 8t/ha FYM	0.56	0.66
100kg/ha NPK x 4t/ha CM	2.18	0.71
100kg/ha NPK x 4t/ha FYM	2.22	0.86
100kg/ha NPK x 8t/ha CM	2.45	0.72
100kg/ha NPK x 8t/ha FYM	2.07	0.72
200kg/ha NPK x 4t/ha CM	2.27	0.78
200kg/ha NPK x 4t/ha FYM	1.85	0.77
200kg/ha NPK x 8t/ha CM	2.56	1.02
200kg/ha NPK x 8t/ha FYM	2.40	0.89
Mean	1.33	0.66
LSD	0.63	0.31
CV%	17.9	7.7

3.4.5 Economics of Navy beans production under various nutrient management options

Here-below are the calculated costs for the treatments in terms of input (seed, manure and NPK fertilizer) and labour requirements (cost of input application):

1. Input requirements: -

Level	**T I**		**T II**		**T III**	
	Quantity	**Cost**	**Quantity**	**Cost**	**Quantity**	**Cost**
- Manure	0 T	-	4 T	8,000/=	8 T	16000/=
- Fertilizer	50 kg	2700/=	100 kg	5400/=	200 kg	10800/=
- Seed	12-15 kg	1200/=		1200/=		1200/=

2. Labour requirement:

Level	**T I**		**T II**		**T III**	
	Quantity	**Cost**	**Quantity**	**Cost**	**Quantity**	**Cost**
- Ploughing @2500/acre	1 ha	6250/=	1 ha	6250/=	1 ha	6250/=
- Harrowing @2000/acre	1 ha	5000/=	1 ha	5000/=	5000/=	6250/=
- Furrowing	30 MD	9000/=	30 MD	9000/=	30 MD	9000/=
- Planting	15 MD	4500=	15 MD	4500/=	15 MD	4500=
Application of: -						
- Manure (4T, 8T)	3.8 MD	1125/=	7.5 MD	2250/=	15 MD	5000/=
- Fertilizer	1.8 MD	525/= .	2.5 MD	750/=	5 MD	1500/=
- Weeding T I (x2), T II and III (x3)						
	18 MD	5600/=	36 MD	10800/=	36 MD	10800/=
- Spraying	0 MD	-	3 MD	900/=	3 MD	900/=
- Harvesting	1 MD	300/=	2 MD	600/=	3 MD	900/=

3.5 Economics of bean crop production under uniform pest management

Table 3.9: Economic analysis for experiment I – Long rains season (December - March) 2010

Treatment	**Av. Yield (T/ha)**	**Value of yield @ Sh.80kg^{-1}**	**Increment over NPK – (200 kgha^{-1}) (1.79T/ha)**	**Value of yield increment @ Sh.80kg^{-1}**	**Production cost**	**Cost-benefit ratio**
Control	0.1	4256	-1.7	-138936	69,350	1:0.1
4t CM	0.1	3656	-1.7	-139536	79,850	1:0.04
4t FYM	0.8	60792	-1.0	-82400	79,850	1:0.8
8t CM	1.2	93040	-0.6	-50152	90,600	1:1.0
8t FYM	1.3	106880	-0.5	-36312	90,600	1:1.2
50kg NPK	0.1	3750.4	-1.7	-139442	72,350	1:0.1
100kg NPK	0.1	6144	-1.7	-137048	75,100	1:0.1
200kg NPK	1.8	143192	0	0	80,600	1:2.0
50kg NPK x 4t CM	1.1	87408	-0.7	-55784	82,600	1:1.1
50kg NPK x 4t FYM	0.4	31928	-1.4	-111264	82,600	1:0.4
50kg NPK x 8t CM	1.2	94368	-0.6	-48824	93,350	1:1.0
50kg NPK x 8t FYM	0.6	45120	-1.2	-98072	93,350	1:0.5
100kg NPK x 4t CM	2.2	174368	0.4	31176	85,350	1:2.0
100kg NPK x 4t FYM	2.2	177600	0.4	34408	86,100	1:2.1
100kg NPK x 8t CM	2.5	195976	0.7	52784	96,850	1:2.0
100kg NPK x 8t FYM	2.1	165480	0.3	22288	96,100	1:2.0
200kg NPK x 4t CM	2.3	181408	0.5	38216	90,850	1:2.0
200kg NPK x 4t FYM	2.2	179040	0.5	35848	90,850	1:2.0
200kg NPK x 8t CM	2.6	204688	0.8	61496	103,100	1:2.0
200kg NPK x 8t FYM	2.4	191904	0.6	48712	101,600	1:2.0

In the long rains the average yields ranged from 0.1 to 2.6 t/ha (control to 200 kg/ha plus 8 t/ha CM) while the value of yield ranged from Ksh.3,656 to Ksh.204,688. The yield increment over the recommended NPK (200 kg/ha) rate ranged from -1.7 to 0.8 t/ha while the value of yield increment Ksh.-139,536 to Ksh.61,496. The production cost ranged from Ksh.69,350 (control) to Ksh.103,100 (200 kg/ha NPK plus 8 t/ha CM). The cost-benefit ratio ranged from 0.1 (4 t/ha CM) to 2.1 (100 kg/ha NPK plus 4 t/ha FYM). Combinations of 100 kg/ha NPK or 200 kg/ha NPK with FYM and CM each at 4 and 8 t/ha had cost benefit ratios of 2.0 and above. Application of 200 kg/ha NPK also had a cost benefit ratio of 2.0.

In the short rains, the average yields ranged from 375.2 to 1,018 kg/ha while the value of yield ranged from Ksh.30,013.6 to Ksh.85,580. The yield increment over 200 kg/ha NPK ranged between

-1,348.9 and 346 kg/ha while the value of yield increment ranged from Ksh. -27,887.2 to Ksh.27,679.2. The production cost ranged from Ksh.350 to Ksh.103,100. None of the treatments had a cost-benefit ratio more than 0.8.

Table 3.10: Economic analysis for experiment I – Short rains season (April - June) 2010

Treatment	Av. Yield (kg/ha)	Value of yield @ Sh.80kg^{-1}	Increment over NPK – (200 kgha^{-1}) (723.76T/ha)	Value of yield increment @ Sh.80kg^{-1}	Production cost (KSh)	Cost-benefit ratio
Control	375.2	30013.6	-348.6	-27887.2	69,350	1:0.4
4t CM	459.2	36738.4	-264.5	-21162.4	79,850	1:0.5
4t FYM	406.4	32511.2	-317.4	-25389.6	79,850	1:0.4
8t CM	553.4	44268.8	-170.4	-13632	90,600	1:0.5
8t FYM	525.4	42028.0	-198.4	-15872.8	90,600	1:0.5
50kg NPK	573.8	45900.0	-150.0	-12000.8	72,350	1:0.6
100kg NPK	695.5	55643.2	-28.2	-2257.6	75,100	1:0.7
200kg NPK	723.8	57900.8	0	0	80,600	1:0.7
50kg NPK x 4t CM	656.4	52512.0	-67.4	-5388.8	82,600	1:0.6
50kg NPK x 4t FYM	581.1	46488.8	-142.7	-11412	82,600	1:0.6
50kg NPK x 8t CM	663.2	53056.0	-60.6	-4844.8	93,350	1:0.6
50kg NPK x 8t FYM	656.6	52528.0	-67.2	-5372.8	93,350	1:0.6
100kg NPK x 4t CM	708.6	56684.8	-15.2	-1216	85,350	1:0.7
100kg NPK x 4t FYM	856.1	68480.0	-22.6	-1809.6	86,100	1:0.8
100kg NPK x 8t CM	721.6	57725.6	-2.2	-175.2	96,850	1:0.6
100kg NPK x 8t FYM	715.6	57247.2	-8.2	-653.6	96,100	1:0.6
200kg NPK x 4t CM	775.8	62060.0	52	4159.2	90,850	1:0.7
200kg NPK x 4t FYM	773.9	61914.4	50.2	4013.6	90,850	1:0.7
200kg NPK x 8t CM	1018.1	85580.0	346	27679.2	103,100	1:0.8
200kg NPK x 8t FYM	891.3	71303.2	167.5	13402.4	101,600	1:0.7

3.6 Discussion

3.6.1 Effect of fertilizer treatments on bean dry matter accumulation, root nodulation and grain yield

Most fertilizer treatments increased shoot biomass and grain yield relative to unfertilized control (0.11-0.12% N) with half and full rates of combined organic and inorganic fertilizer, generally having the highest increase. Application of organic and inorganic fertilizers has been reported to enhance shoot biomass in previous studies (Furtini et al., 2006). The improved biomass accumulation is attributed to increased availability of plant nutrients which may have enhanced the photosynthetic capacity of the plants. It has been suggested that that inorganic fertilizers have a "priming effect" on N uptake by the crops from the organic inputs resulting in increased yields (Bilditici et al., 2005; Soil Management Research Project, 2002).

In a study by Suthongwises et al. (2009) it was observed that high levels of P (4.75-5.37 g plant^{-1}) increased shoot biomass while low P levels (2.55-2.87 g P plant^{-1}) increased root biomass in beans. Good root development is a required characteristic since it proffers agronomic advantages including efficiency in the uptake of moisture and minerals from the soil. This improves disease resistance in plants and results in a decreased need of fungicides (Graham et al., 1999), improving crop yields (Rengel and Graham, 1995). Shoot biomass increased dramatically between podding and late pod fill in the long rains but such an increase was not observed in the short rains due to low rainfall amounts received. Beans have been reported to be susceptible to drought particularly during flowering and pod-formation hence moisture deficits severely constrain plant growth and yield (Wortmann, 1998; FAO STAT, 2001)

Nodule count was also increased by fertilizer and manure treatments at flowering and podding in both the long and short rains seasons. Previous studies have shown that high levels of N inhibit nodule development, but in this study nodule development was prolific. This confirms that original N levels in the soil were low to moderate. Moderate doses of N and available P have been shown to promote nodulation. Nodule establishment and function are important sinks for P (Sinclair and Vadez, 2002), hence P fertilization results in enhanced nodule number and mass, as well as greater nitrogen-fixation activity per plant (Adu-Gyamfi, 1989).

The partial economic analysis of bean production with application of various combinations of inorganic fertilizers and manures in plots given the same pesticide treatment showed higher yields per unit for combined application of fertilizers and manures than most of the non-combined treatments. The analysis showed that costs incurred during production either gave negative or lower returns on invested capital than when 100 kg/ha NPK plus 4 t/ha FYM was used in the long rains.
In the short rains the application of the similar rates of inputs as in the long rains thus gave negative returns on the invested capital except for inputs more than the combined half rates. Therefore application of a combined half rate fertilizers and manures can give optimal yield, and is economically more viable than any other.

3.7 Conclusion and recommendations

This study showed that combining fertilizers and manures could result in improved vegetative growth and yield of beans more than the use of either alone. A partial economic analysis of these results showed that although high rates of inorganic fertilizer alone, and high rates of combined inorganic fertilizer and manures resulted in yields slightly higher than when half rates of both are used, the costs to benefit ratio was more favorable with combined half rates of inorganic fertilizers and manures. This shows that farmers may use little fertiliser N without lowering crop yields below the optimal level.

Since low soil fertility and high costs of fertilizer are other factors contributing to low bean productivity, the observation that reduction in amount of inorganic fertilizer with addition of organic manure could give equally good yields with improved economic returns to the farmer is a promising option that could encourage widespread production of beans. The control of major pests and diseases of beans is important in enabling improved bean productivity, but this study has shown that benefits accruing to reducing the effects of the yield constraining factors outweigh the costs incurred even when pesticides are used, as long as minimal quantities are used.

CHAPTER FOUR: INTERACTIVE EFFECTS OF FERTILIZER APPLICATION AND PESTICIDE SPRAYS ON GROWTH AND YIELD OF CANNING NAVY BEAN

4.1 Abstract

Low soil fertility, insect pests and diseases are the major constraints to improvement of canning Navy bean productivity in Kenya. A study was conducted at the University of Nairobi's Kabete Field Station during 2010 long and short rains to determine the effect of fertilizers and pesticides on growth, yield and quality of canning Navy bean. The fertilizer treatments were 8 t/ha farmyard manure, half dose farmyard manure (4 t/ha) plus half dose NPK (100 kg/ha), 200 kg/ha NPK, *Rhizobium* inoculation, and a control (no fertilizer), while the pesticide treatments were fungicide spray (Ortiva^R), insecticide spray (Actara^R), fungicide spray (Ortiva^R) plus pesticide spray (Actara^R) and a control (no spray). The experimental design was a randomized complete block design laid out in a split plot arrangement with three replications. The variety used was Mexican 142. Results demonstrated that pesticide sprayed and fertilizer supplied plots had significantly ($p<0.05$) higher number of plants than non-treated control plots. Organic fertilizers increased the number of nodules but pesticide application had no effect. Fertilizer application significantly increased shoot biomass in all the plots sprayed with fungicides and insecticides. Pesticide application improved grain yield only in fertilizer supplied plots, while fertilizer treatments had no yield effect in unsprayed crops. Partial cost analysis demonstrated that application of half dose farmyard manure (4 t/ha) plus half dose NPK (100 Kg/ha) in combination with insecticide or insecticide/fungicide sprays was the most cost-effective treatment regime. Pesticide sprays, *Rhizobium* inoculation and combined moderate doses of organic and inorganic fertilizers have the potential to improve navy bean productivity.

4.2 Introduction

Processed and canned Navy bean is mainly imported into the country to meet local demand. High demand both in the local market and even in the export market remains unsatisfied as local production of the canned products relies on raw bean imports. This is because of low local production caused by poor soils and pests and diseases (Chemining'wa et al., 2011). Various strategies available for improving production entail use of organic manures which carry with them other soil improving advantages and are a cost saving option (Ibijbijen et al., 1996; Fening et al., 2010). Efforts to improve production therefore involve identification of appropriate fertilizer application strategy and effective pest control. Specific application rates of these fertilizers should be identified since the need to increase bean production lies in its importance as a source of protein needed to solve nutrient deficiency in children, food sufficiency in general, and farm income (Pachico, 1993; Kibiego, 2003).

Low soil fertility is a major factor contributing to the decline of bean yields, and high fertilizer costs is a factor further prohibiting widespread fertilizer use (Gerner et al., 1995). Modes of fertilization that can alleviate the low fertility situation include cultural practices like the use of crop residues from legumes (Mwangi, 2010), whereas continuous use of organic manures stabilizes the soil structure and promotes build up of microbial populations (Smaling, 1993), increasing water storage capacity of the soil and reducing nutrient leaching from the root zone, thus prolonging the effectiveness of inorganic fertilizers. This increases the productivity of crops. Manures, however, have minimal nutrient content - 1.9% N, 0.6% P and 1.2% K - (Brady, 1984); therefore they complement inorganic fertilizers but are more environmentally sustainable, especially in the subtropical semiarid soils low in organic matter. Combined use of small amounts of inorganic fertilizer nitrogen along with nitrogen fixed by the legumes is a promising strategy in meeting the soil nutrient requirements of smallholder farming situations (Mwangi, 2010). This is because beans are nitrogen fixing, but with this alone only 80-90% of the yield possible with N fertilization can be achieved (Silsbury, 1977; Ryle et al., 1979; Thies et al., 1991).

Pests and diseases are the second most important factors that lead to reduced bean yields, and losses of between 37% and 90% have been reported (Karel and Autrique, 1989). The major pests affecting common beans are: aphids, whiteflies, thrips, pod and seed borers, and bean stem maggot, which is most serious, while the diseases of importance are angular leaf spot, anthracnose, leafrust, common bacterial blight and bean common mosaic virus (Nkalubo et al., 2007). Of these anthracnose reduces the yield potential of susceptible bean cultivars by about 30-45% because it destroys plant photosynthetic tissue (Bassanezi et al., 2001). The highest yield loss is found in the marketable yield where there is almost double the percentage yield loss, of about 63-73% (Nkalubo et al., 2007). The need to control pests to enhance the yield of beans is therefore paramount since varietal resistance is the major attribute of beans relied upon in smallholder production.

The objective of this second experiment is to come up with affordable integrated nutrient and pest management options with optimum yields, which reduce capital requirement burden of smallholder farmers so that the scale of their production could increase and yields realized could also increase as losses attributed to these factors are gradually eliminated.

4.3 Materials and methods

4.3.1 Experimental site

A study on the effect of pesticides and fertilizer application was carried out in Upper Kabete Campus Field Station, University of Nairobi. The centre coordinates of this station are latitude 1^o 14’20’’S and longitude 1^o 15’ 15’’E at an altitude of 1940 m above sea level. The area receives an annual average rainfall of 1000 mm distributed over the long and short rains, in the months of

March to May and October to December respectively. Mean monthly minimum and maximum temperatures are 12 ^{o}C and 23 ^{o}C respectively. The soils are reddish brown clays which overlie dark and red clays classified as humic nitosols. They are deep, fertile, and well-drained, and have a thick acid-top resistant to erosion. The soils have a blocky structure allowing good root penetration and development (Wanjiru, 2010). The site chosen had been fallow for some time, and had low fertility. Laboratory analysis showed the soil had a pH of 5.55, 0.11% N, 1.02% organic C, 11% P, and 1.35% K, while the manure had a pH of 9.18, and 1.5% N, 4.64% organic C, 3.45% P and 3.06% K. Planting for this second experiment was done during the long rains in April 2010, while short rains crop was planted in October 2010. The rains during March-May period averaged 256.4 mm but dropped to 27.9 mm between June and August during which irrigation was done sparingly to crop maturity. As a result there was an increased presence of insect pests in the second season, in contrast to the long rains season. The high competition for irrigation between the plots led to reduced frequency of irrigation on the crop. The water application started at germination due to the prevailing dry spell when maximum air temperatures were as high as 24 ^{o}C (Appendix 2). This started with a frequency of 3 days a week and gradually reduced to 2, but became less reliable towards podding. Averagely, daily irrigation duration was 3 hours and the nozzle discharge rate being below 35 mm per hour, considering irrigation losses, hence achieving less than 105 mm (below 10.5 cm) of soil infiltration (Fig. 4.1). The fertilizer type used was NPK (17:17:17) while *Rhizobium* inoculant was obtained from the Soil Microbiology Laboratory, University of Nairobi.

4.3.2 Experimental designs, treatments and crop husbandry

After land had been prepared and harrowed the plots were laid out so that the planting furrows could be prepared. The plots were laid out in a randomized complete block design (RCBD) with a split plot arrangement and replicated three times. The plots measured 5 m x 1 m in size. The main plot consisted of pesticide treatments while the subplots consisted of the fertilizer treatments. The pesticide treatments consisted of unsprayed control, fungicide spray, insecticide spray, and a combination of fungicide and insecticide sprays. The fertilizer treatments were: 8 t/ha/FYM, 4 t/ha/FYM plus 100 kg/ha NPK, 200 kg/ha NPK, *Rhizobium* inoculation and unfertilized control. While the pesticide treatments comprised spraying using the fungicide Ortiva^{R} or insecticide Actara^{R} or a combination of both. The spraying was done once every fortnight at 20 g/100 l of water per ha appropriate for Actara^{R} while fungicide Ortiva^{R} was sprayed at the third week to control diseases at the rate of 6 ml/20l of water. A spacing of 1m between plots was used to control spray drift into unsprayed plots. Also, spray position was maintained at low levels to reduce spray drift. Inter-row spacing was 50 cm and one seed was planted per hill, spaced 10 cm apart. Weeding was done by hand to ensure weed-free conditions.

4.3.3 Data collection

The data collected were similar to those collected in season one: days to 50% emergence, days to 50% flowering, days to 50% podding, days to 50% maturity and plant height at one week after emergence, weekly plant count, biomass and nodule counts at 2, 4, 6, 8 weeks and at flowering, number of pods per plant, average pod length, number of grains per pod, plot biomass and yield at harvest, and 100 seed weight. Weekly pest and fortnightly disease observation was done on each net subplot after emergence and scored up to senescence. The scale used was 1 to 5 where 1=all plants are healthy with no observable pest/disease symptoms, 2=25% of plants show pest/disease symptoms, 3=50% of plants show pest/disease symptoms, 4=50 to 75% of plants show pest/disease symptoms, and 5=all plants in the plot show pest/disease symptoms, and the mean fortnightly score will be calculated.

Data recording once again started with the number of days to 50% emergence after planting; weekly plant count per net plot. Every fortnight biomass sampling and nodule count was done until podding. Five randomly distributed plants were carefully uprooted leaving the outer two rows. The root nodules were counted, root separated from the shoot and oven dried at 60 ^{o}C until constant weight.

4.3.4 Data analysis

Analysis of variance (ANOVA) was performed on the data collected using Genstat statistical package and the means compared using the least significant difference test (LSD) at p=0.05 (Gomez and Gomez, 1984).

4.4 Results

4.4.1 Effects of fertilizer and pesticide application on mean plant count and pest incidence

In both seasons, the diseases observed in decreasing order of intensity, were bean rust, angular leaf spot, anthracnose, halo blight, and bean common mosaic. The major insects observed in decreasing order of infestation intensity were aphids, white flies and bean flies. Other insects observed in small scale included stinkbugs, the spiny brown bug, blister beetle, stripped bean weevil, ladybird beetle, leafhoppers and leaf miners, particularly in the short rains.

In the long rains, all the plants in the no-pesticide control plots showed disease symptoms (100%, score 5) while in the short rains only 50% (score 3) of the plants showed disease symptoms. In both seasons, plants sprayed with a fungicide showed no disease symptoms (score 1). In the long rains, 50-75% (score 4) of the plants in the no-pesticide control plots were infested by insect pests while in the short rains all the plants (100%, score 5) were infested by insect pests. In the long rains, 75% (score 2) of the plants sprayed with an insecticide were not infested by insect pests while in the short rains 50% (score 3) of the plants sprayed with an insecticide were not infested by insect pests. And in both seasons all the plots sprayed with both fungicide/insecticide had no diseases and insect pests (0%, score 1) – (data not shown).

In the long rains, application of pesticides and fertilizers had significant effects ($p<0.05$) on plant count but their interaction had no significant effect on this parameter (Table 4.1, 4.2, and 4.3). Plots supplied with 8 t/ha FYM and those supplied with 4 t/ha FYM plus 100 kg/ha NPK had significantly higher plant count than no fertilizer control at all sampling periods. In most cases application of 200 kg/ha NPK had higher plant count than the control. *Rhizobium* inoculated plots had a similar number of plants as fertilized plants at all sampling periods. The plots sprayed with a combination of fungicide and insecticide had invariably higher plant count than unsprayed control plots and fungicide sprayed plots. In most sampling periods plots treated with an insecticide had higher plant count than unsprayed control plots and fungicide treated plots, while fungicide treated plots had higher plant count than unsprayed control plots (Table 4.2).

Table 4.1: Effects of fertilizers on mean plant count in the long rains season at 2-9 weeks after emergence

	Weeks after emergence							
	2	3	4	5	6	7	8	9
8t/ha FYM	77.3	75.5	72.9	68.1	63.4	59.8	56.3	55.3
4t/ha FYM+100kg/ha NPK	74.7	72.6	70.2	66.9	63.7	60.7	57.8	54.1
Rhizobium	64.1	61.8	59.4	55.8	52.4	48.4	46.2	45.4
NPK 200kg/ha	66.1	66.1	62.8	56.3	55.8	51.3	49.5	47.4
Control	51.8	49.2	46.4	41.1	36.2	33.0	31.3	29.7
LSD 0.05	15.6	15.3	15.6	16.2	16.6	16.7	16.7	16.9

Table 4.2: Effects of pesticides on mean plant count in the long rains season at 2-9 weeks after emergence

	Weeks after emergence							
	2	3	4	5	6	7	8	9
Control	55.3	53.0	48.3	39.7	37.7	34.3	32.3	31.0
Fungicide	64.4	62.3	60.0	55.3	50.8	46.3	42.6	39.2
Insecticide	71.1	68.8	66.0	62.9	58.6	54.3	52.5	49.5
Fungicide + Insecticide	76.5	76.1	75.1	72.3	70.1	67.7	65.4	64.3
LSD 0.05	6.3	6.4	5.4	7.6	9.6	11.9	14.4	16.6

Table 4.3: Effects of fertilizers on mean plant count in the short rains season at 4, 5 and 9 weeks after emergence

	Weeks after emergence		
	4	5	9
8t/ha FYM	53.9	53.9	43.2
4t/ha FYM+100kg/ha NPK	52.4	52.4	43.7
Rhizobium	45.8	45.8	37.0
NPK 200kg/ha	49.7	49.7	42.8
Control	52.4	52.4	43.5
LSD 0.05	5.7	5.7	5.07

4.4.2 Effects of fertilizer and pesticide application on shoot biomass of beans

Application of both fertilizers and pesticide sprays and their interaction had no significant effect on shoot biomass in the short rain season (Table 4.4). Similar observations were made in the long rains season but fertilizer application had a significant effect on shoot biomass. Application of 8 t/ha FYM had significantly higher shoot biomass than the control and other fertilizer treatments. No differences in shoot biomass were noted among 4 t/ha FYM plus 100 kg/ha, *Rhizobium* inoculation and 200 kg/ha NPK.

Table 4.4: Mean shoot biomass (g/m^2) of beans in plots subjected to fertilizer and pesticide treatments at podding in the 2010 long rains season

	Control	Fungicide	Insecticide	Fungicide+ Insecticide	Fertilizer mean
8t/ha FYM	191.33	166.67	184.00	265.11	201.78
4t/haFYM+100kg/ha NPK	38.44	180.44	139.11	113.56	117.78
Rhizobium	110.89	103.56	95.56	92.67	100.67
NPK 200kg/ha	160.89	97.11	100.00	156.00	128.44
Control	62.22	87.11	58.67	93.11	75.11
Pesticide mean	112.67	126.89	115.33	144.00	
LSD Pesticide	NS				
LSD Fertilizer	46.80				
LSD Fertilizer x Pesticide	NS				
CV%	22.44				

4.4.3 Effects of fertilizer and pesticide application on root biomass of beans

In the long rains fertilizer application had a significant effect ($p < 0.05$) on root biomass at 4 weeks after emergence while pesticide application had no effect (Table 4.5). Plots supplied with 8 or 4 t/ha

FYM plus 100 kg/ha NPK had higher root biomass than inoculated and control plots. Treatment effects on root biomass in the second season were not significant.

At maturity, in the long rains, fertilizer application, pesticide application and their interaction had significant effects on root biomass. In plots treated with 8 t/ha FYM, spraying with fungicide, insecticide, or fungicide/insecticide combination significantly increased root biomass. Fungicide/insecticide treatment had higher root biomass than fungicide and insecticide alone treatments. No difference was noted between the latter in root biomass. Similar observations were made for 4 t/ha FYM plus 100 kg/ha NPK treated plots; however, no differences in root biomass were noted between fungicide or fungicide/insecticide combination and the insecticide treatment had lower biomass than the fungicide treatment.

In *Rhizobium* inoculated plots and plots treated with 200 kg/ha NPK, fungicide/insecticide combination had higher root biomass than the control and all the other treatments. Application of fungicide or insecticide on its own did not significantly increase biomass relative to the control. Only fungicide/insecticide combination treatment had higher root biomass than the unsprayed control in unfertilized control.

Table 4.5: Effects of fertilizers and pesticide treatments on root biomass (g/m^2) at four weeks after emergence in the 2010 long rains

	Control	Fungicide	Insecticide	Fungicide + Insecticide	Fertilizer mean
8t/ha FYM	13.76	5.64	13.44	12.96	11.44
4t/haFYM+100 kg/ha NPK	10.04	12.02	5.33	3.76	7.80
Rhizobium	4.89	2.36	9.09	7.16	5.87
NPK 200 kg/ha	7.98	9.78	5.49	9.33	8.13
Control	11.56	12.47	2.09	2.18	7.07
Pesticide mean	9.64	8.47	7.09	7.07	
LSD Pesticide	NS				
LSD Fertilizer	3.87				
LSD Fertilizer x Pesticide	NS				
CV%	37.56				

Table 4.6: Effects of nutrient treatment and pesticide treatment on root biomass (g/m^2) at maturity in long rains 2010

Fertilizer	Control	Fungicide	Insecticide	Fungicide + Insecticide	Fertilizer mean
8t/ha FYM	2.98	5.07	5.06	6.33	4.86
4t/haFYM+100 kg/ha NPK	4.74	6.37	5.77	6.72	5.90
Rhizobium	5.20	5.40	5.22	6.02	5.46
NPK 200 kg/ha	6.00	5.97	6.11	7.63	6.43
Control	2.82	3.03	3.00	3.35	3.05
Pesticide mean	4.35	5.17	5.03	6.01	
LSD Pesticide	0.40				
LSD Fertilizer	0.36				
LSD Fertilizer x Pesticide	0.71				
CV%	3.78				

4.4.4 Effects of fertilizer and pesticide application on nodule count

Application of fertilizers had a significant effect ($p<0.05$) on nodule count in the short rains season, but had no effect on this parameter in the long rains season (Table 4.7). Plants supplied with 4t/ha FYM plus 100 kg/ha had significantly higher number of nodules than unfertilized control plots. No differences in nodule count were noted among control, 8 t/ha FYM, *Rhizobium* and NPK (200 kg/ha) treated plots. Pesticide application had no effect on nodule count.

Table 4.7: Effects of nutrient treatment and pesticide treatment on nodule count at 6 weeks after emergence in short rains 2010

	Control	Fungicide	Insecticide	Fungicide + Insecticide	Fertilizer mean
8t/ha FYM	14.33	14.67	16.67	13.67	14.83
4t/ha FYM+100 kg/ha NPK	17.33	20.67	21.67	20.67	20.08
Rhizobium	15.67	13.67	13.00	19.33	15.42
NPK 200 kg/ha	8.33	14.67	8.67	17.00	12.17
Control	8.67	13.67	14.67	15.00	13.00
Pesticide mean	12.87	15.47	14.93	17.13	
LSD Pesticide	NS				
LSD Fertilizer	5.26				
LSD Fertilizer x Pesticide	NS				
CV%	17.7				

4.4.5 Effects of fertilizer and pesticide application on yield and yield components

Application of fertilizers had a significant ($p<0.01$) effect on mean number of pods per plant in the long rains season but not in the short rains. *Rhizobium* inoculation and N fertilizer application significantly increased the number of pods per plant compared with the no fertilizer control in the long rains season. Plants supplied with 4 t/ha FYM plus 100 kg/ha NPK had significantly the highest number of pods per plant (Table 4.8 and 4.9). *Rhizobium* inoculation, 8 t/ha FYM and 200 kg/ha were not significantly different in number of pods per plant. Application of pesticides did not have any effect on the yield components.

In the long rains, fertilizer application and its interaction with pesticide application had significant effect on the weight of seeds in the long rains (Table 4.10). The plots supplied with 200 kg/ha NPK, 4 t/ha FYM plus 100 kg/ha NPK, *Rhizobium* and 8 t/ha FYM had higher 100 seed weight than the no fertilizer control under all pesticide treatments. The plots supplied with 4 t/ha FYM plus 100 kg/ha NPK had higher 100 seed weight than inoculated plots under unsprayed control and fungicide/insecticide treatments. Pesticide application had no significant effect on 100 seed weight under 200 kg/ha NPK.

Table 4.8: Mean number of pods per plant of beans in plots subjected to fertilizer, manure and pesticide treatment in the long rains season of 2010

	Control	Fungicide	Insecticide	Fungicide + Insecticide	Fertilizer mean
8t/ha FYM	20.7	24.7	28.3	26.0	24.9
4t/ha FYM+100 kg/ha NPK	29.0	30.3	30.3	29.0	29.7
Rhizobium	17.4	24.0	23.0	22.7	21.8
NPK 200 kg/ha	15.3	16.3	32.7	24.0	22.1
Control	17.7	15.7	14.0	13.3	15.2
Pesticide mean	20.0	22.2	25.7	23.0	
LSD Pesticide	4.06				
LSD Fertilizer	7.05				
LSD Fertilizer x Pesticide	13.0				
CV%	8.9				

Table 4.9: Mean number of pods per plant of beans in plots subjected to fertilizer, manure and pesticide treatment in the short rains season of 2010

	Control	Fungicide	Insecticide	Fungicide + Insecticide	Fertilizer mean
8t/ha FYM	16.4	22.4	21.0	27.7	21.9
4t/ha FYM+100 kg/ha NPK	18.4	18.7	20.9	28.3	21.5
Rhizobium	20.7	19.7	20.9	26.2	21.9
NPK 200 kg/ha	22.1	26.6	26.0	30.8	26.4
Control	15.3	17.2	26.0	14.7	18.3
Pesticide mean	18.5	20.9	22.9	25.5	22.0
LSD Pesticide	6.29				
LSD Fertilizer	6.91				
LSD Fertilizer x Pesticide	13.35				
CV%	14.3				

Table 4.10: Mean 100 seed weight (g) of beans in plots subjected to fertilizer and pesticide treatments per plot in long rains 2010

	Control	Fungicide	Insecticide	Fungicide + Insecticide	Fertilizer mean
8t/ha FYM	16.23	16.65	15.67	13.39	16.13
4t/ha FYM+100kg/ha NPK	17.15	18.09	16.98	15.81	17.01
Rhizobium	14.64	16.60	15.58	13.39	15.05
NPK 200	15.54	16.12	15.43	16.21	15.83
Control	7.94	11.53	10.18	12.78	10.61
Pesticide mean	14.30	15.80	14.77	14.83	
LSD Pesticide	1.2				
LSD Fertilizer	1.15				
LSD Pesticide x Fertilizer	2.28				
CV%	2.6				

In the first season, application of fertilizers, pesticide spraying and their interaction had significant effects (<0.05) on grain yield of navy bean (Table 4.11). Under no-pesticide spray control plots, application of 200 kg/ha NPK alone had significantly the highest grain yield compared to all the other treatments. In fungicide alone sprayed plots, application of 200 kg/ha NPK and 4 t/ha plus 100 kg/ha NPK had significantly higher grain yield than the unfertilized control and *Rhizobium* inoculated plots. In plots treated with insecticide alone application of 4 t/ha plus 100 kg/ha NPK, 200 kg/ha NPK and *Rhizobium* inoculation significantly increased grain yield relative to the unfertilized control. There was no difference in grain yield between control and application of 8 t/ha

FYM. In fungicide and insecticide treated plots, all fertilizer treatments significantly increased grain yield relative to the non-fertilizer control. Application of 200 kg/ha NPK and 4t/ha FYM plus 100kg/ha NPK had significantly higher grain yield than the *Rhizobium* inoculation.

In plots supplied with 4 t/ha plus 100 kg/ha NPK, all the pesticide spray treatments had significantly higher grain yield than unsprayed control. Combined fungicide and insecticide sprays had higher grain yield than insecticide alone treatment. In the *Rhizobium* treated plots only combined fungicide and insecticide sprays significantly increased grain yield relative to the unsprayed control.

In the short rains the effects of pesticides and fertilizers on grain yield of beans were significant but the pesticide x fertilizer interaction was not significant (Table 4.12). *Rhizobium* inoculation and all fertilizer applications significantly increased grain yield relative to the unfertilized control. Application of 200 kg/ha NPK had higher grain yield than application of 4 t/ha FYM plus 100 kg/ha NPK and *Rhizobium* inoculation. No differences in grain yield was noted among *Rhizobium* inoculation, 4 t/ha FYM plus 100 kg/ha NPK and 8 t/ha FYM application.

Table 4.11: Mean yields of beans (kg/ha) in plots subjected to fertilizer, manure and pesticide treatments in long rains of 2010

	Control	Fungicide	Insecticide	Fungicide + Insecticide	Fertilizer mean
8t/ha FYM	466	1074	851	1770	1040
4t/ha FYM+100kg/ha NPK	388	1626	1094	1980	1272
Rhizobium	574	708	1181	1256	930
NPK 200 kg/ha	1265	1649	1674	2160	1437
Control	572	596	473	250	473
Pesticide mean	653	1131	1055	1483	
LSD Pesticide	500				
LSD Fertilizer	250				
LSD Fertilizer x Pesticide	630				
CV%	13.5				

Table 4.12: Mean yields of beans (kg/ha) in plots subjected to fertilizer, manure and pesticide treatments in short rains of 2010

	Control	Fungicide	Insecticide	Fungicide + Insecticide	Fertilizer mean
8t/ha FYM	476.0	873.0	937.0	1276.0	891.0
4t/ha FYM+100kg/ha NPK	659.0	609.0	813.0	1324.0	851.0
Rhizobium	632.0	678.0	820.0	1137.0	817.0
NPK 200	728.0	942.0	1306.0	1452.0	1107.0
Control	426.0	508.0	672.0	693.0	574.0
Pesticide mean	584.0	722.0	910.0	1176.0	
LSD Pesticide	492.2				
LSD Fertilizer	220.7				
LSD Fertilizer x Pesticide	NS				
CV%	9.6				

The yield obtained in the short rains was again lower than the long rains. This was attributed to reduced precipitation, increased water loss due to high daily maximum temperatures and low relative humidity and increased insect infestation. The amount of water (below105 mm) that may have infiltrated into the soil each week when irrigation was being done three times every week was not adequate for sustained plant metabolic processes particularly in the productive phase as this was lost through evapotranspiration during subsequent dry days. The increased presence of pests and diseases increased the stresses that reduced the plant's production potential (Fig. 4.1 and appendix 2).

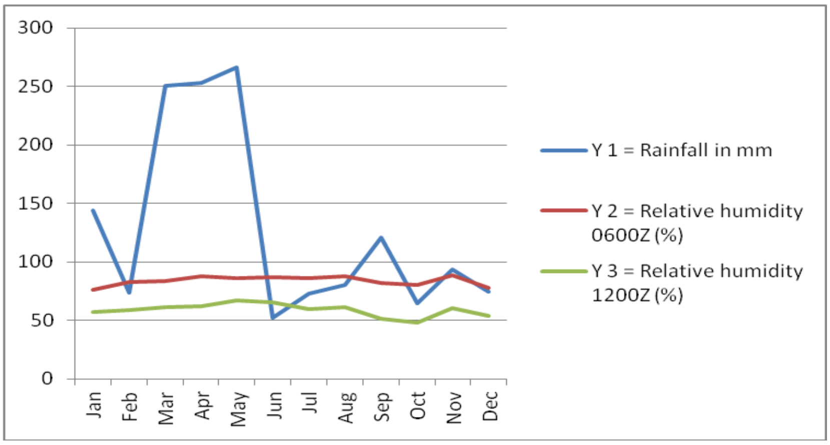

Fig. 4.1: Monthly rainfall and relative humidity at Kabete during the experimental period

4.5 Economics of navy beans production under various fertilizer and pesticide management options

Table 4.13: Rates and Costs of Inputs (pesticides, fertilizers and manure) used in the treatments

Pesticide	**Recommended rate/ha per spray**	**No. of sprays done**	**Amount used**	**Unit price**	**Cost of pesticide**
Fungicide	300-500 ml	4	1200-2000 ml	100 ml @ 750/=	15,000/=
Insecticide	200 g	4	800 g	40 g @ 600/=	12,000/=
Seed dressing	6-8 ml/kg seed	4.8 kg seed	28.8 mls	50 ml @ 250/=	1,200/=
Manure	4T/8T		4T/8T	1 tonne @ 2000/=	8,000/= or 16,000/=
Fertilizer	100/200 kg/ha			50 kg bag @ 2700	5,400/= or 10,800/=
Rhizobium			1 packet	100/=	100/=

4.5.1 Cost and requirement of other inputs: -

Calculated costs for the treatments in terms of input (seed, manure and NPK fertilizer) and labour (cost of input application) requirements

Level	**T I**		**T II**		**T III**	
	Quantity	**Cost**	**Quantity**	**Cost**	**Quantity**	**Cost**
- Manure	0 T	-	4 T	8,000/=	8 T	16000/=
- Fertilizer	50 kg	2700/=	100 kg	5400/=	200 kg	10800/=
- *Rhizobium*	100g	100/=	100 g	100/=	100 g	100/=
- Seed	12-15 kg	1200/=		1200/=		1200/=

3. Labour requirement:

Level	**T I**		**T II**		**T III**	
	Quantity	**Cost**	**Quantity**	**Cost**	**Quantity**	**Cost**
- Ploughing @2500/acre	1ha	6250/=	1ha	6250/=	1ha	6250/=
- Harrowing @2000/acre	1ha	5000/=	1ha	5000/=	1ha	5000/=
- Furrowing	30MD	9000/=	30MD	9000/=	30MD	9000/=
- Planting	15MD	4500/=	15MD	4500/=	15MD	4500/=
Application of: -						
- Manure (4T, 8T)	3.8 MD	1125/=	7.5MD	2250/=	15MD	5000/=
- Fertilizer	1.8 MD	525/=	2.5MD	750/=	5MD	1500/=
- Weeding T I (x2), T II and III (x3)	18 MD	5600/=	36MD	10800/=	36MD	10800/=
- Spraying	0 MD	-	3MD	900/=	3MD	900/=
- Harvesting	1 MD	300/=	2MD	600/=	3MD	900/=

Table 4.14: Economic analysis for experiment II - Long rains season (April to July) 2010

Main plot treatment	Subplot Treatment	Av. Yield (T/ha)	Value of yield @ Sh. 80 kg^{-1}	Increm-ent over NPK 200 kg ha^{-1} (1.27T)	Value of yield increment @Sh.80 kg^{-1}	Cost of Product -ion	Cost-Benefit ratio
Control	Control	0.6	45,750/=	- 0.7	-55.5	37350	1:1.2
	8t/ha FYM	0.5	37,250/=	- 0.8	-64	58350	1:0.6
	4t/ha FYM +100kg/ha NPK	0.4	31,070/=	- 0.9	-70.2	53750	1:0.6
	Rhizobium	0.6	45,898/=	- 0.7	-55.3	37450	1:1.2
	200kg/ha NPK	1.3	101,237/=	0	0	46200	1:2.2
Fungicide	*Rhizobium*	0.7	56,606/=	- 0.6	-44.6	52450	1:1.1
	200kg/ha NPK	0.7	51,921/=	- 0.6	-49.3	61200	1:0.9
	Control	0.6	47,675/=	- 0.7	-53.6	52350	1:0.9
	8t/ha FYM	1.1	85,904/=	- 0.2	-15.3	73350	1:1.2
	4t/ha FYM +100kg/ha NPK	1.6	13,010/=	0.4	28.9	68750	1:0.2
Insecticide	4t/ha FYM +100kg/ha NPK	1.1	87,534/=	- 0.2	-13.7	65750	1:1.3
	Rhizobium	1.2	94,493/=	- 0.1	-6.7	49450	1:1.9
	8t/ha FYM	0.9	68,094/=	- 0.4	-33.1	70350	1:1
	200kg/ha NPK	1.7	133,918/=	0.4	32.7	58200	1:2.3
	Control	0.5	37,852/=	- 0.8	-63.4	49350	1:0.8
Insecticide / fungicide	8t/ha FYM	1.8	141,576/=	0.5	40.3	85650	1:1.7
	Control	0.3	20,007/=	- 1.0	-81.2	65250	1:0.3
	200kg/ha NPK	2.2	172,786/=	0.9	71.6	75000	1:2.3
	4t/ha FYM +100kg/ha NPK	2	158,415/=	0.7	57.2	81650	1:1.9
	Rhizobium	1.3	100,486/=	-0	-0.8	65350	1:1.5

Table 4.15: Economic analysis for experiment II – Short rains season (October to December) 2010

Main plot treatment	Subplot treatment	Av. Yield (T/ha)	Value of yield @ Sh 80kg^{-1}	Increment over NPK 200 kgha^{-1} rate (0.73T)	Value of yield increment @ Sh 80kg^{-1}	Cost of Product-ion	Cost-Benefit ratio
Control	Control	0.4	34059.76	- 0.7	-55.5	37350	1:0.9
	8t/ha FYM	0.5	38056	- 0.8	-64	58350	1:0.7
	4t/ha FYM +100kg/ha NPK	0.7	52691.2	- 0.9	-70.2	53750	1:1
	Rhizobium	0.6	50590.4	- 0.7	-55.3	37450	1:1.4
	NPK (200kg/ha)	0.7	58242.6	0	0	46200	1:1.3
Fungicide	*Rhizobium*	0.7	54277.8	- 0.6	-44.6	52450	1:1.0
	NPK (200kg/ha)	0.9	75333.4	- 0.6	-49.3	61200	1:1.2
	Control	0.5	40602.6	- 0.7	-53.6	52350	1:0.8
	8t/ha FYM	0.9	69853.8	- 0.2	-15.3	73350	1:1
	4t/ha FYM + 100kg/ha NPK	0.6	48690.2	0.4	28.9	68750	1:0.7
Insecticide	4t/ha FYM + 100kg/ha NPK	0.8	65011.2	- 0.2	-13.7	65750	1:1
	Rhizobium	0.8	65585.6	-0.1	-6.7	49450	1:1.3
	8t /ha FYM	0.9	74979.8	-0.4	-33.1	70350	1:1.1
	200kg/ha NPK	1.3	104511.2	0.4	32.7	58200	1:1.8
	Control	0.7	53743	-0.8	-63.4	49350	1:1.1
Insecticide / fungicide	8t/ha FYM	1.0	82774.4	0.5	40.3	85650	1:1
	Control	0.7	55412.8	-1.0	-81.2	65250	1:0.9
	200kg/ha NPK	1.4	113323.2	0.9	71.6	75000	1:1.5
	4t/ha FYM +100kg/ha NPK	1.6	128067.2	0.7	57.2	81650	1:1.6
	Rhizobium	1.1	90997.8	0	-0.8	65350	1:1.4

4.6 Discussion

4.6.1 Effects of fertilizers and pesticides on yield of beans

Rhizobium inoculation increased plant survival, nodule number, grain yield and yield components of beans in plots treated with insecticide or insecticide/fungicide combination. This study is in agreement with observations obtained in previous studies. In a study by Otieno et al. (2007), legume species, fertilizer application and their interactions reduced number of nodules per plant and nodule dry weight in GLP2 relative to the control while inoculation of the two bean varieties increased number of nodules. *Rhizobium* inoculation may have improved plant survival in the current study by making N available for plant growth and development up to when the plant developed more vigour overcoming the effects of damage of pests and diseases. The pesticides on the other hand may have increased plant survival by minimizing the effect of pests and diseases on the physiologically active plant parts. Similar increase was observed in shoot biomass in both long and short rains, but the plots with combined fungicide/insecticide sprays had the highest increase. Increased nodulation as a result of inoculation was also observed in the short rains. Increased nodulation, root and shoot biomass due to availability of adequate quantities of N have been reported (Chemining'wa et al., 2012).

Fertilizers did not increase nodule count and root biomass. This is consistent with previous research studies. During the reproductive phase of the crop both insect pests and diseases were present on the crop and neither the fungicide nor insecticide alone could effectively improve plant survival. A combination of pesticides had more impact on plant count by effectively reducing the damage due to both pests (Rahman et al., 2009). In studies by Thies et al. (1995), it was found that in general, improved C and N nutrition resulted in greater leaf area, increased rate of node production (CGR), and extended seed fill duration, which in turn, resulted in significantly increased biomass and seed yield. Edge et al, reported that mean seed yield of beans were increased by application of N fertilizer at more than 40 kg/ha, and lower rates did not. While Haag et al. (1999) found that 124 bean genotypes differed significantly in response to variable fertilizer levels. They reported that high N rates significantly increased seed yields per plant, number of pods per plant, and single seed weight. The results also showed that whereas the genotypes responded differently to increasing N fertilizer rates, number of pods per plant exerted a predominant influence on bean yields at all the fertilizer levels. Araújo et al. (2008) found that higher grain yield, pod number, and total dry matter were obtained with the increase in the N level. For grain yield, the increase was 16% when 60 kg/ha N was used and 31% with 120 kg/ha nitrogen.

The soil at this site had low fertility (0.11%N) hence the observed responses in these parameters due to application of fertilizer. Inorganic fertilizer provided the initial nutrient requirement before the N fixation ability was developed and sustained the development of physiological functions to maturity, while manures are a source of N and P but they mineralize slowly releasing nutrients gradually. However, these nutrients are made available in the active growth phase of the crop. The nutrients are fixed in their matrix enhancing their availability in the reproductive phase therefore increasing the plants growth vigour against the damage by pests thus improving plant’s ability to survive. Subsequent growth and leaf expansion with developed photosynthetic capacity enhanced effective utilization of fertilizer nutrients resulting in the increased yield components and hence yields (Otieno et al., 2007).

Rabbani et al. (2005) reported that in low fertility soils improving legume productivity could be done with application of *Rhizobia* in combination with 25 kg/ha P and 1.5 kg/ha Mo since both are directly involved in nitrogen fixing enzyme, nitrogenase. Chemining’wa and Vessey (2006) reported that high levels of inorganic N, especially nitrate-N, suppress nodulation of legumes, but under low soil mineral N, a moderate dose of starter-N stimulates seedling (root and shoot) growth and nodule development. Studies by Bildirici et al. (2005) showed that the interaction between N, P, and *Rhizobia* increased yield and gave the highest of 5369kg/ha when the same quantities were combined with the inoculant. In his study more than 60kg/ha N decreased nodule number, size and weight, but 22kg/ha N increased nodulation. They reported that P increases symbiotic fixation while N decreases bacterial activity in preference for available N. In the current study soil N and P may have been sufficient for root growth and the supplemental nutrients may have suppressed nodulation.

Kuslum et al. (2007) observed that manure makes the inorganic N less easy to leach and the presence of both sources of nutrients enabled the crop to grow more vigorously and resulted in more improved ability to survive, and Chemining’wa et al. (2007) showed the need for small doses of starter-N under low fertility soils to stimulate seedling growth. Similar observations were made by Bilidirici et al., 2005; Thies et al., 1995; Amjad et al., 2004; Kibunja et al., 1976; and Araujo et al., 2008).

4.6.2 The economics of both fertilizer and manure, and pesticide application on productivity of beans

An economic analysis of the use of pesticides on beans treated with different fertilizers showed that in the long rains season, when both pests and diseases abound, the yields obtained with both fungicidal and insecticidal sprays gave more profits than either one or none of them. In the short rains season the application of insecticidal controls with minimal fungicides gave more economical yields. It was also less costly when pesticides were applied on plants given full rate of fertilizer (200kg/ha NPK) than the ones treated with half rate fertilizer and half rate manure (100kg/ha NPK and 4 ton/ha farm yard manure). This was because it gave on average slightly higher yield than the latter, although past studies show that high levels of essential nutrients lead to yield reduction, and also because the total cost of production is higher for the tonnage of manure required than for the combined manure/fertilizer treatment. However the production costs go down drastically when the manure is produced on the farm, reducing the monetary expenditures. When as expected the yield obtained is higher on plants given half rates of fertilizer and manure, then the cost benefit ratio is slightly above that of the full rate fertilizer plots. But this ratio is much larger when manure is produced on farm.

The scarcity of manure attributed to reduced land sizes for animals and inappropriate preparation techniques and storage methods used, which lower its quality, make it attract high commercial values because of its advantages in improving soil properties. This is particularly so under nutrient/spraying treatments during the crop growth cycle.

4.7 Conclusion and Recommendations

Application of 100kg/ha NPK fertilizer plus 4 ton/ha farm yard manure combined with sprays of both fungicides and insecticides in the long rains and only insecticidal sprays and minimal fungicides during the short rains is recommended and could be more economically remunerative to farmers under smallholder bean production.

Rhizobia could be applied with minimal N and P fertilizers for better yields in poor soils where inoculation is beneficial. The application of both fungicide and insecticide enabled the control of the biotic destruction of the plants' photosynthetic activity so that nutrient partitioning into grain was more efficient as fewer calories were needed for fighting the pathogenic activities. The result was a healthier robust crop with more leaf area for metabolite formation for seed production.

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSIONS AND RECOMENDATIONS

5.1 General Discussion

In this study *Rhizobium* inoculation increased plant survival, nodulation, and yield parameters of beans. Inoculation is therefore beneficial and should be used as strategy to increase bean production in more arid low income areas where costs of fertilizers are prohibitive, soils have low fertility, and rainfall is low and erratic. Under moderate fertility and medium rainfall, combined use of inoculation and inorganic fertilizers offers an option that previous studies have shown to give unusually high production levels, which could help realize the yield potential of beans, but which remain largely unexploited.

Inorganic fertilizers increased yield in this study attaining highest output levels usually not realized at smallholder level, but most soils in bean production areas have very low fertility and require intensive fertilizer use. In moderate rainfall areas where economic returns to farming are mainly affected by pests and diseases and not soil fertility and rainfall, it is worth investing in bean production, particularly in highly commercial and industrial varieties like Navy bean with emphasis on pests and diseases control. Application of combined organic and inorganic fertilizers were found to give almost as good yields as intensive levels of pure inorganic fertilizers, and offered a more affordable option to farmers across the bean production zones.

Control of pests by application of either fungicide, insecticide or a combination of the two, with respect to season, was also found to increase bean yields when damage of pests and/or diseases was adequately suppressed, and the returns still remained above optimal, since they greatly constrain bean production, but this should be subjected to further analysis.

5.2 Conclusion and Recommendations

The two experiments tested the effect of source of N and control of pests on the growth and yield of Navy bean, and the mode of treatment/s that would offer most optimal yields and motivate increased production of the crop by smallholders where bean income loss has been caused by low soil fertility and inability of farmers to access adequate quantities of fertilizers and manures, which have been limiting production respectively because of high costs and availability of insufficient quantities on the farm and biotic factors, beside post-harvest losses caused by reduced bean quality due to poor nutrition and/or poor post harvest practices like harvesting time and storage. The evaluation shows that application of moderate dose of N fertilizers in form of combined inorganic and organic sources would offer a more affordable alternative when pests are also controlled through sprays of both fungicides and insecticides in the long rains when both insect and fungal pests abound; and when emphasis on insect pest control is done and fungicidal sprays are minimized in the short rains when dry spells are common leading to the increased insect-pest attack on the succulent crop. Availability of manure in quantities that would improve soil fertility to increase bean productivity is a challenge farmers face because of reducing land sizes and lower stocking rate (livestock numbers per farm holding), and requires combination of multiple techniques in the generation of large amounts, but the labour and cost implications still remain prohibitive to most smallholder farmers.

In the investigation increasing availability of N was observed to increase yields and components of yield. Combinations of different sources of N used included varying rates of chicken or farm yard manure and inorganic fertilizer. These were applied as sole source of N or combinations of both, with the rates varying from zero up to the maximum recommended levels. The observations may be explained that combinations of the two N sources is more appropriate during the crop development phase because during early growth ready supply of N is provided by the soluble nitrate fertilizer as the crop develops N fixation capability, while organic manures which decompose slowly release N during the advanced growth and maturity phase especially during the reproductive period. This was seen when moderate amounts of fertilizer plus full rate chicken manure gave high yields, that nearly equaled full rates of both sources combined and when full rate inorganic fertilizer as a single source gave almost the same amount of yield. These yields were observed when pest control was done on the crop by applying both fungicide and insecticide or insecticide alone, depending on the gravity and kind of pest. These observations are in line with several past research observations.

Inoculation would be recommended where it leads to better yields, however, under low soil fertility circumstances, inoculation could be combined with minimal quantities of N and P for improved yields. Under any of the foregoing situations inoculation would greatly reduce labour requirements in bean production. Where indigenous *Rhizobia* give good yields application of a little N at planting is recommended. It is therefore conclusive that control of pests and diseases is a recommended practice in yield and quality enhancement for increased bean production to meet rising food and nutritional needs in smallholding environments, and in its commercial production.

CHAPTER SIX: REFERENCES

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APPENDICES

Appendix 1: Weather data for the short rains (October to December) 2009 and long rains (March to May) 2010 seasons in Mwea experimental sites

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Rainfall	175	184	118	50	53	142	100	263	0	0	0	0
R/days	10	7	7	2	5	8	3	8	0	0	0	0
Max. ^oC	29	28	30	29	29	28.5	28	29	27	26	27	28.9
Min. ^oC	18	18	15	17.5	18	18.5	18	18	17	16.5	16.9	17.2
Rel. hum. (%)												
0600 Z	77.8	80.8	78.8	78.4	79.1	81.2	78.2	78.1	80.0	82.1	82.3	77.5

Appendix 2: Weather data for the long rains (March to May) 2010 and short rains seasons (October to December) of 2010 in Kabete Field Station experimental sites

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	143.5	73.8	250.3	252.8	266.1	51.9	72.5	80.5	121	64.3	93.3	74.5
R/days	6	8	14	19	13	3	2	6	3	6	13	9
Max. ^oC	23.7	24.9	23.9	23.8	22.5	21.5	21.1	21.5	23.8	24.8	22.5	23.7
Min. ^oC	14.0	15.0	14.8	15.5	14.8	13.5	11.5	11.8	12.0	13.8	14.4	13.8
Rel. hum. (%)												
0600 Z	76	83	83.6	87.3	86	87	85.7	88	81.8	80	88.4	78
1200 Z	57	59	60.9	61.8	67	65	59.5	61	51.6	48	60.5	54

Appendix 3: Laboratory analysis results for experimental sites (Macronutrients)

Location: Mwea site	pH	% N	% P	% K	Kabete site:	pH	% N	% P	% K
Soil: Site 1	5.9	0.11	52	0.96		5.55	0.11	11	1.35
Site 2	4.97	0.12	57	0.67					
Manure: Cattle	8.28	0.94	1.12	0.91		9.18	1.5	3.45	3.06
Chicken	8.24	1.46	1.21	1.35					

Appendix 4: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on shoot biomass at four weeks after emergence) in the long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	2.6466	1.3233	3.38	
Treatment	19	19.5194	1.0273	2.62	0.006***
Residual	38	14.8846	0.3917		
Total	59	37.0506			

***Highly significant at p<0.001

Appendix 5: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on shoot biomass at four weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocs stratum	2	47.56	23.78	0.39	
Treatment	19	1534.08	80.74	1.33	0.224^{NS}
Residual	38	2313.54	60.88		
Total	59	3895.18			

^{NS}Not significant

Appendix 6: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on shoot biomass at six weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	0.01647	0.00824	0.40	
Treatment	19	22.41620	1.17980	57.91	<0.001***
Residual	38	0.77412	0.02037		
Total	59	23.20680			

***Highly significant at p<0.001

Appendix 7: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on shoot biomass at six weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocs stratum	2	89.51	44.76	0.50	
Treatment	19	4068.68	214.14	2.39	0.011*
Residual	38	3400.51	89.49		
Total	59	7558.70			

*Significant at p<0.05

Appendix 8: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on shoot biomass at flowering during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	0.7972	0.3986	2.79	
Treatment	19	283.5525	14.9238	104.52	<0.001***
Residual	38	5.4260	0.1428		
Total	59	289.7757			

***Highly significant at p<0.001

Appendix 9: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on shoot biomass at flowering during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	40.68	20.34	0.35	
Treatment	19	46444.67	2444.46	42.29	<0.001***
Residual	38	2196.59	57.81		
Total	59	48681.94			

***Highly significant at p<0.001

Appendix 10: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on root biomass at podding during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.316	0.158	0.02	
Treatment	19	24699.573	1299.978	169.32	<.001***
Residual	38	291.757	7.678		
Total	59	24991.646			

***Highly significant at p<0.001

Appendix 11: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on shoot biomass at podding during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocs	2	51.02	25.51	0.45	
Treatment	19	49300.29	2594.75	45.43	<0.001***
Residual	38	2170.46	57.12		
Total	59	51521.76			

***Highly significant at p<0.001

Appendix 12: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on root biomass at two weeks after emergence in the long rains (2010)

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Block	2	0.00141	0.00071	0.05	
Treatment	19	0.24637	0.01297	1.01	0.475^{NS}
Residual	37(1)	0.47583	0.01286		
Total	58(1)	0.72316			

^{NS}Not significant

Appendix 13: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on root biomass at two weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	0.1091	0.0546	0.32	
Treatment	19	7.2140	0.3797	2.21	0.018*
Residual	38	6.5231	0.1717		
Total	59	13.8462			

*Significant at p<0.05

Appendix 14: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on root biomass at four weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	0.19308	0.09654	1.39	
Treatment	19	1.79793	0.09463	1.36	0.206^{NS}
Residual	38	2.64498	0.06960		
Total	59	4.63599			

^{NS}Not significant

Appendix 15: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on root biomass at four weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	0.6736	0.3368	2.10	
Treatment	19	18.3699	0.9668	6.02	<0.001***
Residual	38	6.0980	0.1605		
Total	59	25.1415			

***Highly significant at p<0.001

Appendix 16: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on root biomass six at weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	0.0016111	0.0008056	1.91	
Treatment	19	0.6572828	0.0345938	81.95	<0.001***
Residual	38	0.0160409	0.0004221		
Total	59	0.6749349			

***Highly significant at p<0.001

Appendix 17: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on root biomass at six weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	0.0773	0.0387	0.26	
Treatment	19	16.8160	0.8851	6.06	<0.001***
Residual	38	5.5532	0.1461		
Total	59	22.4465			

***Highly significant at p<0.001

Appendix 18: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on root biomass at flowering during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.65945	0.32973	11.32	
Treatment	19	2.99990	0.15789	5.42	<.001***
Residual	38	1.10728	0.02914		
Total	59	4.76663			

***Highly significant at p<0.001

Appendix 19: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on root biomass at flowering during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	0.1618	0.0809	0.65	
Treatment	19	20.5422	1.0812	8.69	<0.001***
Residual	38	4.7261	0.1244		
Total	59	25.4301			

***Highly significant at p<0.001

Appendix 20: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on root biomass at podding during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocs stratum	2	0.001623	0.000812	0.58	
Treatment	19	3.573485	0.188078	133.56	<.001***
Residual	38	0.053510	0.001408		
Total	59	3.628618			

***Highly significant at p<0.001

Appendix 21: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on root biomass podding during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	0.0642	0.0321	0.13	
Treatment	19	22.3589	1.1768	4.93	<0.001***
Residual	38	9.0615	0.2385		
Total	59	31.4846			

***Highly significant at p<0.001

Appendix 22: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on nodule count at two weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	697.23	348.62	4.63	
Treatment	19	5344.32	281.28	3.73	<0.001***
Residual	38	2863.43	75.35		
Total	59	8904.98			

***Highly significant at p<0.001

Appendix 23: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on nodule count at two weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	4160.1	2080.0	2.34	
Treatment	19	27515.1	1448.2	1.63	0.098^{NS}
Residual	38	33737.2	887.8		
Total	59	65412.4			

^{NS}Not significant

Appendix 24: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on nodule count at four weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	3006.0	1503.0	2.04	
Treatment	9	48994.7	2578.7	3.50	<0.001***
Residual	38	27964.0	735.9		
Total	59	79964.7			

***Highly significant at p<0.001

Appendix 25: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on nodule count at four weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	854.2	427.1	0.92	
Treatment	19	45074.6	2372.3	5.12	<0.001***
Residual	38	17621.1	463.7		
Total	59	63549.9			

***Highly significant at p<0.001

Appendix 26: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on nodule count at six weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	572.2	286.1	0.81	
Trt	19	36382.6	1914.9	5.40	<0.001***
Residual	38	13473.1	354.6		
Total	59	50427.9			

***Highly significant at p<0.001

Appendix 27: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on nodule count at six weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	1096.4	548.2	1.63	
Treatment	19	44438.6	2338.9	6.96	<0.001***
Residual	38	12760.9	335.8		
Total	59	58295.9			

***Highly significant at p<0.001

Appendix 28: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on nodule count at flowering during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	422.1	211.1	1.04	
Treatment	19	26001.6	1368.5	6.76	<0.001***
Residual	38	7691.9	202.4		
Total	59	34115.6			

***Highly significant at p<0.001

Appendix 29: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on nodule count at flowering during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	3043.6	1521.8	5.33	
Treatment	19	26785.9	1409.8	4.94	<0.001***
Residual	38	10853.1	285.6		
Total	59	40682.6			

***Highly significant at p<0.001

Appendix 30: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on nodule count at podding during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	64.6	32.3	0.31	
Treatment	19	5172.2	272.2	2.57	0.006**
Residual	38	4021.4	105.8		
Total	59	9258.2			

**Significant at p<0.01

Appendix 31: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on nodule count at podding during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	217.23	108.62	1.88	
Treatment	19	9188.07	483.58	8.36	<0.001***
Residual	38	2197.43	57.83		
Total	59	11602.73			

***Highly significant at p<0.001

Appendix 32: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on yield during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	2.2716	1.1358	7.85	
Treatment	19	47.5250	2.5013	17.28	<0.001***
Residual	38	5.5004	0.1447		
Total	59	55.2970			

***Highly significant at p<0.001

Appendix 33: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on yield in ton/ha during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.12269	0.06135	2.01	
Treatment	19	1.46719	0.07722	2.53	0.007**
Residual	38	1.16078	0.03055		
Total	59	2.75066			

**Significant at p<0.01

Appendix 34: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment on 100 seed weight during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	17.598	8.799	6.34	
Treatment	19	62.235	3.276	2.36	0.012*
Residual	38	52.751	1.388		
Total	59	132.584			

*Significant at p<0.05

Appendix 35: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on days to 50% emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	0.4333	0.2167	0.31	
Pesticide	3	11.0667	3.6889	5.23	0.041*
Residual	6	4.2333	0.7056	0.92	
Fertilizer	4	10.1000	2.5250	3.28	0.023*
Pesticide x Fertilizer	12	16.4333	1.3694	1.78	0.096^{NS}
Residual	32	24.6667	0.7708		
Total	59	66.9333			

^{NS}Not significant *Significant at p<0.05

Appendix 36: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on days to 50% flowering during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	8.1000	4.0500	2.45	
Pesticide	3	7.6500	2.5500	1.55	0.297[NS]
Residual	6	9.9000	1.6500	2.20	
Fertilizer	4	5.1000	1.2750	1.70	0.174[NS]
Pesticide x Fertilizer	12	14.1000	1.1750	1.57	0.152[NS]
Residual	32	24.0000	0.7500		
Total	59	68.8500			

[NS]Not significant

Appendix 37: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on days to 50% podding during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	44.10	22.05	0.84	
Pesticide	3	113.52	37.84	1.43	0.323[NS]
Residual	6	158.43	26.41	2.64	
Fertilizer	4	37.57	9.39	0.94	0.454[NS]
Pesticide x Fertilizer	12	53.90	4.49	0.45	0.929[NS]
Residual	32	320.13	10.00		
Total	59	727.65			

[NS]Not significant

Appendix 38: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on days to 50% podding during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	25.833	12.917	8.91	
Pesticide	3	8.600	2.867	1.98	0.219[NS]
Residual	6	8.700	1.450	1.31	
Fertilizer	4	6.567	1.642	1.48	0.231[NS]
Pesticide x Fertilizer	12	13.567	1.131	1.02	0.455[NS]
Residual	32	35.467	1.108		
Total	59	98.733			

[NS]Not significant

Appendix 39: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on days to 50% maturity during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	2.500	1.250	0.31	
Pesticide	3	3.333	1.111	0.28	0.841[NS]
Residual	6	24.167	4.028	0.92	
Fertilizer	4	19.167	4.792	1.10	0.376[NS]
Pesticide x Fertilizer	12	50.833	4.236	0.97	0.497[NS]
Residual	32	140.000	4.375		
Total	59	240.000			

[NS]Not significant

Appendix 40: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on days to 50% maturity during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	92.500	46.250	37.67	
Pesticide	3	27.333	9.111	7.42	0.019*
Residual	6	7.367	1.228	0.45	
Fertilizer	4	4.667	1.167	0.43	0.788^{NS}
Pesticide x Fertilizer	12	28.667	2.389	0.87	0.580^{NS}
Residual	32	87.467	2.733		
Total	59	248.000			

^{NS}Not significant *Significant at p<0.05

Appendix 41: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at one week after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	311.43	155.72	1.75	
Pesticide	3	337.25	112.42	1.26	0.369^{NS}
Residual	6	534.70	89.12	1.84	
Fertilizer	4	475.40	118.85	2.46	0.066^{NS}
Pesticide x Fertilizer	12	534.33	44.53	0.92	0.538^{NS}
Residual	32	1547.87	48.37		
Total	59	3740.98			

^{NS}Not significant

Appendix 42: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at two weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	4230.4	2115.2	41.97	
Pesticide	3	3756.4	1252.1	24.84	<.0.001***
Residual	6	302.4	50.4	0.14	
Fertilizer	4	4856.8	1214.2	3.46	0.019*
Pesticide x Fertilizer	12	4870.4	405.9	1.16	0.353^{NS}
Residual	32	11227.2	350.8		
Total	59	29243.6			

^{NS}Not significant *Significant at p<0.05 ***Highly significant at p<0.001

Appendix 43: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at two weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	157.73	78.87	1.25	
Pesticide	3	528.18	176.06	2.79	0.132^{NS}
Residual	6	378.27	63.04	1.09	
Fertilizer	4	491.57	122.89	2.13	0.100^{NS}
Pesticide x Fertilizer	12	347.90	28.99	0.50	0.898^{NS}
Residual	32	1847.33	57.73		
Total	59	3750.98			

^{NS}Not significant

Appendix 44: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at three weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	5655.2	2827.6	55.11	
Pesticide	3	4325.7	1441.9	28.10	<0.001***
Residual	6	307.8	51.3	0.15	
Fertilizer	4	5130.6	1282.7	3.81	0.012*
Pesticide.Fertilizer	12	5395.7	449.6	1.33	0.248^{NS}
Residual	32	10786.9	337.1		
Total	59	31601.9			

^{NS}Not significant *Significant at p<0.05 ***Highly significant at p<0.001

Appendix 45: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at three weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	247.43	123.72	1.17	
Pesticide	3	261.20	87.07	0.83	0.526^{NS}
Residual	6	632.70	105.45	2.22	
Fertilizer	4	483.07	120.77	2.54	0.059^{NS}
Pesticide x Fertilizer	12	588.13	49.01	1.03	0.446^{NS}
Residual	32	1521.20	47.54		
Total	59	3733.73			

^{NS}Not significant

Appendix 46: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at four weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	3716.4	1858.2	50.71	
Pesticide	3	5655.4	1885.1	51.44	<0.001***
Residual	6	219.9	36.6	0.10	
Fertilizer	4	5225.6	1306.4	3.73	0.013*
Pesticide.Fertilizer	12	4939.4	411.6	1.18	0.340^{NS}
Residual	32	11195.1	349.8		
Total	59	30951.6			

^{NS}Not significant *Significant at p<0.05 ***Highly significant at p<0.001

Appendix 47: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at four weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	256.43	128.22	1.27	
Pesticide	3	260.33	86.78	0.86	0.512^{NS}
Residual	6	607.17	101.19	2.16	
Fertilizer	4	500.67	125.17	2.68	0.049*
Pesticide x Fertilizer	12	577.33	48.11	1.03	0.448^{NS}
Residual	32	1496.40	46.76		
Total	59	3698.33			

^{NS}Not significant *Significant at p<0.05

Appendix 48: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at five weeks after emergence during long rains (2010)

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2	3430.4	1715.2	23.79	
Pesticide	3	8537.4	2845.8	39.48	<0.001***
Residual	6	432.5	72.1	0.19	
Fertilizer	4	5708.7	1427.2	3.78	0.013*
Pesticide x Fertilizer	12	5040.6	420.0	1.11	0.384^{NS}
Residual	31(1)	11691.1	377.1		
Total	58(1)	34067.9			

^{NS}Not significant *Significant at p<0.05 ***Highly significant at p<0.001

Appendix 49: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at five weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	256.43	128.22	1.27	
Pesticide	3	260.33	86.78	0.86	0.512^{NS}
Residual	6	607.17	101.19	2.16	
Fertilizer	4	500.67	125.17	2.68	0.049*
Pesticide x Fertilizer	12	577.33	48.11	1.03	0.448^{NS}
Residual	32	1496.40	46.76		
Total	59	3698.33			

^{NS}Not significant *Significant at p<0.05

Appendix 50: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at six weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	2032.1	1016.1	8.86	
Pesticide	3	8338.3	2779.4	24.25	<0.001***
Residual	6	687.7	114.6	0.29	
Fertilizer	4	6030.6	1507.6	3.79	0.012*
Pesticide x Fertilizer	12	4921.4	410.1	1.03	0.447^{NS}
Residual	32	12742.8	398.2		
Total	59	34753.0			

^{NS}Not significant *Significant at p<0.05 ***Highly significant at p<0.001

Appendix 51: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at six weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocs stratum	2	276.93	138.47	1.39	
Pesticide	3	240.45	80.15	0.81	0.534^{NS}
Residual	6	595.60	99.27	2.07	
Fertilizer	4	487.77	121.94	2.54	0.059^{NS}
Pesticide x Fertilizer	12	576.63	48.05	1.00	0.470^{NS}
Residual	32	1536.80	48.02		
Total	59	3714.18			

^{NS}Not significant

Appendix 52: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at seven weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1386.7	693.4	3.90	
Pesticide	3	8828.7	2942.9	16.55	0.003**
Residual	6	1066.6	177.8	0.44	
Fertilizer	4	6019.7	1504.9	3.73	0.013*
Pesticide x Fertilizer	12	4967.9	414.0	1.03	0.450^{NS}
Residual	32	12914.0	403.6		
Total	59	35183.7			

^{NS}Not significant *Significant at p<0.05 **Significant at p<0.01

Appendix 53: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at seven weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	264.93	132.47	1.35	
Pesticide	3	237.12	79.04	0.81	0.535^{NS}
Residual	6	588.93	98.16	2.02	
Fertilizer	4	483.23	120.81	2.49	0.063^{NS}
Pesticide x Fertilizer	12	565.30	47.11	0.97	0.497^{NS}
Residual	32	1555.47	48.61		
Total	59	3694.98			

^{NS}Not significant

Appendix 54: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at eight weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	941.7	470.9	1.81	
Pesticide	3	8997.7	2999.2	11.53	0.007**
Residual	6	1561.4	260.2	0.64	
Fertilizer	4	5405.8	1351.4	3.34	0.021*
Pesticide x Fertilizer	12	4700.8	391.7	0.97	0.497^{NS}
Residual	32	12938.3	404.3		
Total	59	34545.6			

^{NS}Not significant *Significant at p<0.05 **Significant at p<0.01

Appendix 55: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at eight weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	258.23	129.12	1.39	
Pesticide	3	221.13	73.71	0.80	0.540^{NS}
Residual	6	556.17	92.69	1.88	
Fertilizer	4	501.23	125.31	2.54	0.059^{NS}
Pesticide x Fertilizer	12	588.37	49.03	0.99	0.476^{NS}
Residual	32	1579.60	49.36		
Total	59	3704.73			

^{NS}Not significant

Appendix 56: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at nine weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	788.9	394.5	1.15	
Pesticide	3	9253.9	3084.6	8.99	0.012*
Residual	6	2058.9	343.2	0.83	
Fertilizer	4	4658.9	1164.7	2.83	0.041*
Pesticide x Fertilizer	12	4394.2	366.2	0.89	0.566^{NS}
Residual	32	13168.1	411.5		
Total	59	34323.0			

^{NS}Not significant *Significant at $p<0.05$

Appendix 57: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at nine weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	205.83	102.92	1.46	
Pesticide	3	170.58	56.86	0.81	0.534^{NS}
Residual	6	422.57	70.43	1.90	
Fertilizer	4	395.07	98.77	2.66	0.050*
Pesticide x Fertilizer	12	530.00	44.17	1.19	0.331^{NS}
Residual	32	1186.93	37.09		
Total	59	2910.98			

^{NS}Not significant *Significant at $p<0.05$

Appendix 58: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at ten weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	612.0	306.0	0.64	
Pesticide	3	9229.1	3076.4	6.44	0.026*
Residual	6	2865.2	477.5	1.21	
Fertilizer	4	3914.3	978.6	2.47	0.064^{NS}
Pesticide x Fertilizer	12	4251.2	354.3	0.90	0.560^{NS}
Residual	32	12656.1	395.5		
Total	59	33527.9			

^{NS}Not significant *Significant at p<0.05

Appendix 59: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at ten weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	191.23	95.62	1.42	
Pesticide	3	124.93	41.64	0.62	0.629^{NS}
Residual	6	405.17	67.53	2.21	
Fertilizer	4	398.43	99.61	3.26	0.024*
Pesticide x Fertilizer	12	612.23	51.02	1.67	0.121^{NS}
Residual	2	976.93	30.53		
Total	59	2708.93			

^{NS}Not significant *Significant at p<0.05

Appendix 60: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at eleven weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	634.6	317.3	0.67	
Pesticide	3	9308.6	3102.9	6.54	0.026*
Residual	6	2848.6	474.8	1.19	
Fertilizer	4	4084.6	1021.1	2.57	0.057^{NS}
Pesticide x Fertilizer	12	4135.2	344.6	0.87	0.587^{NS}
Residual	32	12733.5	397.9		
Total	59	33745.0			

^{NS}Not significant *Significant at p<0.05

Appendix 61: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at eleven weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	233.10	116.55	0.88	
Pesticide	3	74.13	24.71	0.19	0.902^{NS}
Residual	6	797.17	132.86	2.79	
Fertilizer	4	218.33	54.58	1.15	0.352^{NS}
Pesticide x Fertilizer	12	432.87	36.07	0.76	0.686^{NS}
Residual	32	1522.40	47.58		
Total	59	3278.00			

^{NS}Not significant

Appendix 62: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on plant count at twelve weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	681.1	340.6	0.70	
Pesticide	3	9389.7	3129.9	6.44	0.026*
Residual	6	2914.2	485.7	1.21	
Fertilizer	4	4215.3	1053.8	2.62	0.053^{NS}
Pesticide x Fertilizer	12	4431.7	369.3	0.92	0.541^{NS}
Residual	32	12882.7	402.6		
Total	59	34514.6			

^{NS}Not significant *Significant at $p<0.05$

Appendix 63: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on shoot biomass at two weeks after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	10.120	5.060	1.72	
Pesticide	3	12.700	4.233	1.44	0.322^{NS}
Residual	6	17.671	2.945	1.35	
Fertilizer	4	12.324	3.081	1.41	0.253^{NS}
Pesticide x Fertilizer	12	12.854	1.071	0.49	0.906^{NS}
Residual	32	69.980	2.187		
Total	59	135.649			

^{NS}Not significant

Appendix 64: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on shoot biomass at two weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	5.5091	2.7546	5.63	
Pesticide	3	0.3599	0.1200	0.25	0.862^{NS}
Residual	6	2.9347	0.4891	2.01	
Fertilizer	4	1.8798	0.4700	1.93	0.129^{NS}
Pesticide x Fertilizer	12	3.0836	0.2570	1.06	0.426^{NS}
Residual	32	7.7813	0.2432		
Total	59	21.5485			

^{NS}Not significant

Appendix 65: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on shoot biomass at four weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	11.721	5.860	6.00	
Pesticide	3	1.451	0.484	0.50	0.699^{NS}
Residual	6	5.861	0.977	0.43	
Fertilizer	4	11.778	2.945	1.30	0.292^{NS}
Pesticide x Fertilizer	12	20.991	1.749	0.77	0.675^{NS}
Residual	32	72.673	2.271		
Total	59	124.475			

^{NS}Not significant

Appendix 66: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on shoot biomass six weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	15.59	7.80	1.79	
Pesticide	3	3.44	1.15	0.26	0.850^{NS}
Residual	6	26.18	4.36	0.25	
Fertilizer	4	59.55	14.89	0.84	0.508^{NS}
Pesticide x Fertilizer	12	122.94	10.24	0.58	0.842^{NS}
Residual	32	565.13	17.66		
Total	59	792.83			

^{NS}Not significant

Appendix 67: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on shoot biomass at flowering during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	615.9	307.9	1.85	
Pesticide	3	1221.8	407.3	2.45	0.162^{NS}
Residual	6	999.4	166.6	1.10	
Fertilizer	4	549.0	137.2	0.91	0.471^{NS}
Pesticide x Fertilizer	12	1480.2	123.4	0.82	0.632^{NS}
Residual	32	4831.6	151.0		
Total	59	9697.9			

^{NS}Not significant

Appendix 68: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on shoot biomass flowering during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	7.81	3.90	0.11	
Pesticide	3	252.33	84.11	2.27	0.181^{NS}
Residual	6	222.78	37.13	0.70	
Fertilizer	4	97.81	24.45	0.46	0.763^{NS}
Pesticide x Fertilizer	12	409.63	34.14	0.64	0.789^{NS}
Residual	32	1695.54	52.99		
Total	59	2685.89			

^{NS}Not significant

Appendix 69: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on shoot biomass at podding during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	1296.0	648.0	1.05	
Pesticide	3	1851.9	617.3	1.00	0.454^{NS}
Residual	6	3692.1	615.3	0.96	
Fertilizer	4	21922.0	5480.5	8.54	<0.001***
Pesticide x Fertilizer	12	10947.9	912.3	1.42	0.207^{NS}
Residual	32	20528.5	641.5		
Total	59	60238.4			

^{NS}Not significant ***Highly significant at p<0.001

Appendix 70: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on shoot biomass at podding during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	11463.4	5731.7	11.34	
Pesticide	3	2716.1	905.4	1.79	0.249^{NS}
Residual	6	3033.7	505.6	0.64	
Fertilizer	4	2007.6	501.9	0.63	0.643^{NS}
Pesticide x Fertilizer	12	12883.4	1073.6	1.35	0.238^{NS}
Residual	32	25376.2	793.0		
Total	59	57480.4			

^{NS}Not significant

Appendix 71: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on shoot biomass at maturity during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	56343.	28172.	0.92	
Pesticide	3	169338.	56446.	1.84	0.241^{NS}
Residual	6	184487.	30748.	2.72	
Fertilizer	4	602994.	150748.	13.34	<0.001***
Pesticide x Fertilizer	12	511353.	42613.	3.77	0.001***
Residual	32	361593.	11300.		
Total	59	1886108.			

^{NS}Not significant ***Highly significant at p<0.001

Appendix 72: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on shoot biomass at maturity during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	323949.	161974.	1.16	
Pesticide	3	517390.	172463.	1.24	0.376^{NS}
Residual	6	836472.	139412.	2.32	
Fertilizer	4	483889.	120972.	2.01	0.117^{NS}
Pesticide x Fertilizer	12	457598.	38133.	0.63	0.798^{NS}
Residual	32	1925022.	60157.		
Total	59	4544320.			

^{NS}Not significant

Appendix 73: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on root biomass at four weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	0.04113	0.02057	6.69	
Pesticide	3	0.01811	0.00604	1.96	0.221^{NS}
Residual	6	0.01846	0.00308	0.23	
Fertilizer	4	0.15830	0.03957	2.91	0.037*
Pesticide x Fertilizer	12	0.06082	0.00507	0.37	0.964^{NS}
Residual	32	0.43448	0.01358		
Total	59	0.73130			

^{NS}Not significant *Significant at p<0.05

Appendix 74: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on root biomass at four weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	0.02181	0.01091	1.81	
Pesticide	3	0.03136	0.01045	1.73	0.260^{NS}
Residual	6	0.03624	0.00604	0.29	
Fertilizer	4	0.13486	0.03371	1.60	0.198^{NS}
Pesticide x Fertilizer	12	0.17808	0.01484	0.70	0.736^{NS}
Residual	32	0.67455	0.02108		
Total	59	1.07690			

^{NS}Not significant

Appendix 75: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on root biomass six weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	0.00485	0.00243	0.09	
Pesticide	3	0.02091	0.00697	0.26	0.850^{NS}
Residual	6	0.15919	0.02653	0.42	
Fertilizer	4	0.26384	0.06596	1.04	0.402^{NS}
Pesticide x Fertilizer	12	0.65704	0.05475	0.86	0.589^{NS}
Residual	32	2.02836	0.06339		
Total	59	3.13419			

^{NS}Not significant

Appendix 76: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on root biomass at flowering during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	7.81	3.90	0.11	
Pesticide	3	252.33	84.11	2.27	0.181^{NS}
Residual	6	222.78	37.13	0.70	
Fertilizer	4	97.81	24.45	0.46	0.763^{NS}
Pesticide x Fertilizer	12	409.63	34.14	0.64	0.789^{NS}
Residual	32	1695.54	52.99		
Total	59	2685.89			

^{NS}Not significant

Appendix 77: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on root biomass at podding during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	1409.3	704.7	1.12	
Pesticide	3	1870.1	623.4	0.99	0.458^{NS}
Residual	6	3771.4	628.6	1.04	
Fertilizer	4	2365.7	591.4	0.98	0.434^{NS}
Pesticide x Fertilizer	12	7214.1	601.2	0.99	0.477^{NS}
Residual	32	19391.0	606.0		
Total	59	36021.5			

^{NS}Not significant

Appendix 78: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on root biomass at podding during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	12.5583	6.2792	13.70	
Pesticide	3	4.4139	1.4713	3.21	0.104^{NS}
Residual	6	2.7506	0.4584	0.74	
Fertilizer	4	1.6334	0.4083	0.66	0.623^{NS}
Pesticide x Fertilizer	12	7.5870	0.6322	1.03	0.450^{NS}
Residual	32	19.7255	0.6164		
Total	59	48.6687			

^{NS}Not significant

Appendix 79: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on root biomass at maturity during short rains (2010)

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Block	2	0.06271	0.03136	0.80	
Pest	3	4.23725	1.41242	35.93	<.001***
Residual	6	0.23586	0.03931	1.06	
Fertilizer	4	16.50303	4.12576	111.55	<.001***
Pesticide x Fertilizer	2	2.16169	0.18014	4.87	<.001***
Residual	31(1)	1.14652	0.03698		
Total	58(1)	24.30386			

***Highly significant at p<0.001

Appendix 80: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on nodule count at four weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	263.20	131.60	1.88	
Pesticide	3	36.60	12.20	0.17	0.910^{NS}
Residual	6	419.85	69.98	3.32	
Fertilizer	4	149.04	37.26	1.77	0.160^{NS}
Pesticide x Fertilizer	12	249.91	20.83	0.99	0.482^{NS}
Residual	32	675.25	21.10		
Total	59	1793.86			

^{NS}Not significant

Appendix 81: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on nodule count six weeks after emergence during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	286.90	143.45	1.17	
Pesticide	3	139.27	46.42	0.38	0.772^{NS}
Residual	6	734.03	122.34	3.06	
Fertilizer	4	456.23	114.06	2.85	0.040*
Pesticide x Fertilizer	12	228.57	19.05	0.48	0.914^{NS}
Residual	32	1280.40	40.01		
Total	59	3125.40			

^{NS}Not significant *Significant at p<0.05

Appendix 82: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on nodule count at flowering during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	69.23	34.62	1.44	
Pesticide	3	114.58	38.19	1.59	0.287^{NS}
Residual	6	143.97	23.99	1.43	
Fertilizer	4	56.93	14.23	0.85	0.507^{NS}
Pesticide x Fertilizer	12	74.67	6.22	0.37	0.965^{NS}
Residual	32	538.80	16.84		
Total	59	998.18			

^{NS}Not significant

Appendix 83: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on nodule count at flowering during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	278.63	139.32	4.96	
Pesticide	3	58.73	19.58	0.70	0.587^{NS}
Residual	6	168.57	28.09	1.45	
Fertilizer	4	62.27	15.57	0.80	0.534^{NS}
Pesticide x Fertilizer	12	261.60	21.80	1.12	0.378^{NS}
Residual	32	622.13	19.44		
Total	59	1451.93			

^{NS}Not significant

Appendix 84: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on nodule count at podding during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	14.033	7.017	0.68	
Pesticide	3	15.067	5.022	0.49	0.704^{NS}
Residual	6	61.833	10.306	1.49	
Fertilizer	4	22.167	5.542	0.80	0.532^{NS}
Pesticide x Fertilizer	12	29.433	2.453	0.36	0.970^{NS}
Residual	32	220.800	6.900		
Total	59	363.333			

^{NS}Not significant

Appendix 85: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on nodule count at podding during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	19.63	9.82	0.32	
Pesticide	3	10.98	3.66	0.12	0.945^{NS}
Residual	6	183.17	30.53	3.00	
Fertilizer	4	40.27	10.07	0.99	0.428^{NS}
Pesticide x Fertilizer	12	106.27	8.86	0.87	0.584^{NS}
Residual	32	325.87	10.18		
Total	59	686.18			

^{NS}Not Significant

Appendix 86: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on number of pods per plant during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	289.22	144.61	7.00	
Pesticide	3	244.82	81.61	3.95	0.072^{NS}
Residual	6	123.89	20.65	0.29	
Fertilizer	4	1337.19	334.30	4.66	0.004**
Pesticide x Fertilizer	12	548.30	45.69	0.64	0.796^{NS}
Residual	32	2297.62	71.80		
Total	59	4841.04			

^{NS}Not significant **Significant at $p<0.01$

Appendix 87: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on number of pods per plant during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	5392.71	2696.35	54.41	
Pesticide	3	394.46	131.49	2.65	0.143^{NS}
Residual	6	297.35	49.56	0.72	
Fertilizer	4	399.91	99.98	1.45	0.242^{NS}
Pesticide x Fertilizer	12	431.49	35.96	0.52	0.886^{NS}
Residual	32	2212.18	69.13		
Total	59	9128.10			

^{NS}Not significant

Appendix 88: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on average pod length during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	8479.8	4239.9	246.43	
Pesticide	3	408.4	136.1	7.91	0.017*
Residual	6	103.2	17.2	0.16	
Fertilizer	4	237.3	59.3	0.54	0.708^{NS}
Pesticide x Fertilizer	12	296.7	24.7	0.22	0.996^{NS}
Residual	32	3523.4	110.1		
Total	59	13048.9			

^{NS}Not significant *Significant at $p<0.05$

Appendix 89: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on number of seeds pod during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	1.033	0.517	0.30	
Pesticide	3	5.400	1.800	1.05	0.437^{NS}
Residual	6	10.300	1.717	1.33	
Fertilizer	4	2.767	0.692	0.54	0.711^{NS}
Pesticide x Fertilizer	12	19.100	1.592	1.23	0.305^{NS}
Residual	32	41.333	1.292		
Total	59	79.933			

^{NS}Not significant

Appendix 90: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide application on number of seeds per pod during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	1.3000	0.6500	4.68	
Pesticide	3	0.8667	0.2889	2.08	0.204^{NS}
Residual	6	0.8333	0.1389	0.68	
Fertilizer	4	0.4333	0.1083	0.53	0.714^{NS}
Pesticide x Fertilizer	12	2.6333	0.2194	1.07	0.412^{NS}
Residual	32	6.5333	0.2042		
Total	59	12.6000			

^{NS}Not significant

Appendix 91: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on grain yield during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	0.77070	0.38535	1.21	
Pesticide	3	5.36985	1.78995	5.61	0.036*
Residual	6	1.91527	0.31921	3.42	
Fertilizer	4	6.54111	1.63528	17.52	<0.001***
Pesticide x Fertilizer	12	6.59425	0.54952	5.89	<0.001***
Residual	32	2.98608	0.09331		
Total	59	24.17726			

*Significant at p<0.05 ***Highly significant at p<0.001

Appendix 92: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on grain yield during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	267362.	133681.	0.44	
Pesticide	3	2958142.	986047.	3.25	0.102^{NS}
Residual	6	1820954.	303492.	4.31	
Fertilizer	4	1736484.	434121.	6.16	<0.001***
Pesticide x Fertilizer	12	581561.	48463.	0.69	0.750^{NS}
Residual	32	2254450.	70452.		
Total	59	9618954.			

^{NS}Not significant *** Highly Significant at p<0.01

Appendix 93: Analysis of variance (ANOVA) table for the effect of fertilizer, manure and pesticide treatment on 100 seed weight after emergence during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	5.961	2.981	1.67	
Pesticide	3	17.817	5.939	3.32	0.098^{NS}
Residual	6	10.734	1.789	0.93	
Fertilizer	4	303.010	75.752	39.46	<0.001***
Pesticide x Fertilizer	12	48.435	4.036	2.10	0.046*
Residual	32	61.427	1.920		
Total	59	447.384			

^{NS}Not significant *Significant at p<0.05 ***Highly significant at p<0.001

Appendix 94: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment and pesticide application on 100 seed weight during short rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	21.202	10.601	1.82	
Pesticide	3	11.556	3.852	0.66	0.605^{NS}
Residual	6	34.961	5.827	2.70	
Fertilizer	4	10.387	2.597	1.20	0.329^{NS}
Pesticide x Fertilizer	12	16.808	1.401	0.65	0.785^{NS}
Residual	32	69.138	2.161		
Total	59	164.051			

^{NS}Not significant

Appendix 95: Analysis of variance (ANOVA) table for the effect of fertilizer and manure treatment and pesticide application on no. of pods per plant during long rains (2010)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	289.22	144.61	7.00	
Pesticide	3	244.82	81.61	3.95	0.072^{NS}
Residual	6	123.89	20.65	0.29	
Fertilizer	4	1337.19	334.30	4.66	0.004**
Pesticide x Fertilizer	12	548.30	45.69	0.64	0.796^{NS}
Residual	32	2297.62	71.80		
Total	59	4841.04			

^{NS}Not significant **Significant at p<0.01