EFFECT OF CHEMICAL PESTICIDES AND NITROGEN SOURCE ON THE PERFORMANCE OF FOOD GRAIN LEGUMES

BY

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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This work is dedicated to my fiancée Millicent and the young Faith, Hillary and Phoebe hoping that the work will inspire them to grow more food to feed the world.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA-Analysis of Variance

cm-centimetre

c.v- coefficient of variation

EC-emulsifiable concentrate

FAO –Food and Agricultural Organization

g-Grams

GLP- Grain Legume Project

ha-hectare

ICRISAT-International Crops Research Institute for Semi-arid Tropics

K-potassium

KARI-Kenya Agricultural Research Institute

Kg- kilogram

Kshs-Kenya shillings

L-litres

LSD-Least Significant Difference

m-metres

mg-milligrams

ml-millilitres

MIRCEN-Microbiological Research Centre

MT-Metric tonnes

N-nitrogen

P-phosphorous

PDA-Potato Dextrose Agar

var-variety

WP-wettable powder

%-percent

^{o}C-Degrees Celsius

ABSTRACT

Plant pests and declining soil fertility are among the major limitations to the production of grain legumes in Kenya. Two field experiments were concurrently conducted to investigate the response of grain legumes to pesticide spray and nitrogen source. A greenhouse experiment was also conducted to investigate the effect of rhizobia inoculation and fungicide treatment on fungal root rots, nodulation and dry matter accumulation of selected grain legumes. Five grain legumes namely common bean (*Phaseolus vulgaris* L.var GLP 2), lima bean (*Phaseolus lunatus* L.), green grams (*Vigna radiata L.*), lablab (*Lablab purpureus*) and chickpea (*Cicer arietinum)* were tested. The field experimental design was a randomized complete block design in a split plot arrangement. Pesticide spray and the legume species were the main plots while the legume species and the nitrogen sources were the subplots for experiment I and II respectively. Parameters observed were; insect pest and disease incidences and damage, nodulation, plant growth, yield and yield components. The greenhouse experiment was laid out in a completely randomized design. Treatments included, inoculation of legumes with pathogen alone or with appropriate rhizobia alone or application of fungicide or their combinations and a control.

Chemical pesticides significantly reduced the incidence of insect pests and foliar fungal diseases assessed by more than half in all the legume species and so were pod and seed damage in lablab, green gram and chickpea. Spraying significantly increased the grain yield of chickpea and lablab by 1413 and 2276 kg in the long rains corresponding to 614 and 761 kg in the short rains respectively. Benefit-Cost analysis showed that it is profitable to apply pesticides to control pests and diseases in lablab, green gram and chickpea but not in GLP 2 and lima bean. Fertilizer application significantly reduced nodulation in most of the legume species, but significantly increased plant height and shoot dry matter. In contrast, inoculation increased number of nodules and nodule dry matter in most species but this was not translated into increased dry matter accumulation and yield. Manure application improved nodulation and grain yield only in the short rains. All the nitrogen sources had no effect on number of seed pod^{-1} and 100 seed weight. Results of the greenhouse experiment indicated that *Sclerotinia* and *Rhizoctonia* were more pathogenic than *Fusarium* and *Macrophomina.* Rhizobia inoculation significantly increased number of nodules per plant in most species. Fungicide seed treatment reduced disease incidence on *Sclerotinia* and *Rhizoctonia* inoculated plants but significantly reduced nodulation of the legumes. However, effect of fungicide on nodulation was significantly suppressed when applied together with rhizobia on infected seeds. The results suggest that combining fungicide with rhizobia is more effective when the aim is to control disease as well as increase nodulation of the legumes than when each was applied alone.

The results suggested that chemical pesticides sprays are beneficial in pest management in chickpea, green gram and lablab but not in common bean and lima bean. Effect of nitrogen fertilizer, farmyard manure and rhizobia inoculation on grain legume depend on soil nutrient status and other environmental factors. Simultaneous use of fungicide seed treatment and rhizobia inoculation is more effective than when each treatment was applied separately.

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Agriculture's challenge in the twenty first century

The ultimate challenge facing agriculture worldwide is to feed the growing human population. Despite global food adequacy, which according to FAO has persisted since 1974, sub-Saharan Africa continues to suffer from food insecurity (Phiri and Modi, 2005). According to FAO (2004), the supply of food especially grains in developing countries will have to rise by around 70 percent by the year 2020 if the 6.5 billion people who are expected to be living there are going to be food secure. Nearly all of this increase in food supply is expected to come from developing countries themselves. Meeting this projected increase will require both a sustained rise in yield of the major grains and legumes and reduction in crop losses due to pests. The need to produce staple crops for a growing population and to grow cash crops to integrate in the monetary system has forced many households to replace an ecologically stable system by a more intensive system that heavily relies upon external inputs.

The supply of adequate and right foodstuffs is becoming a big problem in the developing countries. One of the agriculture's challenges in the developing countries such as Kenya is the production of high quality protein in sufficient amounts to meet the human demands, at prices affordable by the majority of the population. This is based on the fact that animal protein sources are either scarce or too expensive so much that emphasis on improvement of grain legumes is a major priority (Buruchara, 1979). Increase in the production of grain legumes therefore would offer a partial solution to the shortage of world food supply (Bogere, 1980). For this reason, there has been increasing research effort to improve seed quality and yielding capacity of grain legumes such as common bean, pigeon pea, cowpea, soya bean, lima bean, lablab, chickpea and green gram.

Shenoi (1990) estimated that over 85% of the value added in agriculture would come from Kenya's small-scale farmers. The author noted that the small-scale farmers cultivates 66% of the total cropped area but obtain yields that are about half of those obtained by large-scale farmers. The author's conclusion like that of Republic of Kenya Development Plan (1989-1993) was that small scale farmers will play an important role in the economy owing to their potential of increasing yields, their numerical numbers and the fact that they occupy a large portion of the medium and high potential areas.

1.2 History and geographical distribution of grain legumes

The grain legumes were domesticated early in history of the plant domestication in India and Africa where agriculture originated (Willey, 1975) and now form a major component of tropical agricultural cropping systems. Several species are cultivated as monocrops or are intercrops with the cereals. The grain legumes are widely distributed probably because of their unique capacity to fix nitrogen (Willey, 1975). Some species have become more popular than others in various regions of the world due to their nutritional values. In Africa, the grain legumes namely *Phaseolus* spp, *Dolichos* spp, *Vigna* spp and *Cajanus* spp are in general more popular than the others (Willey, 1975).

1.3 Production of grain legumes in Kenya.

The major grain legumes in Kenya are grown mainly in Eastern, Central and Nyanza provinces with Eastern province contributing about 50% of the total area under legumes (Mugo, 1998). The common grain legumes grown and consumed in Kenya are common bean (*Phaseolus vulgaris*, L.), cowpea (*Vigna unguiculata* (L.) Walp.), pigeon pea (*Cajanus cajan* (L.) Millsp.), field pea (*Pisum sativum* L.), groundnut (*Arachis hypogea* L.), green gram (*Vigna radiata* L.), black gram (*Vigna mungo* (L.) Hepper), lima bean (*Phaseolus lunatus* L.), and hyacinth bean (*Lablab purpureus* L.) (Olubayo and Khamala, 1979). The areas under the legumes vary among provinces in relation to respective agricultural practices, climatic variation, other environmental factors, traditions and cultures (Olubayo and Khamala, 1979). The production trend of grain legumes (pulses) in Kenya is as shown in Table 1 (FAOSTAT, 2006). The highest production was observed in 2002 and 2003 followed by a drastic drop in production in 2004. No major increases in production were made in 2005 and the trend may continue in this manner if nothing is done to curb problems that have led to the drop in the production of pulses in Kenya.

Table 1: Average yields and total production of pulses in Kenya.

Year	Average yield (Kg/ha)	Total production (Mt)
1995	434.9	724, 293
1996	352.0	368,493
1997	324.0	347,370
1998	350.5	379,397
1999	471.5	575,424
2000	415.5	478,308
2001	388.6	482,126
2002	517.7	671,477
2003	462.0	607,303
2004	362.9	439,775
2005	385.3	463,250

Source:FAOSTAT (2006)

1.4 Constraints in the production of grain legumes in Kenya

The common production constraints encountered in most grain legumes include narrow range of genetic diversity, low yielding potential and susceptibility to pests (Mbatia and Kimani, 1987; Nderitu *et al*., 1997; Ostyula *et al*., 1998). Consequently, dry seed yields are usually low (Olubayo and Khamala, 1979). Poor seed quality in addition to fluctuating producer prices due to unidentified marketing structure compound these problems (Njeru, 1989; Allen *et al* 1990; Nderitu *et al*., 1997; Mulandi 1998)

1.5 Problem statement and justification of the study

Grain legumes are of great importance in their role in the diets of the inhabitants of Africa due to their comparative high protein content, ease of handling, transportation and storage (Allotey and Oyewo, 2004). In Kenya, grain legumes constitute next to maize the most important group of crops in the diets of its inhabitants. However, according to FAO database (2006), the production of grain legumes in Kenya has shown a steady decline since the year 2002. Plant pests and declining soil fertility are among the major factors limiting grain legume yields (Murdock, 2001; Chemining'wa *et al.,* 2004; Rabie and Almadini, 2005).

The efficacy of various control strategies like chemical method on grain legume plants would be deemed essential to investigate. To provide a sound basis for research priorities and help farmers decide when to apply control measures, there is an urgent need to better quantify yield losses by these stresses (Wortman, 1992; Wortman and Allen, 1994)
Among the major nutrients, requirements for nitrogen exceed any other and rarely do soils in the tropics have enough of this nutrient to produce high sustainable yields (Wrigley, 1982). It is, therefore necessary to restore soil nitrogen by maintaining a high

level of organic matter in the soil. However, the slow rate of organic matter mineralization raises the need for soil to be supplemented with inorganic nitrogen fertilizers (Wrigley, 1982). As a result cheaper sources of plant nutrients need to be sought if yields are to be sustained and food security attained.

There are several options available to manage pests and nutrients in farmers fields with chemical pesticides and fertilizers often considered to be an immediate answer to current pest problems(Murdock, 2001) and nutrient deficiencies in soils(Chemining'wa *et al.*, 2004). Unfortunately, chemical pesticides and fertilizers are expensive and out of reach of most small scale farmers in Kenya. Fertilizer use in most counties in sub-Saharan Africa is best described as a disequilibrium state (Desai and Stone, 1987) where supply side constraints are often more important than the demand factors (Heisey and Mwangi, 1996). Moreover, there are concerns over environmental pollution and human health risks associated with the handling, continuous use and high application of these chemicals.

The findings of this work will provide a basis for a better understanding of the effect of chemical pesticide application and nitrogen source on the performance of food grain legumes leading to a sound decision-making in pest and nutrient management in the production of the grain legumes. This would help increase grain legume seed yield thereby contributing towards household and national food security. On policy matters, the information obtained in this work could be used to advice the government and other agricultural stakeholders on better pest and nutrient management on grain legume production.

1.6 Study objectives

1.6.1 Broad objectives

This study was conducted broad objective to assess the effect of chemical pesticide treatment and nitrogen source on the performance of food grain legumes.

1.6.2 Specific objectives

i) To assess the effect of chemical pesticide spray on field insect pests, foliar fungal diseases and yield of selected food grain legumes.

ii) To assess the effect of rhizobia inoculation, nitrogen fertilizer and manure application on growth, nodulation and yield of selected food grain legumes.

iii) To assess the effect of rhizobia seed inoculation and fungicide seed treatment on fungal root rots, nodulation and dry matter accumulation of selected grain legumes.

CHAPTER TWO

GENERAL LITERATURE REVIEW

2.1 Taxonomy of grain legumes.

Grain legumes consist of a very heterogeneous assemblage of crops, most of which are grown for the seed, which is rich in protein, sufficiently rich to be a meat substitute, although there are important forage crops also. (Hill and Walker, 1991). In the plant kingdom, grain legumes belong to the class *Dicotyledonae*, sub-class *Rosidae*, order *Fabales* and family *Leguminosae*. (Nwokolo, J. 1996). Among flowering plants, the *Leguminosae* is the third largest (after *Compositae* and *Orchidaceae*). The *Leguminosae* has an estimated 16000-19000 species in 750 genera (Allen and Allen, 1981) although fewer than 100 of these are currently being used for food production (Burton, 1979). These cultivated species are chiefly within the sub-family *Papilionoideae* which consist of predominantly the nodulating species with the ability to work symbiotically with rhizobia to fix atmospheric nitrogen (Burton, 1979).

2.2 Importance of grain legumes

2.2.1 Improving soil fertility

A major constraint to smallholder farming in Kenya is declining soil fertility (Chemining'wa *et al.*, 2004). The high population pressure on land has led to continuous cultivation and mining of soil nutrient reserves often without adequate replenishment (Ojiem *et al.*, 2000). The increased pressure on the land has necessitated intensification of land use (Gichangi *et al.*, 2002). Borlaug (1981), stated that the ability of the legumes to fix nitrogen in the soil-crop ecosystem is one of their unique and beneficial characteristics among all plant species. Amount of nitrogen fixed in the soil equals amount of nitrogen input from commercial fertilizers.

Essentially all agriculturally important legume species have the ability to symbiose with rhizobia. In this symbiosis, the bacteria derive energy from the host for growth and nitrogen fixation, and are protected from external stresses; the host accesses a form of nitrogen it could not otherwise utilize. Worldwide some 44 to 66 million tones of nitrogen are fixed annually, providing nearly half of all the nitrogen used in agriculture (Giller, 2001). The amount of nitrogen fixed by legumes varies with species and may supply a major part or the entire nitrogen needed by a crop (Chui *et al.*, 2003).

The quantity of nitrogen needed for agriculture is projected to increase in the period to 2030 (Tillman, 1999), and could lead to grater environmental pollution. Reduced dependence on fertilizer N and attention to farming practices that favour the more economically viable and environmentally prudent nitrogen fixation will benefit both agriculture and the environment (Giller, 2001). Exploiting the full potential of legume-rhizobium symbiosis has a special relevance to the developing countries because of the fact that effective legume-rhizobium symbiosis could reduce dependence on costly nitrogen fertilizers and enhance food and fodder production (Burton, 1979)

According to Obara *et al.* (2000), a promising strategy in nutrient replenishment is a low cost approach based upon localized soil fertility restoration in the affected area, through returns of organic matter, enhance biological nitrogen fixation and direct application of rock phosphate. The general principle is the application of the slowly available rock phosphate sufficient for several cropping seasons with readily available nitrogenous fertilizers and to intercrop with a legume that provides residual fixed-nitrogen and organic inputs to the soil.

Legumes can also play a major role in improving farm productivity in smallholder agriculture as short-term fallow species (Hudgens, 2000). Their quick growth and fruiting patterns are complementary advantages in complex peasant farming systems. Fujita *et al.* (1992), Sanginga *et al.* (1994), and Hudgens (1996), argued that symbiotically fixed nitrogen has been considered as a useful source of nitrogen to non-fixing plants in intercropping systems. Legumes are routinely used in the tropics as green manure and cover crops and are often rotated or mixed with other crops

2.2.2 Food security

Grain legumes occupy an important place in the global food requirements. They form a major source of proteins of high biological value, energy, minerals and vitamins for many people especially in Tropical Africa where main diets consist of mostly starchy staples and minimal animal protein (Taylor, 1997). The protein content of edible species of legumes with exceptions of soybean and groundnut varies between 18 and 32 percent (Willey, 1975) as compared to the commonly consumed maize with only 9 percent protein content. In addition, grain legumes provide a non-processed, storable and transportable protein food concentration suitable for both rural and urban utilization (Willey, 1975).

FAO (1959) asserted the importance of grain legumes or pulse crops in human nutrition when it stated that the crop was becoming increasingly appreciated in tropical and sub-tropical countries where the diet was generally deficient in protein. The consumption of grain legume range from insignificant amounts in Europe and North America to fairly large quantities in Asia, South America and Africa. In several countries in East and Central Africa, food legumes mainly beans and peas are a daily component of the diet.

For instance, it has been estimated that the average daily consumption of legumes ranges from about 65 grams in Kenya to nearly 75 grams in Uganda (Protein Advisory Group (PAG) (1973).

Grain legumes constitute next to maize the most important group of food crops in the diets of people in Kenya (Schoenherr and Mbugua, 1976). Excellent reviews by Bressani (1975), Walker (1982), Martin *et al.* (1975) and Sgabieri (1989) indicate the effects of legumes in human diet. Walker (1982) observes that legumes are variable source of protein calcium, iron, thiamine and riboflavin. Omanga (1997), indicated that common beans, cowpea, green grams, lablab and pigeon peas are mainly grown for food to supplement cereal based diets which are deficient in proteins.

2.2.3 Livestock feed

A major problem facing livestock producers in tropical areas is proper nutrition for their animals during dry season when pastures, cereal residues and maize stover are limiting in nutritional quality. One way of improving the utilization of such crop residues is by proper supplementation with leguminous forages (Poppi and McLennan, 1995). In recent years, the use of forage legumes in livestock production systems for ruminants in the tropics has increased. Forage legume offer several advantages to tropical farming systems. They can be grazed, harvested and fed fresh or stored as hay or silage (Harricharan *et al.*, 1988) .A sustainable way of improving the feeding value of poor quality crop residues and pastures, especially for resource poor smallholders is through supplementation with forages.

2.3 Insect pests of grain legumes and their importance

Bohlen (1973) made an extensive survey of crop pests of Tanzania and reported 44 insect species associated with grain legumes. In their survey, Hill and Walker (1991) reported a total of 50 insect pest species attacking grain legumes in the world. Of these species, 16 species; one each in the orders *Coreidae, Miridae, Thripidae, Noctuidae, Agromyzidae, Anthomycidae, Coccinellidae*, two each in the orders *Aphididae, Pyralidae, Bruchidae* and three in the order *Meloidae* were considered as serious insects pests of grain legumes. Others of minor importance included one each in the following orders: *Aphididae, Cicadellidae, Tettigometridae, Coccidae, Pseudococcidae, Coreidae, Miridae, Pentatomidae, Thripidae, Arctidae, Noctuidae, Tortricidae, Springidae, Agromyzidae, Coccinelidae, Chrysomelidae, Ceratycidae, Apionidae, Curculiomidae.*

ICRISAT (1988/89) survey showed that although infestation was very low in 1988/89, *Helicoverpa armigera* was the dominant pest of chickpea at ICRISAT center and at all other locations surveyed in Asia. The pod borer, *Helicoverpa armigera* was again the dominant insect pest on chickpea in the 1987/1988 post rainy season at the ICRISAT center and at all locations where chickpea selections were grown unprotected.In Kenya Khaemba(1980) indicated that *Maruca testulalis* (Geyer) was a major pest in the hot humid areas of Coast and Nyanza province while the African bollworm which is known to attack flowers and pods was the dominant species in semi-arid regions of eastern, north eastern and high rainfall areas of central Rift Valley and Western provinces.

In the field it is common to find more than three insect pest species on the same plant, with pest infestation overlapping in their incidence and damage. Insect pests that feed on the reproductive plant parts and harvested grains are reported to cause the most economic damage and often necessitate control (Jackai and Adalla, 1997; Murdock *et al*, 1997;

Karungi *et al.*, 2000). These pests include pod borers (Lepidopterans), pod suckers (Hemipterans), pod flies (Melanogromyza chalcosoma Spencer) and bruchids. Lohr(1996) reported losses of French bean of 40-60 percent of pods in pre-sorting at the farm and another 20 percent at the collection points due to thrips. Nderitu *et al.* (1991) reported a loss of 60 percent due to the pest.

Hill and Walker (1991) described a number of ways by which insect pests cause damage and economic loss on grain legumes. These include insect pests feeding on plant parts (leaves, roots, stems, pods, flowers, flower buds and seeds), transmission of disease pathogens by the insect pests and introduction of toxic saliva on crops. The aphid pest cause wilting and stunting of the young plants and in some cases they transmit virus diseases, which are often, more damaging than all pests together. The plants usually tolerate leaf eating by caterpillars and beetles, as is leaf mining (Hill and Walker, 1991). But pod boring is more serious as the seeds are eaten. Previous workers found that leaf and stem feeding pests constituted the largest group among insects attacking cultivated grain legumes in tropical Africa. However, evidence show that effects of leaf and stem feeding insect pests can be compensated during the vegetative plant growth (Walker, 1991) as compared to flower, pod and seed feeders.

2.4 Diseases of grain legumes and their importance

Hill and Walker (1991) identified the following diseases as major on grain legumes: charcoal root rot or ashy stem blight (*Macrophomina phaseolica*), anthracnose (*Colletotrichum lindemuthianum*), cercospora leaf spot (*Cercospora carescens, Cercospora (Mycosphaerella) cruenta*, rust (*Uromyces appendicuatus*, *Uromyces ciceris-arietinin, U. dolicholi*), chickpea blight (*Ascochyta rabiei)*. Others include *Ascochyta* *phaseolorum*, *Ascochyta pisi* (pod and leaf spot), angular leaf spot (*Phaeoisariopsis griseola*), halo blight (*Pseudomonas syringae pv. phaseolicola*), bean common mosaic virus, wilts (*Fusarium oxysporum* f. sp *ciceris*), scab (*Elsinoe phaseoli*), cowpea scab (*Cladosporum vignae)*, target spot *(Corynespora casiicola*), septoria leaf spot (*Septoria vignae*), mycorothecium leaf spot (*Myrotheciona romidum* and *M. leucortrichum*), powdery mildew (*Erysiphe polygoni* and *Leveillula taurica*) flowery leaf spot (*Mycovellosiella phaseoli)* (=Ramularia phaseoli), black spot (leaf smut) (*Protomycopsis phaseoli = Entyloma vignae*).

Fusarium yellows caused by *Fusarium oxysporum* f.sp *phaseoli* occur in the roots and hypocotyls usually at wound sites. The disease has been reported from several African countries including Kenya and Central America (Abawi *et al*, 1990). Root rot caused by *Rhizoctonia solani* results in seed rot, damping off, stem canker, root and pod rot .The disease has been reported from several countries including Kenya and Central America. (Anderson, 1982). *Pythium* root rot caused by various species of *Pythium* has also been reported in several countries in Africa and Latin America. In Kenya the disease has been reported from Western province (Muriungi, 1997).

Southern blight caused by *Sclerotium rolfsii* has been reported from Kenya, Uganda, Malawi and many others. (Punja, 1989). Black root rot caused by *Macrophomina phaseolina* has also been reported in several African countries including Kenya and Central America. (Dhingra and Similar, 1978). Texas root rot (*Aphanomyces* root rot) commonly occurs in Africa and Central America. In Kenya, a survey in Eastern and Central provinces on 26 roadside chickpea fields 7-10 km in the two provinces was done for disease incidence by ICRISAT. Diseases recorded were dry rot (*Rhizoctonia.*

bataticola) (15%), wilt (*Fusarium oxysporum.* f. sp *ciceri)* (12%), collar rot (*Sclerotinium. rolfsii*) (10%) and stunt (6%) (ICRISAT, 1988).

Grain legume diseases cause stunting of crops, contamination of produce and reduced yields through infection of plant parts (Hill and Walker, 1991). Damping- off and root rot caused by *Rhizoctonia solani* and species of *Pythium* and *Phytophthora* are major problem in greenhouse production, causing poor stands stunting growth (Wheeler and Rush, 2001) resulting in mortality or lower quality of the propagated plant material (Chase, 1992; Daugdtrey *et al.*, 1995; Wheeler and Rush 2001). Fungicide drenches can be used to improve seedling emergence and reduce root rot severity (Stephens and Stebbins, 1985; Wheeler and Rush, 2001), however some fungicide treatments have a deleterious effects on rooting (Powell, 1988).

2.5 Management of insect pests and diseases in grain legumes

Pest management is the development and use of procedures to manage the ecosystem in the field in such a way that the pest population does not reach the economic injury level or threshold. This is based on the notion that a plant could stand some attack by pests without significant loss of production. Various pest control measures have been developed and recommended. (Bhatnagar *et al.*, 1981; Hill, 1983) and these include cultural, chemical, biological, pest resistance, and genetic and integrated pest management. In order to apply any of these methods, a good knowledge of the biology and ecology of the pest is essential. Fenemore (1984) gave a brief description of the various pest management strategies as follows.

Cultural control involves manipulation of cultural practices to the pests or disease pathogen's disadvantage by such means as method and time of cultivation, modification of sowing dates and manipulation of irrigation practices. Biological control involves the use of predators and parasites to control pest species Plant resistance involves the use of species or varieties of plants that can grow and produce despite the presence of the pest. Quarantine involves restrictions on the international movement of pests and diseases. Mechanical control includes killing or trapping pests by mechanical means or use of barriers to prevent pests from gaining access to plants, stored produce or other materials. Chemical control principally involves use of chemicals that are toxic to pests and diseases. Integrated pest management is a sustainable approach to managing pests by combining biological, cultural, physical and chemical tools in a way that minimizes economic, health and environmental risks.

The wide range of different pests and diseases affecting grain legumes makes an overall strategy difficult to formulate. (Hill and Walker, 1991). To be economical, control measures against both insect pests and plant diseases must cost less than the value of the increase in crop yield that the control measure produce. Therefore the potential benefit from controlling insect pests and diseases of grain legumes must depend on the magnitude of the losses caused by the absence of control and the efficiency of the control measure. Economic damage begin to occur when monetary requirements for suppressing pest injury is equal to the potential monetary loss from a pest population (Pedigo, 1999).

Pesticides are chemicals or natural substances used to control all kinds of pests in plants, animals and material. Pesticides are a necessary tool to provide high crop yields ensuring enough food supply for mankind and high quality food products (Smet *et al.*, 2005).

2.6 Role of nitrogen in plants

The most recognized role of nitrogen (N) in the plant is its presence in the structure of the protein molecule (Devlin and Witham, 1986). It is found in important molecules such as purines and pyrimidines in nucleic acids DNA and RNA (di-oxyribo and ribo-nucleic acids, respectively) essential for protein-synthesis. It is also present in porphyrins found in such metabolically vital compounds such as chlorophyll pigments and cytochromes essential in photosynthesis, respiration and in co-enzymes that are essential for the function of many enzymes (Devlin and Witham, 1986; Tisdale *et al.*, 1990). It is also essential for carbohydrate use. Within plants, N stimulates roots and growth and development as well as the uptake of other nutrients (Brady, 1990). Nutrient uptake enhancement effect is due to excretion of bicarbonate icons (HCO_3^-) by the plants in exchange for nitrate (NO_3^-), thus producing favourable conditions for cation uptake (Lewis, 1986). In view of such synergism, a plant exhibiting N deficiency may not be lacking in N per se, but it may also be indicative of a low supply of essential cations.

An adequate supply of N is associated with vigorous vegetative growth and dark green colour. An imbalance of N or an excess of this nutrient in relation of other nutrients such as phosphorous (P), potassium (K), and sulphur (S) can prolong the growth period and delay crop maturity. Oversupply of N leads to sappy growth, resulting in plants with weak stems (Forbes and Watson, 1992). Plants become more susceptible to diseases and insect pests because they rot easily when they lodge. Deficiency of N causes chlorosis due to chlorophyll loss (Salisbury and Ross, 1990). This appears last in younger leaves because of the high mobility of N in the plant. Under severe conditions of deficiency, the lower-most leaves on plants such as tobacco and bean are yellow, dry and in most cases will abscise (Devlin and Witham, 1986). When this happens, nourishment of the younger leaves by the lower leaves ceases, their growth is impaired and dry matter production decreased.

In legumes, N in soil and plants influences N fixation. Nitrogen fixation requires enormous amount of carbon (C) as energy source and, therefore costly to the plant (Paul and Clark, 1989). A plant requires 1.7 to 3.5g C/g of N fixed as compared to 0.3 to 0.4g C required to assimilate 1g of ammonia. The contribution of N fixation to total N per plant is increased by moderate levels of N but declines at higher levels (Marchener, 1990). This enhancing effect of low levels on N is related to the lag phase between *Rhizobium* infection and onset of N fixation. Nitrogen shortage during the lag phase is detrimental to the formation of a source leaf area that is sufficiently large to supply the photosynthates needed for nodule growth and activity. The plant N requirement may not be met during early vegetative and later productive phases by N_2-fixation (Amos *et al.*, 2001). At these critical times, mineral N becomes the most important source of N for grain legumes.

2.6.1 Factors affecting nitrogen availability

Physiological, chemical and physical factors that influence uptake of nutrients from the soil directly bears on their availability to plants. Nitrogen occurs in soils in several forms such as amino group (NH_2) bound in organic molecules, ammonium (NH_4^+) irons which can occur as exchangeable cations, nitrates (NO_3^-) and nitrite (NO_2) anions (Forbes and Watson, 1992). Plants mainly take up N from the soil (Katayama *et al.*, 1999). There is a strong positive correlation between uptake of fertilizer derived N and soil derived N following application of fertilizer-N. Most plants utilize the NO_3^- form of N (Devlin and Witham, 1986; Gathungu *et al.*, 2000). Where N is applied as NH_4^+, it has to be oxidized to NO_2^- and NO_3^- for optimal absorption, without which the rate of absorption from the soil is low.

Uptake of nutrient elements in form by roots is an active physiological process. Roots, therefore, require continuous energy supply in order to sustain the NO_3^- uptake system. Uptake of NH_4^+ has a wide diurnal variation that can be disturbed by providing continuous light or by supplying glucose to the nutrient media during darkness (Haynes, 1986) thus, decline in NH_4^- uptake in darkness may be attributed to depletion of carbohydrates reserves (energy supply) in roots in the absence of photosynthesis.

Soil pH affects N availability by influencing nitrification process (Tisdale *et al.*, 1990). The range of soil reaction over which nitrification takes place has generally been given as pH 5.5 to about 10.0 with the optimum being pH 8.5. It is known that nitrates are produced in some soils with a pH value of 4.5. Nitrification has been reported in a pasture soil with a pH value of 3.8 (Tisdale *et al.*, 1990). Low levels of nitrates have also been detected in acid forest soils, particularly after treatment with N sources such as urea which temporally raises soil pH. This maximizes availability of NO_3^- form of N.

Moisture supply affects availability via its influences on mobility (Tisdale *et al.*, 1990; Forbes and Watson, 1992). Under conditions of excessive precipitation or irrigation, N is leached out of the upper soil horizons. This is due to the negative charge of the ion, which prevents it from being retained by most soils whose particles also posses negative charges. Excess water as found in waterlogged soils suppresses nitrification because of lack of oxygen (Lewis, 1986); this is responsible for loss of N from fertilized soils. In dry soils, however, there is no enough moisture for bacterial metabolism. Moistening of such soils rapidly increases the biosynthesis of NO_3^- (Lewis, 1986). During extremely dry weather and when capillary movement of water is possible, there occurs upward movement of N with the upward movement of water (Tisdale *et al.*, 1990)

Temperature affects the rate of release from organic matter (Tisdale *et al.*, 1990). The Q_{10} of N mineralization is two-fold over the ranges 5°C to 35°C increase in temperature. Within this temperature range, mineralization doubles for every 10°C increase in temperature. Time of application influences availability of N. Plant needs for nutrients is to the same throughout the growth period and, therefore, supply of N not coinciding with the plant needs may lead to sub-optimal utilization by the crop (Meelu *et al.*, 1987). Therefore there is no defined time of N application.

2.6.2 Effects of nitrogen on growth and yield of grain legumes

Based on site specificity of climatic factors and edaphic environment, effects of N fertilizers on legumes have received mixed reactions from scientists. Some studies report no effects on growth and yield while others indicate significant responses to the fertilizers. Under similar growing conditions, differences in responses to fertilizer-N vary within and between plant species. Srivatava and Verma (1984) reported significant response of field pea (*Pisum sativum* L. var. arvense) to inoculation of seed with *Rhizobium* culture in terms of number of pods, grain yield and protein percentage in grain. Application of 20kg N ha^{-1} also favourably influenced all the yield and quality traits. It is possible that response to fertilizer N is probable.

In pigeon pea, split application of N at sowing and at flowing resulted in highest seed yield and seed crude protein content (Jagadele *et al.*, 1985). Saimbhi and Randhawa

(1986) evaluated the effects of different N levels on two pea cultivars "Punjab 87" and "Punjab 88" grown for processing. In "Punjab 88" maximum yield was obtained with 75 kg ha^{-1}, which was significantly higher than other N Levels. Levels of N up to 50 kg ha $^{-1}$ significantly increases pod yield and yields of shelled and dehydrated peas over the control in "Punjab 87" Differences between the two highest N Levels were not significant. It was therefore apparent that increasing fertilizer level beyond the optimum increases the cost of production without significant increase in yields.

Gunawardena *et al.* (1997, working with different cultivars of pea observed significant differences in shoot growth among cultivars but not between N levels. Nitrogen application did not affect root dry matter at any stage for any of the cultivars. Nitrogen partitioning between shoots and roots was unaffected by either cultivars or N application during the growing period. Grain legumes such as peas, beans and soybeans are known to have rates of N fixation and often depend on soil N for 50% of their N requirements (Brady, 1990; Paul and Clark, 1989).

2.7 Biological nitrogen sources

Biological materials may offer a solution in alleviating soil fertility problems and hence increase in crop production. The use of farm-derived sources such as crop residues, compost, manures, household wastes, has commonly been used by farmers in the management of soil fertility (Kimani *et al.*, 1998). Animal manure and compost are beneficial in soils because they can increase the water holding capacity and cation exchange capacity (Nandwa, 1995). They are important sources of N for crop production.

The exclusive use of organic inputs as external nutrient sources has been advocated as a logical alternative to expensive fertilizers in Africa (Reinjitjes *et al.*, 1992). In addition, in countries where nitrogen fertilizers are imported and the technology for manufacturing them is limited or too expensive to afford, a greater demand is being made on alternative and inexpensive sources of nitrogen (Mwangi, 1994). Some African countries such as Rwanda, Malawi, Egypt and Zimbabwe have turned to efficient exploitation of biological nitrogen fixation (BNF) by legumes in their farming systems in an attempt to cut down on fertilizer expenses (Mwangi, 1994).

Inoculation with an effective and persistent *Rhizobium* strain has numerous advantages, which include non-repeated application of nitrogen fertilizers (Saginga *et al.*, 1994). Several researchers have reported beneficial effects of rhizobia inoculation. Black (1968) suggested that higher grain yield in food legumes inoculated with *Rhizobium* was due to an increase in nodulation. Khachani (1981) and Million (1989) reported an increase pod yield due to inoculation of French bean plants.

2.8 Chemical seed treatment

Root and hypocotyls rot of bean caused by *Rhizoctonia solani* and *Fusarium solani* f. sp *phaseoli* was suppressed significantly before preplant incorporation of dinoseb at the rate of 6-7 kg/ha as indicated by disease severity decrease and yield increases. Other treatments using dinoseb at 10.1 kg/ha and at the lower rate in combination with trifuralin were also effective (Ndeye *et al.*, 2003). Chemical seed treatment with metaxyl + chloroneb increased plant stand and weight in snap beans diseases caused by Pythium and *Rhizoctonia solani* (Lewis *et al.* 1983). Seed treatment with fungicides such as Thiram, Benomyl and captafol has been found to be effective in control of fusarium root rot of beans (Papavizas *et al.*, 1977).

2.8.1 Fungicide-rhizobia interaction

Fungicides are usually used in agriculture in order to protect seeds from diseases caused by fungi. The main known fungicides are however toxic to rhizobia (Diatloff, 1970; Hofer, 1958). In most cases the rhizobia remain viable but are not able to nodulate the host plants or their ability to fix nitrogen is reduced (Fisher, 1976; Staphorst and Strijdom, 1976). Hashen *et al.* (1997) indicated differences in compatibility with fungicides between peanuts (*Arachis hypogea*) and *Bradyrhizobium* inoculants. Considerable tolerance among species and strains of rhizobia to different fungicides has been reported by Tesfai and Mallick (1986).

Studies on the compatibility of rhizobial strains with fungicides are controversial. Application of captan, PCNB (Curley and Burton, 1975), and apron (Rivellin *et al.*, 1993) on soybean (*Glycine max*) seeds reduced the viability of *Bragyrhizobium japonicum* by 18, 75 and 61 percent, respectively, after 1-hour exposure. Graham et al (1980) observed that less than 10 percent of *Rhizobium phaseoli* strains survived on thiram treated seeds of common bean. By contrast no detrimental effect was found on the compatibility with *Rhizobium japonicum* applied to soybean seeds (Diatloff, 1986) or with *Rhizobium.meliloti* on alfalfa seeds (Edmisten *et al.*, 1988).

2.9 Interaction between rhizobia and other microbes

The agriculturally important symbiotic microorganisms play a remarkable role in nutrient acquisition for plants. In pursuit of that goal, various workers (Cairney, 2000; Alkaraki *et al.*, 2001; Rabie *et al.*, 2005) have used arbascular mycorhiza (AM) fungi and N-fixing bacteria as single inoculants and in combination which each other in various plants, regardless of the presence or absence of the anthropogenic stresses. The application of bioinoculants like AM fungi and one of the plant growth-promoting rhizobacteria is an environment friendly, energy efficient and economically viable approach for increasing biomass production.The beneficial effects of *Rhizobium* in combination with AM fungi have been reported by a number of workers(Tain *et al.*, 2002;Domonech *et al.*, 2005; Rabie and Almadini, 2005). On the other hand, other reports stated that the presence of AM fungi is known to enhance nodulation and N-fixation by legumes (Johansson *et al.*, 2004). However, the interaction between rhizobia and pathogenic fungi is not well known.

CHAPTER THREE

EFFECT OF CHEMICAL PESTICIDE SPRAY ON INSECT PESTS, FOLIAR FUNGAL DISEASES AND YIELD OF FOOD GRAIN LEGUMES

3.1 Introduction

Pests and diseases play a determining role in plant productivity (Rao *et al*., 2000; Schroth *et al*., 2000). A great percentage of people in the developing countries are engaged in agriculture, but the yields of their produce are low due to diseases (Adejumo, 2005; Okori *et al*., 2004) and insect pests (Huis, 1989; Kumar, 1991) that plague their crops. Due to their comparative high protein contents, ease of handling, transportation and storage, grain legumes are of great importance in the diet of the people of African. However, grain legumes are subject to attack by many groups of biodeteriorative agents of which insect pests and diseases are the most important (Allotey and Oyewo, 2004).

High crop yields can be achieved with sustainable agriculture if plants are protected from diseases and insect pests (Cook, 1986). This will make plants to grow well, take up nutrients, compete with weeds and yield to the limit of their environment. Most small-scale farmers do not adequately control insect pests and diseases because of the high cost of chemicals and labour (Opole *et al*., 2005) According to Adejumo (2005), small-scale farmers require crop protection measures that are affordable, simple to use, cost-effective and sustainable.

The use of fungicides (Cook, 1986) and insecticides (Adejumo, 2005) is generally most reliable and popular with farmers because of their quick, effective action. However, this is a short-term solution. In Kenya and elsewhere in the world the tendency has been to rely heavily on chemicals for control of diseases and insect pests (Allen, 1982). Various chemicals have been evaluated and reported to be effective against major crop diseases and insect pests. Mukakunsi *et al.* (1998) reported that insecticide sprays like Dimethoate and cypermethrine increased groundnut yield considerably.

Although the use of chemicals as a control measure is advisable, various problems have arisen. Other than the prohibitive costs of pesticides, high applications have dangerous effect on the environment and on human health. In addition, evaluation of pesticides in relation to their efficacy and economic viability is not exhaustive in most crops in Kenya, particularly the grain legumes. The study was conducted to evaluate effect of chemical pesticide spray on the incidence of insect pests, foliar fungal diseases and yield of selected food grain legumes.

3.2 Materials and methods

3.2.1 Experimental site.

The experiments were carried out at the Field Station Farm of Kabete campus, Faculty of Agriculture, University of Nairobi. This site lies at an altitude of 1940 m above sea level and lies at latitudes 1^0 14' 20'' to 1^0 15' 15'' South and longitudes 36^0 44' to 36^0 45' East. The mean monthly maximum temperature is 23^oC while the mean minimum temperature is 12^oC. The area has a bimodal rainfall pattern, with peaks in April and November. The annual rainfall is slightly above 1000 mm. The soils in Kabete have been taxonomically described as humic nitosols peleustuist (Jaetzold and Schmidt, 1982). They are deep friable kaolinitic clay types formed *in situ* from the tertiary trachytic lava (Siderius, 1976).

3.2.2 Land preparation, planting and crop management.

Land preparation and plot marking for planting were done in late February and late September when the weather was dry for long and short rains respectively. This ensured that the land was ready for planting when rains started in mid March and late October 2005 respectively. Tractors were used for both ploughing and harrowing thus providing a fine seed bed. The seeds were obtained from KARI Katumani. During planting, each hill carried 2-3 seeds. Seedlings were thinned to one plant per hill at three weeks after emergence. The land was irrigated immediately after planting and thereafter periodically whenever necessary during the short rains. This was done to supplement for the low and erratic rainfall observed during the short rains. To ensure good crop stand, weeding commenced two weeks after emergence. This was manually conducted twice in each season.

3.2.3 Experimental design and treatments.

The experimental design was a randomized complete block design in a split plot structure replicated four-times. The pesticide treatment formed the main plots with the grain legumes making the subplots. Each plot measured 3 x 2 m with a 1 m alley between the plots and blocks to minimize interplot interference. Pesticide treatment consisted of a calendar spray of a mixture of dimethoate 40% emulsifiable concentrate at a rate of 0.7 L/ha for the control of a broad spectrum of grain legume insect pests and copper oxychloride, a preventive fungicide applied at a rate of 2 kg/ha for the control of a broad spectrum foliar fungal diseases and a control plot, which received no pesticide treatment. The pesticides were tanked mixed and sprayed beginning two weeks after emergence (WAE). Spraying was done in early morning when it was cool and not windy to avoid pesticide drift. The selected grain legumes were common bean (*Phaseolus* vulgaris L.var

GLP 2), lima bean (*Phaseolus lunatus* L.), green gram (*Vigna radiata* L.), lablab (*Lablab purpureus* L.) and chickpea (*Cicer arietinum*). Nitrogen, phosphorous and potassium (N_{23}:P_{23}:K_0) fertilizer was applied at the rate of 200 kg/ha and mixed thoroughly with the soil to avoid direct contact with the seeds. The legumes were planted at a spacing of 30 x 15 cm, 30 x 10 cm, 45 x 35 cm, 45 x 35 cm and 75 x 45 cm for GLP 2, green gram, lima bean, chickpea and lablab, respectively.

3.2.4 Insect pests' population assessment

The population of three of the major field insects of grain legumes was used to assess the effect of pesticide treatment on the insect pests attacking grain legumes in the field. These were flower thrips (*Megalurothrips sjosdetji* Trybom), African bollworm (*Helicorverpa armigera* Hubner) and legume pod borer (*Maruca testulalis* Geyer) (Hill and Walker, 1991). Mainly physical search and picking by hand of specimen facilitated with fine forceps and brushes was used to collect the insect pests.

Assessment of the insect pests was done from commencement of flowering. Five plants from each test plot were randomly sampled and tagged for weekly *in situ* observation. The tagged plants were closely observed for flower thrips, African bollworms and legume pod borer attack. Two flower buds or flowers were picked from each of the tugged plants for observation in the laboratory depending on the stage of growth of the crop. The flowers were washed twice in 50 per cent ethyl alcohol before and after dissection of flowers to ensure maximum insect recovery. Counts of all the flower thrips, and legume pod borers present were made under a binocular microscope. The pods were dissected under the dissecting stereomicroscope. Observation on flower thrips and legume pod borers was terminated when the first pods began to dry out. Assessment of the population of African bollworms was however done by the direct count method on the tagged plants from commencement of flowering till pod maturity. At each sampling the total insect population was divided by the total number of flower buds, flowers or plants assessed to obtain the average number of each pest per flower bud, flower or plant

3.2.5 Pathogen isolation and identification

Diseased plants of samples collected were examined under a dissecting and a compound microscope to establish the extend of damage. Small leaf sections with early stages of infection were sliced from diseased areas and washed under running tap water for 15-30 seconds then surface- sterilized with 10% sodium hypochlorite for 2-5 minutes. The working area was kept clean and disinfected by wiping with 70% ethyl alcohol before each isolation or culture transfer. Knives, needles, forceps and other metal tools to be used was sterilized by dipping in 70% ethyl alcohol for a few seconds and flamed. Potato dextrose agar (PDA) medium was prepared and sterilized at 121°C.

Streptomycin at the rate of 0.4 mg/L was added to the cooled medium at 45°C to suppress bacterial growth. The streptomycin was then thoroughly mixed by shaking before pouring medium into 9 cm petri dishes. Those sections of surface sterilized tissues were plated in potato dextrose agar (PDA) plates prepared earlier. Four plates were made for each sample. The plates were then incubated at 27°C for 5 days. Thereafter, the pure cultures were prepared. Identification was done based on cultural and morphological characteristics of pure cultures of the isolates. Visual and microscopic examination was done to determine the genus.

The visual and microscopic examination was done on the one week old pure cultures of the isolates grown on potato dextrose agar (PDA). Visual examination on mycelial colour, growth form, smell and other visible characters was done as a preliminary identification. Microscopic slides of the specimens were prepared from each isolate and stained with cotton blue in lactophenol and water and observed under a compound microscope.

3.2.6 Disease assessment

The tagged plants used to assess insect pests' incidence were also used to assess the incidence of selected fungal diseases. The disease incidence assessment of the selected foliar fungal diseases started at four weeks after crop emergence. The disease incidence was recorded as the number of diseased plants expressed as a percent of total plants by counting the number of plants infected by a particular disease for each test plot. Disease severity was measured as the portion of the leaves showing the characteristic symptoms for a particular disease expressed as a percent of the total leaf area. Thereafter, disease severity was rated by a scale based on he descriptive key diagrams appropriate for each disease.

3.2.7 Assessment of yield and yield components

Number of pods per plant, percent number of borer-damaged pods, seeds per pod, percent seed damage, 100 seed weight, total seed yield and percent marketable yield were determined. At pod maturity ten plants not used for the insect pest and disease assessment were randomly selected from each test plot and tagged for yield and yield components assessment. These plants were labeled for harvesting to be carefully carried out, since not all the pods ever matured at the same time. The pods were harvested and placed into labeled paper bags each corresponding to a specific tagged plant in a given plot and taken to the laboratory. The contents of each bag were emptied in a tray and the number of pods counted and recorded for each plant. The pods were counted for each harvest until the final harvest and expressed as average number of pods per plant. The borer-damaged pods were separated from the undamaged pods and expressed as a percent of the total number of pods per plant. This was repeated until all the pods from the tagged plants were dry and harvested.

The harvested pods from the sampled plants were shelled and seeds counted for each plant. The average number of seeds per plant was then divided by the average number of pods per plant by that particular plant and expressed as the average number of seeds per pod. During pod splitting, the borer damaged, discoloured and shriveled seeds were separated from the healthy seeds and expressed as a percent of total seeds per pod. The final grain yield was determined by weighing all the seeds from the sampled plants and converting the yield in kilograms per hectare. To determine 100 seed weight one hundred seeds were randomly sampled from the shelled seeds from each test-plot and their weights measured and recorded. Three random samples were taken for each test plot. The marketable yield was obtained by taking the weight of the clean undamaged seeds for each legume species and expressed as a percent of the total grain yield.

3.2.8 Determination of economic profitability

The cost of pesticide application is presented in Appendix 4a and 4b. The cost benefit analysis was used to calculate the profitability (Marginal Returns) of the treatment following procedures outlined by Alghali (1992) as:

$$\text{MR} = \frac{\text{Value of yield gain from pesticide treatment}}{\text{Cost of pesticide treatment}}$$

Grain legume free market prices at the time of the experiment were obtained from the Market Research and Information Department of the Ministry of Agriculture, Nairobi. Marginal return value greater than one was considered as profitable.

3.2.9 Data analysis

Pests and yield data were subjected to analysis of variance (ANOVA) using the PROC ANOVA procedure of Genstat (Lawes Agricultural Trust Rothamsted Experimental Station, 1998, version 8) and differences among the treatment means compared using Fisher's Protected LSD test at 5% probability level.

3.3 Results

3.3.1 Effect of insecticide spray on the population of insect pests

Spraying regime, legume species and their interaction on number of flower thrips (*Megalurothrips sjosdetji* Trybom) per flower was significant ($P<0.05$) in both seasons (Table 2). Spraying significantly reduced the number of flower thrips per flower in all the tested legume species. Averaged across legume species, sprayed plots recorded significantly lower number of flower thrips per flower relative to the unsprayed checks (control). The highest number of flower thrips per flower was recorded in GLP 2 followed by lablab and green gram in that order. Chickpea and lima bean had the lowest but statistically similar number of flower thrips per flower. Generally, higher populations of flower thrips were recorded during the short rains than the long rains.

Number of African bollworms (*Helicorverpa armigera* Hubner) per plant responded significantly ($P<0.05$) to the interaction between spraying and legume species (Table 3) such that spraying significantly reduced the number of African bollworm per plant in all the legume species tested in both seasons except for lima bean during the short rains. Spraying regime significantly influenced number of African bollworms per plant. Sprayed plot had significantly lower number of African bollworms per plant relative to the unsprayed plot. Number of African bollworms per plant was also significantly different among the legume species. During long rains, chickpea had the highest number of African bollworm per plant followed by lablab and GLP 2 in that order. However, GLP 2 and green gram were statistically similar in number of African bollworms per plant. The lowest number of African bollworms per plant was recorded in lima bean. Similar observations were made during the short rains except that green gram had higher number of African bollworm per plant than lima bean.

The interaction between spraying and legume species on number of legume pod borers per flower was significant (P<0.05) in both seasons (Table 4). Spraying significantly reduced the number of legume pod borer per flower in all the legume species except lima bean. Number of legume pod borers per flower was significantly affected by the spraying regime whereby sprayed plot had higher number of legume pod borers per flower relative to the control. The number of legume pod borers per flower also varied significantly among the legume species. During long rain season, lablab had the highest number of legume pod borers per flower followed by chickpea, GLP 2, green gram and lima bean in that order. In contrast, during short rains, green gram had significantly higher number of legume pod borers than GLP 2.

Table 2: Mean number of legume flower thrips per flower on grain legume species with and without insecticide spray during the long and short rains of 2005.

Legume species	Long rains			Short rains		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	1.6	0.6	1.1	3.7	1.4	2.6
Lablab	3.8	1.9	2.9	5.9	2.5	4.2
GLP 2	4.9	2.6	3.8	7.0	3.4	5.2
Green gram	2.2	1.2	1.7	4.4	2.1	3.2
Lima bean	1.8	0.8	1.3	3.8	1.3	2.6
Means	2.8	1.4		5.0	2.1	
$LSD_{0.05}$						
Spraying		0.1			0.1	
Legume		0.2			0.2	
Spaying x Legume		0.3			0.3	
C.V (%)		9.9			6.1	

Where WAE is weeks after emergence

Table 3: Mean number of African bollworms per plant on grain legume species with and without insecticide spray during the long and short rains of 2005

Legume species	Long rains			Short rains		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	1.7	0.8	1.3	3.2	1.7	2.5
Lablab	1.0	0.4	0.7	1.8	1.0	1.4
GLP 2	0.7	0.3	0.5	0.8	0.4	0.6
Green gram	0.6	0.2	0.4	0.9	0.6	0.8
Lima bean	0.4	0.1	0.3	0.5	0.2	0.4
Means	0.9	0.4		1.4	0.8	
$LSD_{0.05}$						
Spraying		0.1			0.1	
Legume		0.1			0.3	
Spraying x Legume		0.2			0.3	
C.V (%)		20.7			23.7	

Where WAE is weeks after emergence

Table 4: Mean number of legume pod borers per plant on grain legume species with and without insecticide spray during the long and short rains of 2005

Legume species	Long rains			Short rains		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	0.6	0.3	0.5	0.9	0.4	0.7
Lablab	0.7	0.4	0.6	1.1	0.6	0.9
GLP 2	0.4	0.3	0.4	0.5	0.2	0.4
Green gram	0.4	0.1	0.3	0.7	0.4	0.6
Lima bean	0.2	0.1	0.2	0.3	0.1	0.2
Means	0.5	0.2		0.7	0.3	
$LSD_{0.05}$						
Spraying		0.1			0.2	
Legume		0.1			0.1	
Spraying x Legume		0.1			0.2	
C.V (%)		16.3			22.7	

Where WAE is weeks after emergence

3.3.2 Effect of fungicide spray on the incidence of foliar fungal diseases

Generally, it was noted that disease incidence recorded increased with time in most species. Spraying regimes, legume species and their interaction effect on leaf blight incidence was significant ($P<0.05$) in both seasons and at all the stages the disease incidence was recorded. Spraying significantly reduced the incidence of leaf blight in all the legume species at all the stages the disease incidence was recorded (Table 5 and 6). In both seasons, sprayed plot showed lower leaf blight incidence relative to the unsprayed plot. During the long rains, at 4 WAE, green gram showed significantly higher leaf blight incidence followed by GLP 2, lablab, chickpea and lima bean. However, leaf blight incidence on chickpea and lima bean were not significantly different. At 6 WAE, green gram showed the highest leaf blight incidence followed by GLP 2 with lima bean having the lowest leaf blight incidence. Chickpea and lablab were not significantly different in leaf blight incidence.

Similar observations were recorded during the short rains with a few exceptions. At 4 WAE, GLP 2 had the highest leaf blight incidence followed by green gram, lablab, lima bean and chickpea in that order. At 6 WAE, green gram had the highest leaf blight incidence followed by chickpea, GLP 2, lablab and lima bean in that order. However, leaf blight incidence in chickpea and GLP 2 were not significantly different.

In both seasons, the effect of spraying regime, legume species and their interaction on leaf rust incidence was significant (P<0.05). Spraying significantly reduced leaf rust incidence in all the legume species and at all the stages the disease was recorded except for lima bean at 4 WAE during the long rain seasons (Table 7 and 8). Averaged across the legume species, sprayed plot had significantly lower leaf rust incidence relative to the unsprayed plot at all the weeks the disease incidence was recorded.

During the long rains at 4 WAE, GLP 2 had the highest leaf rust incidence whereas lima bean showed the lowest leaf rust incidence. However, lablab and green gram were not significantly different in leaf rust incidence so were lima bean and chickpea. At 6 WAE, GLP 2 had the highest leaf rust incidence followed by green gram, lablab, lima bean and chickpea. However, chickpea and lima bean statistically similar in leaf rust incidence. At 8 WAE, GLP 2 had the highest leaf rust incidence but was significantly different only from green gram and lima bean. During the short rains, at 4 WAE, GLP 2 showed the highest leaf rust incidence. Green gram and lima bean were statistically similar in leaf rust incidence. No leaf rust incidence was recorded in chickpea and lablab plants. At 6 WAE, GLP 2 had the highest leaf rust incidence but was significantly different from green gram alone. Chickpea showed the lowest leaf rust incidence. At 8 WAE, chickpea had the highest leaf rust incidence followed by green gram, lablab, lima bean and GLP 2 in that order. However, lablab and green gram were not significantly different with respect to leaf rust incidence.

Powdery mildew incidence was not observed in all the legume species except for green gram and GLP 2 in long rains and green gram alone in the short rains. The interaction between spraying and legume species on powdery mildew incidence was significant ($P<0.05$) in both seasons. Spraying significantly reduced powdery mildew incidence in green gram and GLP 2 (Table 9 and 10). Averaged across legume species, sprayed plot had significantly lower powdery mildew incidence compared to the unsprayed plot. At all the stages the disease incidence was recorded, green gram showed significantly higher powdery mildew incidence than GLP 2.

Table 5: Mean percent leaf blight incidence on grain legume species with and without fungicide spray during the long rains of 2005

Legume species	4 WAE			6 WAE			8 WAE		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	11.6	9.1	10.3	37.8	29.1	33.5	32.7	16.1	24.4
Lablab	18.6	11.5	15.1	38.6	33.7	36.1	32.6	16.8	24.7
GLP 2	29.4	18.0	23.7	50.2	34.0	42.1	40.2	17.0	28.6
Green gram	35.1	24.0	29.5	65.5	43.8	54.6	42.6	18.0	30.3
Lima bean	9.1	7.3	8.2	19.4	14.0	16.7	25.7	17.0	21.3
Means	20.8	14.0		42.3	30.9		34.7	17.0	
$LSD_{0.05}$									
Spraying		2.3			6.1			3.5	
Legume		2.3			4.8			3.4	
S X L		3.3			7.3			4.8	
C.V (%)		12.9			12.7			6.0	

Table 6: Mean percent leaf blight incidence on grain legume species with and without fungicide spray during the short rains of 2005

Legume species	4 WAE			6 WAE			8 WAE		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	3.5	0.0	1.8	13.5	6.3	9.9	27.3	14.3	20.8
Lablab	7.0	0.0	3.5	10.8	6.3	8.5	26.8	16.3	21.5
GLP 2	8.0	3.5	5.8	13.8	5.5	9.6	26.3	17.3	21.8
Green gram	7.3	2.8	5.0	15.0	9.3	12.1	31.3	14.3	22.8
Lima bean	4.5	0.0	2.3	8.8	2.5	5.6	25.3	14.3	19.8
Means	6.1	1.3		12.4	6.0		27.4	15.3	
LSD0.05									
Spraying		0.5			0.8			1.0	
Legume		0.7			0.7			1.0	
S X L		0.9			1.0			1.4	
C.V (%)		18.9			6.9			4.5	

Table 7: Mean percent leaf rust incidence on grain legume species with and without fungicide spray during the long rains of 2005

Legume species	4 WAE			6 WAE			8 WAE		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	15.4	10.1	12.8	24.9	13.1	19.0	33.4	17.8	25.6
Lablab	20.4	13.6	17.0	28.3	18.2	23.3	35.7	17.7	26.7
GLP 2	39.8	26.7	33.2	51.9	23.9	37.9	37.7	17.8	27.7
Green gram	24.7	13.6	19.2	40.6	23.0	31.8	25.4	17.4	21.4
Lima bean	15.1	12.1	13.6	25.0	13.4	19.2	25.4	12.0	18.7
Means	23.1	15.3		34.1	18.3		31.5	16.5	
LSD0.05									
Spraying		2.6			1.3			3.5	
Legume		3.2			3.5			3.4	
S X L		4.3			4.5			4.8	
C.V (%)		16.0			12.8			6.0	

Table 8: Mean percent leaf rust incidence on grain legume species with and without fungicide spray during the short rains of 2005

Legume species	4 WAE			6 WAE			8 WAE		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	0.0	0.0	0.0	5.0	2.5	3.8	43.3	18.5	31.0
Lablab	0.0	0.0	0.0	5.5	3.5	4.5	16.5	11.5	14.0
GLP 2	4.5	0.0	2.3	10.5	5.0	7.8	14.5	7.5	11.0
Green gram	2.5	0.0	1.3	9.5	5.5	7.5	17.5	11.5	14.5
Lima bean	2.5	0.0	1.3	8.5	5.0	6.8	14.5	10.5	12.5
Means	1.9	0.0		7.8	4.3		21.3	11.9	
LSD0.05									
Spraying		1.2			0.3			0.2	
Legume		0.5			0.5			0.2	
S X L		1.1			0.7			0.2	
C.V (%)		22.6			8.3			10.0	

Table 9: Mean percent powdery mildew incidence on grain legume species with and without fungicide spray during the long rains of 2005

Legume species	6 WAE			8 WAE		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	0.0	0.0	0.0	0.0	0.0	0.0
Lablab	0.0	0.0	0.0	0.0	0.0	0.0
GLP 2	10.5	6.3	8.4	15.6	6.9	11.2
Green gram	28.6	10.3	19.5	76.4	15.0	50.7
Lima bean	0.0	0.0	0.0	0.0	0.0	0.0
Means	7.8	3.3		18.4	6.4	
LSD0.05						
Spraying		2.0			1.8	
Legume		1.5			2.4	
S X L		2.4			3.2	
C.V (%)		26.5			18.6	

Table 10: Mean percent powdery mildew incidence on grain legume species with and without fungicide spray during the short rains of 2005

Legume species	Unsprayed	Sprayed	Means
Chickpea	0.0	0.0	0.0
Lablab	0.0	0.0	0.0
GLP 2	0.0	0.0	0.0
Green gram	83.0	45.3	64.1
Lima bean	0.0	0.0	0.0
Means	16.6	9.1	
$LSD_{0.05}$			
Spraying		2.3	
Legume		3.0	
Spraying x Legume		4.1	
C.V (%)		22.5	

3.3.3 Effect of pesticide spray on yield and yield components grain legumes

3.3.3.1 Pod yield

Significant (P<0.05) effect of spraying regime, legume species and their interaction on number of pods per plant of the legume species was observed. Spraying significantly increased number of pods per plant only in chickpea and lablab (Table 11). The highest number of pods per plant was recorded in sprayed chickpea and lablab plants during the long rains and short rains respectively. Overall, sprayed plot had significantly higher number of pods per plant relative to the unsprayed plot. During long rains, chickpea and lablab had the highest but statistically similar number of pods per. Green gram and GLP 2 had the lowest but statistically similar number of pods per plant. Similar observations were recorded during the short rains except that lablab had the highest number of pods per plant compared to all the other species.

In both seasons, percent borer- damaged pods responded significantly ($P<0.05$) to the effect of spraying regime, legume species and their interaction. Spraying significantly reduced percent borer-damaged pods in all the tested legume species except for GLP 2 and lima bean during the short rains (Table 12). Averaged across the species, sprayed plot had significantly lower percent borer-damaged pods relative to the unsprayed plot. During the long rains, the highest overall percent borer damaged pods was recorded in chickpea followed by lablab and green gram. Lima bean and GLP 2 had the lowest percent borer-damaged pods compared to the other species. During the short rains, chickpea had the highest percent borer-damaged pods. Lablab, GLP 2 and green gram were not significantly different in percent borer- damaged pods.

Table 11: Mean number of pods per plant of grain legume species with and without pesticide spray during the long and short rains of 2005

Legume species	Long rains			Short rains		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	82.0	139.0	110.5	50.4	79.3	64.9
Lablab	80.6	130.3	105.5	68.6	101.5	85.1
GLP 2	10.2	11.8	11.0	7.0	7.6	7.3
Green gram	5.9	11.2	8.6	4.1	7.6	5.9
Lima bean	19.0	22.7	20.8	16.2	19.4	17.8
Means	39.5	63.0		29.3	43.1	
$LSD_{0.05}$						
Spraying		12.6			7.7	
Legume		10.2			6.1	
Spraying x Legume		15.4			9.3	
C.V (%)		19.4			16.4	

Table 12: Mean percent borer-damaged pods per plant on grain legume species with and without insecticide spray during the long and short rains of 2005

Legume species	Long rains			Short rains		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	39.0	18.3	28.7	52.1	23.9	38.0
Lablab	32.1	15.8	24.0	30.5	20.8	25.6
GLP 2	19.6	14.0	16.8	24.9	20.3	22.6
Green gram	36.5	10.1	23.3	42.6	16.3	29.5
Lima bean	23.1	16.5	19.8	17.5	14.8	16.2
Means	30.1	15.0		33.5	19.2	
$LSD_{0.05}$						
Spraying		2.8			2.0	
Legume		2.2			7.7	
Spraying x Legume		3.4			9.8	
C.V (%)		12.6			9.5	

3.3.3.2 Seed yield

Spraying regime, legume species and their interactive effect on number of seeds per pod was significant ($P<0.05$) Spraying significantly increased number of seeds per pod in green gram alone in both seasons and in lablab during the short rains (Table 13). In general, sprayed plot had significantly higher number of seeds per pod than the unsprayed plot. Among the legume species, green gram had the highest number of seeds per pod followed by GLP 2, lablab, lima bean and chickpea in that order.

In both seasons spraying regime, legume species and their interaction effect on seed damage was significant ($P<0.05$). Spraying significantly reduced percent-discoloured seeds (Table 14), borer damaged seeds (Table 15) and shrivelled seeds (Table 17) in all the legume species except GLP 2 and lima bean. Overall, sprayed plots showed significantly lower seed damage relative to the unsprayed checks. Green gram showed the highest percent discoloured and shrivelled seeds whereas lablab had the highest percent borer damaged seeds. The lowest seed damage was recorded in GLP 2.

Table 13: Mean number of seeds per pod of grain legume species with and without pesticide spray during the long and short rains of 2005

Legume species	Long rains			Short rains		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	1.3	1.7	1.5	1.1	1.4	1.3
Lablab	3.3	3.6	3.5	2.9	3.3	3.1
GLP 2	4.4	4.5	4.5	4.1	4.4	4.3
Green gram	6.7	10.0	8.4	4.2	5.9	5.1
Lima bean	2.7	2.8	2.8	2.4	2.6	2.5
Means	3.7	4.5		3.0	3.50	
$LSD_{0.05}$						
Spraying		0.5			0.2	
Legume		0.5			0.2	
Spraying x Legume		0.7			0.3	
C.V (%)		12.7			6.4	

Table 14: Mean percent discoloured seeds per plant of grain legume species with and without pesticide spray during the long and short rains of 2005

Legume species	Long rains			Short rains		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	18.4	13.0	15.7	18.6	11.9	15.3
Lablab	18.5	11.4	15.0	27.9	12.4	20.2
GLP 2	13.1	9.7	11.4	8.21	6.7	7.5
Green gram	34.2	16.6	25.4	28.6	15.1	21.9
Lima bean	11.3	10.0	10.7	6.5	4.8	5.7
Means	19.1	12.1		18.0	10.2	
$LSD_{0.05}$						
Spraying		2.2			1.0	
Legume		2.6			1.9	
Spraying x Legume		3.6			2.5	
C.V (%)		16.1			13.1	

Table 15: Mean percent borer damaged seeds per plant of grain legume species with and without pesticide spray during the long and short rains of 2005

Legume species	Long rains			Short rains		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	3.8	0.0	1.9	6.9	2.6	4.8
Lablab	13.8	6.5	10.2	16.1	9.3	12.7
GLP 2	6.3	4.0	5.2	3.8	3.1	3.5
Green gram	11.3	6.8	9.1	9.9	7.1	8.5
Lima bean	4.3	1.8	3.1	2.6	2.3	2.5
Means	7.9	3.8		7.9	4.9	
$LSD_{0.05}$						
Spraying		2.2			1.0	
Legume		2.6			1.9	
Spraying x Legume		3.6			2.5	
C.V (%)		16.1			13.1	

Table 16: Mean percent shriveled seeds per pod of grain legume species with and without pesticide spray during the long and short rains of 2005

Legume species	Long rains			Short rains		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	7.8	4.5	6.2	20.9	10.3	15.6
Lablab	11.3	4.8	8.1	20.3	10.3	15.3
GLP 2	10.5	7.3	8.9	7.2	5.7	6.5
Green gram	13.5	5.5	9.5	20.4	11.7	16.1
Lima bean	7.0	5.8	6.4	7.1	6.2	6.7
Means	10.0	5.6		15.2	8.8	
$LSD_{0.05}$						
Spraying		1.5			2.5	
Legume		1.0			1.6	
Spraying x Legume		1.6			2.6	
C.V (%)		11.7			12.5	

3.3.3.3 Grain yield

Spraying regime and its interaction with grain legume species had no significant effect (P>0.05) on the 100 seed weight. However significant differences were observed among the grain legume species in both seasons. All the grain legume species had significantly different 100 seed weight from each other (Table 17). In both seasons, the trend for 100 seed weight was in the order lima bean>common bean >lablab>chickpea>green gram.

Spraying regime, legume species and their interactions significantly (P<0.05) influenced grain yield of the legume species tested. Spraying significantly increased the grain yield of chickpea and lablab by 1413 and 2276 kg in the long rains corresponding to 614 and

761 kg in the short rains respectively (Table 18). No significant effect on the grain yield of the other legumes was recorded. Among the grain legume species, green gram had the lowest grain yield. Chickpea, lablab, GLP 2 and lima bean were statistically similar in grain yield.

During the long rains legume species had no significant effect (P> 0.05) on percent marketable yield of the legume species. However, spraying regime and its interactions with the legume species significantly influenced percent marketable yield of the legume species. Spraying significantly increased percent marketable yield in chickpea, lablab and green gram only (Table 19). During the short rains, the interaction between spraying and legume species on percent marketable yield was not significant. However, spraying regimes and legume species differed significantly in percent marketable yield. Sprayed plot had the highest percent marketable yield relative to the unsprayed plot. Overall, lima bean had the highest percent marketable yield but was significantly different only from lablab.

Table 17: Mean 100 seed weight (g) of grain legume species with and without pesticide spray during the long and short rains of 2005

Legume species	Long rains			Short rains		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	15.6	16.2	15.9	13.3	14.2	13.7
Lablab	27.1	27.7	27.4	24.3	24.9	24.6
GLP 2	37.1	37.5	37.3	34.1	35.0	34.6
Green gram	3.0	3.3	32	2.6	2.8	2.7
Lima bean	44.9	45.4	45.1	36.8	37.6	37.2
Means	25.5	26.0		22.2	23.0	
LSD$_{0.05}$						
Spraying		NS			NS	
Legume		1.70			1.70	
Spraying x Legume		NS			NS	
C.V (%)		11.8			7.3	

Where NS, is not significant at *P*=0.05

Table 18: Mean total grain yield (kg/ha) of grain legume species with and without pesticide spray during the long and short rains of 200

Legume species	Long rains			Short rains		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	1220	2633	1926	534	1148	841
Lablab	1096	3372	2234	1261	2022	1642
GLP 2	2704	2860	2782	1237	1468	1377
Green gram	361	774	568	107	366	286
Lima bean	2548	2925	2737	2061	2378	2219
Means	1586	2513		1040	1476	
$LSD_{0.05}$						
Spraying	504			286		
Legume	769			223		
Spraying x Legume	1010			341		
C.V (%)	36.0			17.2		

Table 19: Mean percent marketable yield of grain legume species with and without pesticide spray during the long and short rains of 2005

Legume species	Long rains			Short rains		
	Unsprayed	Sprayed	Means	Unsprayed	Sprayed	Means
Chickpea	77.2	85.1	81.2	80.0	86.0	83.0
Lablab	78.3	86.3	82.3	72.0	78.9	75.5
GLP 2	79.8	83.4	81.6	77.4	80.2	78.8
Green gram	67.0	86.0	76.5	72.9	84.9	78.9
Lima bean	81.3	81.8	81.6	83.1	83.3	83.2
Means	76.4	84.5			82.7	
$LSD_{0.05}$						
Spraying		2.0			4.0	
Legume		NS			4.8	
Spraying x Legume		6.6			NS	
C.V (%		6.2			5.8	

Where NS is not significant at P=0.05

3.3.3.4 Economic profitability

Marginal returns resulting from pesticide application was greater than 1 for lablab, green gram and chickpea in the long rains (Table 20). GLP 2 and lima bean had their marginal returns less than 1. During the short rains, GLP 2, lima bean and green gram had marginal return values less than 1. Only lablab had marginal value greater than 1 whereas chickpea had marginal value equal to 1. The results for the long rains showed that additional benefits obtained from pesticide application were more than thrice for lablab, about twice for chickpea and marginal for green gram. In contrast, the additional benefits resulting from pesticide application on GLP 2 and lima bean were less than the additional costs involved in applying the pesticides. However, during the short rains, the additional benefits resulting from pesticide spray were less than the additional costs involved for all the legume species except lablab (Table 21). The additional benefits and costs resulting from pesticide spray break-evened for chickpea.

Table 20: Marginal returns resulting from pesticide application on food grain legumes for the short rains

Economic indicator	GLP 2	Lima bean	Green gram	Lablab	Chickpea
Additional marketable yield (kg)	156	377	413	2276	1413
Price/ 90 kg bag (Kshs)	2800	3500	4000	3800	3500
Additional benefits (Kshs)	4850	14660	18360	96090	54950
Additional costs (Kshs)	15450	24720	15450	39160	32980
Marginal returns (MR)	0.3	0.6	1.2	2.5	1.7

Table 21: Marginal returns resulting from pesticide application on food grain legumes for the short rains

Economic indicator	GLP 2	Lima bean	Green gram	Lablab	Chickpea
Additional marketable yield (kg)	231	317	259	761	614
Price/ 90kg (Kshs)	2800	3500	4000	3800	3500
Additional benefits (Kshs)	7180	12330	11510	32130	23900
Additional costs (Kshs)	12360	18540	12360	26800	23710
Marginal returns (MR)	0.6	0.7	0.9	1.2	1.0

3.4 Discussions

3.4.1 Effect of pesticide treatment on insect pests and fungal disease incidences

The extend of insect population and damage in any system is determined by plant species and the interaction between pest and environmental factors (Rao *et al.*, 2000, Kekenou *et al.*, 2006). In the present study it was generally observed that there was a high insect pest incidence during the short rains when the rains were low and temperature high than during long rains when the rains were heavy and temperature low. The reverse was observed in the case of the fungal diseases. Insect pests are known to develop and be active better during moderate to high temperatures. A high moisture regime favours the development of most fungal diseases (Neegard, 1979). Pesticide spray significantly reduced the incidence of major insect pests and diseases assessed. The population of the pod borers was appreciably lowered by the application of Dimethoate 40 % EC. The findings of these studies support those of Smaine (1968), Koehler and Rachie (1971), Okeyo-Owuor (1978), Chabra *et al.* (1980) and Mugo (1998) who reported that Dimethoate reduced pod borer infestation on pigeon pea. The results are in agreement with the findings that were reported by Kimani (1987) and Kimani and Mbatia (1990)

3.4.2 Effect of pesticide treatment on yield and yield components

Pod and seed yield losses caused by the pod borers and pod-sucking bugs is rather devastating. Though little work has been conducted regarding pod loss due to pod borers and other pod feeding insect pests, greater attention has been paid to seed yield losses experienced because of the insect borers in most grain legumes. During this study period, pesticide trials conducted showed that significant differences occurred between damaged pods on treated plots and untreated plots. The difference in pod damage is worth highlighting because damaged pods may not produce seeds or if so the seeds may be of low quality and sometimes may not be viable (Mugo, 1998). Thus, the pesticides used provided a good protection cover against pods infestation by the pod borers paving way for better seed yield.

Seed yield losses caused by various insects pests and diseases have been investigated by several researchers in various parts of the world. Koehler and Rachie (1971) in Uganda reported seed yield loss of 5% due to *Helicoverpa armigera* on pigeon pea. In Kenya, Okeyo-Owuor and Kamala (1980) working on pigeon pea found that seed yield losses due to insect pod borers ranged between 25.8% and 62.7% at Kabete and Katumani respectively. During this study, significantly higher grain yields were recorded in sprayed plots relative to the unsprayed checks. This implies that the incidence of insect pests and foliar fungal diseases attacking the grain legumes was lowered to a manageable level by application of pesticides.

The spraying resulted in effective control of insect pests and foliar fungal diseases. This may have enabled the plants to manufacture and utilize assimilates and allocate them to produce more biomass. High biomass yield is desirable for efficient utilization of water and nutrients. This according to Olupot *et al.* (2004), enables a crop accumulate assimilates that are used for kernel development. A high biomass yield also encourages efficient utilization of light and suppression of weeds (Abulo *et al.*, 2005). All these factors contribute to the final grain yield. Similarly, removal of leaves may result in yield reduction as it depresses the photosynthetic activity (Maposse and Cossa, 2005). Similar work conducted at Kabete by Okeyo-Owuor (1978) revealed that yield losses obtained under different treatments was lower in the Dimethoate treated plots than other treatments including the control.

Averaged across varieties, Kyamanywa (1996) reported that there was 93% loss in grain yield in untreated plots based on cowpea sprayed through out. The pesticides had better results probably because Dimethoate 40% with both contact and systemic properties applied alone had effective impact on all grain legume insect pest complex that lower the seed yield. Similarly, copper fungicide with its protective action protected the legumes from attack by foliar fungal diseases. However, common bean and lima bean did not respond significantly to pesticide spray with respect to pod and seed yield. Green gram did not respond to pesticide spray with respect to total seed yield. This may be due to the high incidence levels of leaf blight and powdery mildew recorded in green gram. KARI (1996) reported that green gram is more susceptible to powdery mildew resulting in high disease incidence and consequently low grain yields. However, benefit-cost analysis showed that pesticide spray on lablab, chickpea and green gram is profitable. Kyamanwa (1996), working with cowpea in Uganda reported that insecticide application was profitable in cowpea production.

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CHAPTER FOUR

EFFECT OF RHIZOBIA INOCULATION, FARM YARD MANURE AND NITROGEN FERTILIZER ON GROWTH, NODULATION AND YIELD OF SELECTED FOOD GRAIN LEGUMES

4.1 Introduction

Declining soil fertility and high fertilizer costs are major limitations to crop production in smallholder farms in Kenya (Maobe *et al*., 2000; Ojiem *et al*., 2000; Cheruiyot *et al.* 2001; Chemining'wa *et al.,* 2004). In Kenya, this has been augmented by intensification of agriculture coupled with the reduction in farm sizes (Saha and Muli, 2000). Among the major nutrients, requirements for nitrogen (N) exceed any other and rarely do soils in the tropics have enough of this nutrient to produce high sustainable yields(Wrigley, 1982; Mkandawire, 1996). This lack of adequate amounts of nitrogen in most soils puts a limitation on the farmers' goals of increasing yield per unit area. The farmers are therefore faced with the challenge of continuously supplying nitrogen to these soils. Rebuilding soil fertility in traditional agricultural systems has been achieved through long-duration fallow periods (Poubom *et al*., 2005). However, with increased human population and land pressure, long fallow periods are no longer feasible (Gichangi *et al*., 2002; Alika *et al*., 2005; Poubom *et al*. 2005).

The quantity of nitrogen needed for agriculture is projected to increase in the period to 2030 (Tillman, 1999) and would lead to greater environmental degradation. Reduced dependence on fertilizer nitrogen and adopting farming practices that favour the more economically viable and environmentally prudent nitrogen fixation will benefit both agriculture and the environment (Vance, 2001). There are several options, which are available to manage nitrogen in farmers' fields with chemical fertilizers often considered to be an immediate answer to current nutrient deficiencies in soils (Chemining'wa *et al.*, 2004; Woomer *et al.*, 1997). Nitrogen requirement of legumes can be met by both mineral N assimilation and symbiotic N_2-fixation (George and Singleton, 1992)

Unfortunately, commercial nitrogen fertilizers are expensive and out of reach of most small-scale farmers in Kenya. Fertilizer use in most counties in sub-Saharan Africa is best described as a disequilibrium state (Desai and Stone, 1987) where supply side constraints are often more important than the demand factors (Heisey and Mwangi, 1996). As a result cheaper sources of nitrogen need to be sought if yields are to be sustained and food security attained.

Improved nitrogen management is needed to optimize economic returns to farmers and minimize environmental concerns associated with nitrogen use (Bundy and Andraski, 2005). This study was therefore conducted to assess the response of food grain legumes to fertilizer nitrogen, farmyard manure and rhizobia inoculation with respect to growth, nodulation and yield.

4.2 Materials and methods

4.2.1 Experimental design and treatments.

The experiment was laid out in a randomized complete block design in a split plot arrangement replicated three-times. The legumes formed the main plots with the nitrogen sources making the subplots each measuring 3 x 2 m with a 1 m alley between the plots and blocks to minimize interplot interference. The selected grain legumes were common bean (*Phaseolus* vulgaris L.cv GLP 2), lima bean (*Phaseolus lunatus* L.), green gram

(*Vigna radiata* L.) and lablab (*Lablab purpureus*). The legumes were supplied with 46 kg/ha of nitrogen, or 8 T/ha of farmyard manure or rhizobia inoculant. A control plot that did receive any of the nitrogen source treatments was also maintained.

Nitrogen was applied as NPK (23:23:0) for the respective plots that required it and mixed thoroughly with the soil to avoid direct contact with the seeds. To minimize the effect of phosphorous, 20kg of phosphorous in the form of TSP (45%P_2O_5) was applied uniformly across plots treated with manure, rhizobia and the controls. Cattle manure was applied at the rate of 8 T/ha and mixed well with the soil. Appropriate amounts of inorganic fertilizer or manure were evenly applied along 2.5-5 cm deep furrows and mixed well with the soil.

The inoculation rate recommended by the inoculant manufacturer (MIRCEN laboratory of the University of Nairobi) was adopted. This was 100 grams of inoculant for 15 kg of seeds already wetted with 290-300 mls of adhesive. The moist seeds were thoroughly mixed with the inoculant in the shade, sown immediately and covered with soil in order to minimize rhizobia exposure to ultra-violet (U.V) light from the sun that kills the bacteria (Mukindia, 1992). Before planting composite soil samples were taken at the two experiments plots, at a depth of 0-30 cm for complete nutrient analysis. Two to three seeds were placed in the furrows at the recommended spacing. The plants were thinned to one plant per hill after emergence. The crops were sprayed with Dimethoate 40 % EC and copper oxychloride WP for the control of insect pests and diseases.

4.2.2 Nodule number and dry matter determination

Three plants were randomly selected from each plot and dug out at 7 weeks after emergence. The plants were separated into shoot and root using secateurs and the roots dipped in bucket of water to soak the soil. The roots with undisturbed nodules were placed in labeled plastic bags, which were then taken to the laboratory. The nodules were picked from the roots and their numbers recorded for each plant. The shoots, roots and nodules, which were in separate paper bags, were oven-dried at $70^{O}C$ for 48 hours for dry weight determination.

4.2.3 Plant height measurement

Three plants were selected at random from each plot and tagged for plant height measurement at the second, fourth and sixth week after emergence using a metre rule.

4.2.4 Determination of yield and yield components

Number of pods per plant, seeds per pod, 100 seed weight, and total grain yield were determined. At pod maturity ten plants were randomly selected from each test plot and tagged for yield and yield components assessment. These plants were labeled for harvesting to be carefully carried out, since not all the pods ever matured at the same time. The pods were harvested and placed into labeled paper bags each corresponding to a specific tagged plant in a given plot and taken to the laboratory. The contents of each bag were emptied in a tray and the number of pods counted and recorded for each plant. The pods were counted. This was repeated until all the pods from the tagged plants were dry and harvested.

The harvested pods from the sampled plants were shelled and seeds counted for each plant. The average number of seeds per plant was then divided by the average number of pods per plant by that particular plant and expressed as the average number of seeds per pod. The final grain yield was determined by weighing all the seeds from the sampled plants and converting the yield in kilograms per hectare. To determine 100 seed weight one hundred seeds were randomly sampled from the shelled seeds from each test-plot and their weights measured and recorded. Three random samples were taken for each test plot.

4.2.5 Data analysis

All the data obtained in the experiment were subjected to analysis of variance (ANOVA) using the PROC ANOVA procedure of Genstat (Lawes Agricultural Trust Rothamsted Experimental Station, 1998, version 8) and differences among the treatment means compared using Fisher's Protected LSD test at 5% probability level.

4.3 Results

4.3.1 Effect of rhizobia inoculation, fertilizer nitrogen and farmyard manure on nodulation

Legume species, N source and their interactions had a significant effect ($P<0.05$) on number of nodules per plant in both seasons. During the long rains, fertilizer application significantly reduced the number of nodules per plant in lablab and GLP2 but had no significant effect on green gram and lima bean nodule numbers relative to the control (Table 22). Manure application had no significant effect on number of nodules per plant in all the legume species tested compared to the control. In contrast, rhizobia inoculation significantly increased number of nodules per plant in lablab and GLP2 but had no significant effect on green gram and lima bean plants. During the short rains, fertilizer application had no effect on number of nodules per plat relative to the control. Manure application and rhizobia inoculation significantly increased the number of nodules per plant in all the legumes species except lima bean.

Number of nodules per plant varied significantly among the legume species. During the long rains, GLP2 had the highest number of nodules per plant though was not significantly different from lablab. The lowest number of nodules per plant was recorded in lima bean. During the short rains, the legume species had a similar influence on number of nodules per plant as for long rains

During the long rains, the interaction between legume species and N source on nodule dry weight was not significant ($P<0.05$). However, significant differences on nodule dry weight per plant were observed among the legumes species and the N sources. Among the N sources, rhizobia inoculation and manure application resulted in the highest nodule dry weight (Table 23). Fertilizer treatment and the control were statistically similar in nodule dry weight. The highest nodule dry weight per plant was recorded in lablab whereas lima bean had the lowest nodule dry weight per plant. GLP2 and green gram were statistically similar in their nodule dry weight per plant.

During the short rains, legume species, N source and their interactions had a significant ($P<0.05$) effect on nodule dry weight per plant. Fertilizer and manure application had no significant effect on number of nodules per plant in all the legumes tested whereas rhizobia inoculation increased nodule dry weight of lablab and GLP2 but not that of green gram and lima bean. Among the legume species lablab had the highest nodule dry weight per plant followed by GLP2, green gram and lima bean in that order. Nodule dry weight recorded for green gram and lima bean were not significantly different.

Table 22: Mean number of nodules per plant of grain legume species under different nitrogen sources during the long and short rains of 2005

Legume Species	Control	Fertilizer	Manure	Rhizobia	Means
			Long rains		
Lablab	8.0	4.3	8.1	11.6	8.0
GLP 2	8.2	5.4	10.1	11.1	8.8
Green gram	3.8	1.4	4.8	5.1	3.8
Lima bean	2.9	1.6	2.8	2.5	2.4
Means	5.7	3.2	6.5	7.6	
			Short rains		
Lablab	7.7	7.5	9.4	11.8	9.1
GLP 2	8.8	8.3	10.0	12.5	9.9
Green gram	4.3	3.8	5.5	5.6	4.8
Lima bean	1.8	2.3	2.1	2.7	2.2
Means	5.6	5.5	6.8	8.2	

$LSD_{0.05}$	Long rains	Short rains
Legume	1.0	0.8
N source	1.4	0.4
Legume x N source	2.6	1.0
C.V (%)	29.7	8

Table 23: Mean nodule dry weight per plant (g) of grain legume species under different nitrogen sources during the long and short rains of 2005

Legume Species	Control	Fertilizer	Manure	Rhizobia	Means
		Long rains			
Lablab	61.1	37.8	62.4	105.6	66.7
GLP 2	25.6	19.9	53.3	68.6	41.8
Green gram	12.2	7.8	38.0	45.8	25.9
Lima bean	13.3	14.3	11.1	17.8	14.1
Means	28.0	19.9	41.2	59.4	
		Short rains			
Lablab	171.1	154.4	189.7	246.6	190.5
GLP 2	68.8	67.0	96.1	114.7	85.8
Green gram	37.8	44.5	48.1	52.0	45.6
Lima bean	18.3	19.0	19.4	20.1	19.2
Means	74.0	70.4	88.3	108.3	

$LSD_{0.05}$	Long rains	Short rains
Legume	20.1	33.9
N source	18.2	11.4
Legume x N source	NS	36.6
C.V (%)	27.1	15.8

Where NS is not significant at *P*=0.05

4.3.2 Effect of rhizobia inoculation, fertilizer nitrogen and farmyard manure on growth

In both seasons, the interaction between legume species and the N-source on plant height was not significant (P>0.05) (Table 24). However, significant differences on plant height were observed among the legume species and the N-sources. Overall, fertilizer application significantly increased the plant height of the legume species relative to the control while manure application and rhizobia inoculation had no effect on this plant attribute. Among the legume species, GLP 2 had the tallest plants during the long rains and was significantly different from the other legume species. Green gram plants were significantly the shortest. However, lima bean plants were statistically similar in height with lablab and green gram. During the short rains, lima bean plants were not significantly different from GLP 2 and lablabs. Green gram plants were significantly the shortest.

The interaction between the legume species and the N source on dry matter was not significant (P>0.05) in both seasons (Table 25). However, significant differences were observed among the legume species in both seasons and the N sources in the long rains. During the long rains, the highest overall shoot dry matter was recorded in plants treated with fertilizer. Manure application and rhizobia inoculation had no effect on shoot dry matter relative to the control. GLP 2 had significantly the highest shoot dry matter followed by green gram. Lima bean shoot dry matter was significantly lower than for green gram but significantly superior to lablab. During the short rains, GLP 2 had the highest shoot dry matter followed by green gram. Lablab and lima bean were not significantly different with respect to shoot dry matter.

Root dry weight was neither significantly (P>0.P05) affected by N source or its interaction with legume species (Table 26). However, the legume species differed significantly in their rot dry weight. Green gram had the lowest root dry weight compared to all other legume species tested. GLP 2, lablab and lima bean did not differ significantly in root dry weight.

Table 24: Mean plant height (cm) of grain legume species under different nitrogen sources during the long and short rains of 2005

Legume Species	Control	Fertilizer	Manure	Rhizobia	Means
		Long rains			
Lablab	39.5	50.3	42.6	45.2	44.2
GLP 2	61.4	71.2	56.1	62.2	62.7
Green gram	25.8	31.3	28.1	30.7	29.0
Lima bean	40.5	43.4	38.4	35.6	39.5
Means	41.8	49.0	41.3	43.2	
		Short rains			
Lablab	30.1	33.2	30.5	30.0	31.7
GLP 2	32.4	31.5	32.0	30.9	31.7
Green gram	22.9	24.0	23.8	23.3	23.5
Lima bean	31.0	33.2	31.7	31.9	32.0
Means	29.1	34.5	29.5	29.1	

$LSD_{0.05}$	Long rains	Short rains
Legume	10.1	2.2
N source	5.3	1.1
Legume x N source	NS	NS
C.V (%)	11.5	3.7

Where NS is not significant at *P*=0.05

Table 25: Mean shoot dry weight (g/m^2) of grain legume species under different nitrogen sources during the long and short rains of 2005

Legume Species	Control	Fertilizer	Manure	Rhizobia	Means
			Long rains		
Lablab	18.0	19.6	17.5	18.1	18.3
GLP 2	138.2	156.5	135.0	141.4	142.8
Green grams	58.7	74.8	62.8	62.2	64.6
Lima bean	30.3	36.8	30.3	33.0	32.6
Means	61.3	71.9	61.4	63.7	
			Short rains		
Lablab	12.4	11.1	12.4	13.6	12.4
GLP 2	93.3	98.0	91.9	97.4	95.2
Green gram	43.3	52.4	50.0	48.9	48.7
Lima bean	21.0	21.1	24.1	24.8	22.7
Means	42.5	45.7	44.6	46.2	

$LSD_{0.05}$	Long rains	Short rains
Legume	5.3	11.8
N source	7.5	NS
Legume x N source	NS	NS
C.V (%)	13.7	13.2

Where NS is not significant at *P*=0.05

Table 26: Mean root dry weight (mg) per plant of grain legume species under different nitrogen sources during the long and short rains of 2005

Legume Species	Control	Fertilizer	Manure	Rhizobia	Means
		Long rains			
Lablab	252.3	313.0	282.0	335.7	295.8
GLP 2	269.0	316.7	314.7	350.7	312.8
Green gram	159.3	177.7	141.0	166.3	161.1
Lima bean	287.7	321.7	222.0	256.3	271.9
Means	242.1	282.2	239.9	289.8	
		Short rains			
Lablab	281.7	273.3	258.3	328.3	285.4
GLP 2	269.0	273.3	263.3	276.7	261.7
Green grams	103.3	122.0	143.3	131.3	125.0
Lima bean	248.3	298.3	268.3	276.7	272.9
Means	216.7	241.8	233.3	263.2	

$LSD_{0.05}$	Long rains	Short rains
Legume	52.7	38.5
N source	NS	NS
Legume x N source	NS	NS
C.V (%)	10.1	8.2

Where NS is not significant at *P*=0.05

4.3.3 Effect of rhizobia inoculation, fertilizer nitrogen and farmyard manure on yield and yield components

The interaction between the legume species and the N source on number of pods per plant of the legume species was not significant (P>0.05) in both seasons. However significant differences were noted among the N sources during the short rains where fertilizer treated plants had significantly higher number of pods per plant relative to the control while manure treated and rhizobia inoculated plants were statistically similar to the control (Table 27). The effect of N source and its interaction with legume species on number of seeds per pod of the legume species were not significant (P>0.05) in both seasons. (Table 28)

The interaction between N source and legume species on a hundred seed weight was not significant (P>0.05) in both seasons and so was the N source. However, significant differences were observed among the grain legume species in both seasons. All the legume species showed significantly different a hundred seed mass between them (Table 29). On average across the seasons the hundred seed weight of the legume species varied in the order lima bean>GLP 2>lablab>green gram.

With respect to grain yield, no significant (P>0.05) interaction between the legume species and the N source was observed in both seasons. However, significant differences between the N-sources on grain yield of the legume species was noted in the short rains but not in the long rains. Overall, manure and fertilizer application resulted in significantly higher grain yield relative to the control (Table 30). However application of fertilizer was significantly superior to manure application in grain yield while rhizobial inoculation had no significant effect on grain yield.

Table 27: Mean number of pods per plant of grain legume species under different nitrogen sources during the long and short rains of 2005

Legume Species	Control	Fertilizer	Manure	Rhizobia	Means
			Long rains		
Lablab	156.0	170.7	159.0	161.0	159.2
GLP 2	9.1	9.9	8.7	9.3	9.2
Green grams	6.6	6.8	7.1	9.9	7.6
Lima bean	37.8	41.8	31.3	35.6	36.6
Means	52.4	57.3	54.3	54.0	
			Short rains		
Lablab	91.1	99.3	94.0	97.0	95.4
GLP 2	7.0	8.9	8.0	8.2	8.0
Green gram	5.6	8.8	9.7	8.8	8.2
Lima bean	13.2	18.8	16.4	17.4	16.5
Means	29.2	33.9	32.0	32.9	

$LSD_{0.05}$	Long rains	Short rains
Legume	21.3	7.1
N source	5.0	3.8
Legume x N source	NS	NS
C.V (%)	20.1	11.1

Where NS is not significant at *P*=0.05

Table 28: Mean number of seeds per pod of grain legume species under different nitrogen sources during the long and short rains of 2005

Legume Species	Control	Fertilizer	Manure	Rhizobia	Means
			Long rains		
Lablab	3.0	3.4	3.0	3.2	3.2
GLP 2	4.0	4.0	4.3	3.8	4.0
Green grams	7.5	8.5	8.8	8.0	8.2
Lima bean	2.9	3.0	2.9	2.9	2.9
Means	4.3	4.7	4.7	4.5	
			Short rains		
Lablab	3.2	3.4	3.3	3.3	3.3
GLP 2	4.5	4.4	4.5	4.5	4.5
Green gram	6.2	6.3	6.3	6.2	6.3
Lima bean	2.5	2.6	2.6	2.5	2.6
Means	4.1	4.2	4.2	4.2	

$LSD_{0.05}$	Long rains	Short rains
Legume	1.8	0.3
N source	NS	NS
Legume x N source	NS	NS
C.V (%)	19.6	3.5

Where NS is not significant at *P*=0.05

Table 29: Mean hundred seed weight of grain legume species under different nitrogen sources during the long and short rains of 2005

Legume Species	Control	Fertilizer	Manure	Rhizobia	Means
			Long rains		
Lablab	29.8	28.4	28.3	28.3	28.7
GLP 2	40.4	40.0	40.0	39.3	39.8
Green grams	3.4	3.7	3.5	3.6	4.1
Lima bean	44.1	46.2	44.6	45.0	45.0
Means	29.4	30.0	29.1	29.0	
			Short rains		
Lablab	25.3	25.3	26.0	25.7	25.6
GLP 2	34.3	36.7	35.3	35.7	35.5
Green gram	2.8	2.8	2.9	2.8	2.8
Lima bean	8.3	39.3	38.3	38.7	38.7
Means	25.2	26.0	25.7	25.7	

$LSD_{0.05}$	Long rains	Short rains
Legume	1.3	1.3
N source	NS	NS
Legume x N source	NS	NS
C.V (%)	2.2	2.5

Where NS is not significant at *P*=0.05

Table 30: Mean total grain yield (kg/ha) of grain legume species under different nitrogen sources during the long and short rains of 2005

Legume Species	Control	Fertilizer	Manure	Rhizobia	Means
			Long rains		
Lablab	2989	3040	2784	306	2944
GLP 2	2430	2723	2628	2650	2608
Green grams	180	157	258	264	215
Lima bean	2856	3047	2904	2645	2863
Means	2089	2242	2144	2155	
			Short rains		
Lablab	1057	1255	1163.	1056	1133
GLP 2	1501	1804	1836	1796	1734
Green gram	274	356	350	365	365
Lima bean	2333	2600	2829	2368	2532
Means	1292	1775	1544	1211	

$LSD_{0.05}$	Long rains	Short rains
Legume	377.1	472.2
N source	NS	207.3
Legume x N source	NS	NS
C.V (%)	8.7	16.5

Where NS is not significant at *P*=0.05

4.4 Discussions

4.4.1 Effect of rhizobia inoculation, fertilizer nitrogen and manure on nodulation

Many studies have been performed to test the effects of nitrogen on root nodulation and nitrogen production in nodules. It is generally accepted that when sufficient levels of nitrogen are present in the soil, nodulation is inhibited (Gentili and Huss-Danell, 2003, 2002; Laws and Graves, 2005). In the present study, fertilizer application significantly reduced number of nodules and nodule dry weight per plant in most species during long rains. Inhibitory effects of added nitrogen fertilizer to nodulation and nitrogen fixation have been reported by other investigators (Taylor *et al.*, 2005, Chemining'wa *et al.*, 2004; Karanja *et al.*, 1997; Floor, 1985; Ssali, 1981). The addition of 20 kg N/ha as ammonium nitrate depressed nodulation and nitrogen fixation in soybean (Dean and Clark, 1980). Results of Peck and Macdonald (1984) showed that French bean plants grown without N-fertilization had many nodules on their root. They also observed that N-fertilization reduced the number of nodules on the roots. Similarly, Chui *et al.* (1985) observed that the application of N fertilizer caused a significant high nodule number degeneration on French beans relative to the uninoculated control. Considering that the soil nitrogen was not limiting, the application of nitrogen fertilizer probably raised the nitrogen in the soil to levels that caused nodule degeneration.

Manure application neither decreased nor improved nodulation of any of the species. However averaged across legume species higher number of nodules was recorded from plants treated with manure relative to the control. This was probably due to the slow mineralization of manure hence slow nitrogen release. Nitrogen is known to impact negatively on nodulation (Laws and Graves, 2005). In addition, the additional phosphorous present in the manure perhaps resulted in the positive effect of manure on nodulation. Phosphorous has been reported to improve nodulation (Floor, 1985).

Rhizobia inoculation increased number of nodules and nodule dry weight per plant for most species but increase in nodulation was neither translated to dry matter accumulation in the shoot and root nor to the yield and yield components. Salez and Saint Macary (1987) found an increase in the number and weight of French bean plant nodules due to inoculation. Results of the present work show that the legumes had nodules that were equally effective even without inoculation. Similar findings from the same site were reported by Chemining'wa *et al.* (2004). They found out that indegeneous rhizobia nodulating grain legume species were present in Kabete soils on sites that had no history of grain legume cultivation. In addition, negligible nodulation was reported in lima bean even with inoculation. Similarly, green gram did not respond to inoculation. This suggests that rhizobia strains that form effective nodules with these species are either absent in the soils tested or the inoculant strain used may not be effective with neither lima bean nor green gram. Previous work has suggested that inoculation does not always enhance nodulation. Observations on cowpea field experiments showed no stimulation on nodulation by inoculation (Rotimi, 1972).

4.4.2 Effect of rhizobia inoculation, fertilizer nitrogen and manure on growth

Based on site specificity of climatic factors and edaphic environment, effects of N fertilizers on legumes have received mixed reactions from scientists. Some studies report no effects on growth while others indicate significant responses to the use of the fertilizers. In the present study, fertilizer application resulted in taller plants compared to those treated with rhizobia or manure. In addition it improved shoot dry matter in the long rains corroborating the fact that adequate supply of N is associated with vigorous vegetative growth (Forbes and Watson, 1992). However, rhizobia inoculation and manure application did not have effect on plant height, shoot and root dry weight. This suggests that either the rhizobia strains used were not effective or there were indegeneus rhizobia starins in the soil in the experimental site that were equally effective. Slow mineralization of manure may have resulted in low nitrogen present to the plants to adequately promote plant growth.

4.4.3 Effect of rhizobia inoculation, fertilizer nitrogen and manure on yield and yield components

The interaction between legumes species and nitrogen sources on number of pods per plant, number of seeds per pod, 100 seed weight and grain yield was not significant. This may be due to the fact that adequate amount of nitrogen was present in the experimental site hence external nitrogen input did not have a significant impact on these yield parameters. Ireri (2001) reported the same from the same site with common bean. However, the legume species and the nitrogen sources differed significantly in these plant attributes. Averaged across legume species, fertilizer treated plants had higher number of pods per plant during the short rains compared to rhizobia , manure and the control. In a field trial, Hedge and Srinivas (1989) found the highest green pod yield of French bean to be from plants supplied with the highest nitrogen rate (120 kg N/ha) indicating the positive effect of fertilizer nitrogen on pod yield of grain legumes. However, sometimes nitrogen fertilization increases only vegetative growth but not seed yield (Karden and Hunt, 1985). As expected, lablab had significantly the highest number of pods per plant compared to the other legumes. Lima bean had significantly higher number of pods per plant compared to GLP 2 and green gram that were statistically similar in number of pods per plant

All the alternative nitrogen sources tested had no effect on number of seeds per pod of the grain legume species. This suggests that the number of seeds per pod is a highly heritable trait and may not be influenced by plant nutrition levels.

Despite the documented variability in seed weight among species, populations, cytotypes, individuals and even within an inflorescence, it has been observed as one of the more stable morphological characteristic of many plant species (Chmielewski and Ruit, 2002). During the present study, all the alternative nitrogen sources tested had no effect on hundred seed weight of the grain legumes. Similar findings were reported by Ireri (2001). However, the seeds produced during the long rains were heavier than those produced during the short rains. This may be because during the long rains the seed filling period was longer than during the short rains.

All the nitrogen sources had no effect on total grain yield except during the short rains when fertilizer and manure treatments resulted in higher yields averaged across the species compared to rhizobia, manure and the control. The favourable response from manure application may be due to the nutrients availed to plants after mineralization or/and due to its influence on soil organic matter (Mukindia, 1992). Organic matter increases the moisture retention of soils and more importantly it improves soil structure and in turn soil porosity. This allows better root growth and hence better nutrient uptake. In addition, applications of readily decomposed organic manure have been shown to improve crop tolerance to root rots (CIAT, 1992; Mutitu *et al.*, 1989) and hence crop yield. The positive response of legumes to manure has also been attributed to; the quantity of manure N Already available for the plants, amount of N that becomes available after mineralization during the season, release and availability of P, K and microelements and improvement in soil structure and permeability (Bochi and Tano, 1994). Manure also contains high amount of organic matter. Organic matter has been reported to increase soil moisture storage and dissolution of nutrients particularly P (Nyende, 2001; Olupot, 2004). Addition of fertilizer or organic manure may affect the root rot pathogens, either directly or indirectly, for instance, through attack of the pathogens by soil microorganisms or competition for some essential substrates (Otsyula *et al*., 1998)

Rhizobia inoculation did not have a significant effect on grain yield. Lack of significant yield improvement by inoculation has also been documented by some researchers (Dunigan *et al*., 1984; Howle *et al*., 1987; Chemining'wa *et al*., 2004). The lack of response due to inoculation is attributed mainly to the presence of native effective strains of rhizobia in the soil (Ham *et al*, 1971), high soil nitrogen (Sparrow and Ham, 1983), cultivar and strain interaction (Caldwell, 1966) in addition to drought that affect symbiosis between host and rhizobia, influencing rhizobial survival in the soil, the host or the process of nodulation (Graham, 1992) hence grain yield. There was drought during the short rains when the species were planted. The resulting moisture stress may have led to the degeneration of the rhizobia.

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CHAPTER FIVE

EFFECT OF FUNGICIDE SEED TREATMENT AND RHIZOBIA INOCULATION ON FUNGAL ROOT ROTS, NODULATION AND DRY MATTER ACCUMULATION OF FOOD GRAIN LEGUMES.

5.1 Introduction

In Kenya, root rot diseases caused by fungi belonging to the genera *Fusarium* have been a major factor limiting bean production. The disease depresses seedling germination, since the causal agents are seed borne (Neegard, 1979; Buruchara, 1985). Farmers in Kenya often use seeds saved from previous harvest (Rono and Shakoor, 1990), a practice that negates the principle of sanitary practices (Buruchara, 1990). Although the root rot problem in Kenya is a serious one, there are few reports of yield loss assessment, diagnosis of the causal agent and research in control measures (Abawi and Pastor, 1990).

On the other hand, effective control strategies against root rot fungal pathogens have not been fully developed (Mutitu *et al.*, 1989). Options available for controlling root rots after planting are very limited and of questionable effectiveness. Thus identity of causal pathogens and other information is essential for formulating control program (Abawi and Pastor, 1990). Proper diagnosis of root rot is essential for developing effective control measures. Sanitation and the use of clean growing media and planting material is the primary way of preventing damping-off and other root diseases. However, it is difficult to prevent contamination of growing media and planting materials especially in large-scale operations (Stephens *et al.*, 1983). Other control measures are often necessary to prevent loss (Mercier, 2005). Microbiologically based fungicides from antagonistic strains of bacteria and fungi have been developed for greenhouse use as products such as SoilGard, Root Shield, Mycostop and Bio Yield (Paulitz and Belanger, 2001). Although promising, biocontrol has limitations as most antagonists will only control a limited spectrum of root rot pathogens (Mercier, 2005).

Chemical seed treatment is a common practice before planting (Kedera, 1988) consequently the extent of seed germination and crop yields is increased (Odeyemi and Alexander, 1977). This is not only because the pesticides help prevent seed and seedling rots, damping off and other fungal diseases (Kedera, 1988) but they also inhibit protozoa preying to the root nodule microsymbionts (Alexander, 1985). Biratu *et al.* (1990), stated that in vitro screening can be used to establish effectiveness of chemicals and to clarify the mode of action of a chemical under *in vitro* conditions. It is accepted that some of the root rot caused by members of *Fusarium* spp can be controlled effectively by use of fungicides (Tu and Zheng, 1993). Although chemical control can minimize legume losses such as in beans (Nevil *et al*., 1990.; Sozzi and Chin, 1990.; Urech, 1990) its efficacy on various legumes has not been evaluated.

On the other hand, inoculation of the seed with appropriate strain of rhizobia ensures introduction of the highest number of bacteria into the soil closest to the roots leading to good nodulation (Alexander, 1985). However, problems arise when the legume inoculants are to be used in conjunction with pesticide treatment of seed before planting (Kedera, 1988). In some cases the applied seed fungicide may fail to protect against the intended pathogen. Kataria *et al.* (1985) found that 2-methoxyethyl-mercury chloride (MEMC) applied to cowpea seeds with *Rhizobium* provided little or no control of seedling rot caused by *Rhizoctonia solani* while a similar treatment but without *Rhizobium* resulted in 40 percent control of the disease. They further showed that the fungicide quintozene was rendered ineffective against *Rhizoctonia solani* by rhizobia. Moreover, it has been found that application of both arbascular mycorrhizal fungi and rhizobacteria are becoming efficient by inhibiting parasitic growth on the plant (Berta *et al.*, 2003). The objective of this study was to investigate the effect of fungicide seed treatment and rhizobia seed inoculation on fungal root rots, nodulation and dry matter accumulation of grain legumes.

5.2 Materials and methods

5.2.1 Pathogen isolation and identification

Root or hypocotyls portions of legume plants showing symptoms of root rot were collected from the University of Naorobi's Field Station, Kabete. One centimeter portions were cut and placed asceptically onto agar medium plates and incubated at room temperature (27°C) for 5 days. Hyphal tip transfer was done onto potato dextrose agar (PDA) and incubated at room temperature (27°C) until the formation of conidia. Identification of the pathogens was done using cultural and morphological characteristics. A small block of each isolate was transferred onto a PDA and incubated at 27°C for 8 days. The resulting cultures were used to determine the nature of aerial mycelial growth produced by the isolates. The nature of nycelial growth was determined by visual observation while pigmentation or the mycelia colour was determined by the help of mycological colour chart (Rayner, 1970). The conidia type and shape were determined from single spore produced from Riddel slide (Riddel, 1950).

5.2.2 Preparation of the inocula

The inocula were prepared for each isolate by growing them on PDA plates for one week at room temperature. Whole cultures were mixed by maceration using a blender to make slurry using sterile distilled water

5.2.3 Experimental design and treatments

The experimental design was a completely randomized design with three replicates. The grain legume seeds used were common bean (*Phaseolus vulgaris* L.var GLP 2), green gram (*Vigna radiata* L.) and lablab (*Lablab purpureus* L. Treatments included, inoculation of legumes with pathogen alone (*Fusarium* spp or *Macrophomina* spp or *Sclerotinia* spp or *Rhizoctonia* spp), or with appropriate rhizobia alone or application of fungicide (copper oxychloride) or their combinations and a control. The experiment was laid out in a completely randomized design replicated thrice. Soil inoculation method was used to inoculate the legume plants. The inoculum slurry (15 ml) of each isolate was mixed into steam-sterilized. Copper oxychloride WP fungicide was admixed with seeds of each of the selected grain legumes, which were slightly wetted and shaken in polythene bags to ensure even coating of the seeds. After drying for a few minutes, the seeds were then sown on the appropriate bags previously prepared and labeled. Enough seeds were prepared for the bags that required fungicide treatment.

Adequate amount of seeds requiring rhizobia inoculation was first surface sterilized for one minute in 10% sodium hypochlorite and washed in two series of sterile distilled water before inoculation. The inoculation rates employed in the microbiological resource centre (MIRCEN) laboratory of the University of Nairobi was adopted. At planting, five seeds for each treatment were directly sown per bag using sterile forceps. All seeds for planting were initially surface sterilized. Each bag had three holes at the base to allow for drainage. The bags were then arranged in a completely randomized design in the greenhouse. Distilled water was added regularly to avoid moisture stress.

5.2.4 Disease, nodulation and dry matter accumulation assessment

Disease was assessed on the basis of percent seedling emergence, seedling mortality and plant dry weight. Percent seedlings emergence was recorded after germination while percent seedling mortality was recorded on the second, fourth and sixth week after emergence. During the termination of the experiment on the sixth week, the potting medium was washed off the roots and the number of nodules counted for each plant. The plant were then separated into roots and shoots and dried in an oven at 70°C for 48 hours for dry weight determination.

5.2.5 Data analysis

The data obtained in all the experiments were subjected to analysis of variance (ANOVA) using the PROC ANOVA procedure of Genstat (Lawes Agricultural Trust Rothamsted Experimental Station, 1998, version 8) and differences among the treatment means compared using Fisher's Protected LSD test at 5% probability level.

5.3 Results

5.3.1Effect of fungicide treatment and rhizobia inoculation disease incidence

The interaction between the treatments and legume species on percent pre-emergence damping-off was not significant ($P<0.05$). However, significant differences were observed among the treatments and legume species. *Rhizoctonia* and *Sclerotinia* pathogens significantly increased pre-emergence damping off of the legume species relative to the control (Table 31). However, *Fusarium* and *Macrophomina* pathogens as well as rhizobia inoculation had no effect on pre-emergence damping-off. Fungicide application significantly reduced pre-emergence damping-off on *Rhizoctonia* and *Sclerotinia* inoculated seeds compared to when the pathogens were applied alone and with rhizobia in the case of *Sclerotinia*. It was also noted that the combination of rhizobia and fungicide combination on significantly reduced pre-emergence damping-off on *Sclerotinia* inoculated seeds relative to *Sclerotinia* alone or *Sclerotinia* plus rhizobia but was statistically similar in effect to *Sclerotinia* plus fungicide. The combination rhizobia and fungicide on *Rhizoctonia* treated seeds also resulted in lower percent pre-emergence damping-off than when the pathogen alone. However, the combination of rhizobia and fungicide had no effect with *Fusarium* and *Macrophomina* pathogens. Green gram showed higher pre-emergence damping-off compared to common bean and lablab

Treatments, legume species and their interaction had a significant ($P<0.05$) effect on the percent post-emergence damping-off. All the pathogens except *Rhizoctonia* had no effect on post emergence damping-off (Table 32). Treatment of the seeds with *Rhizoctonia* significantly increased post-emergence damping-off relative to the control. Rhizobia inoculation on seeds treated with pathogens alone had no effect on post-emergence damping-off compared to pathogen alone except in green gram. In contrast, there was a slight reduction in post-emergence damping-off when rhizobia were inoculated on *Fusarium* treated seeds in GLP 2 and green gram. Fungicide application on *Rhizoctonia* and *Sclerotinia* treated seeds significantly reduced post-emergence damping-off relative to pathogen alone (*Rhizoctonia* and *Sclerotinia*). Fungicide seed treatment had no effect in *Fusarium* and *Macrophomina* treated seeds. Combination of rhizobia and fungicide reduced post emergence damping-off on *Rhizoctonia* treated seeds relative to *Rhizoctonia* alone and its combination with rhizobia in lablab and common bean but only relative to rhizobia-*Rhizoctonia* combination in green gram. Fungicide-rhizobia combination had no effect with *Fusarium, Macrophomina* and *Sclerotinia.*

Table 31: Mean percent pre-emergence damping-off of grain legume species under pathogen, rhizobia and fungicide treatments.

	Legume species			
Treatment	Lablab	GLP 2	Green gram	Means
Control	100.0	100.0	100.0	100.0
Rhizobia	100.0	100.0	100.0	100.0
Rhizobia +Fungicide	100.0	100.0	100.0	100.0
Fungicide	100.0	100.0	100.0	100.0
Fusarium	100.0	100.0	93.3	97.8
Fusarium + Rhizobia	100.0	100.0	93.3	97.8
Fusarium +Fungicide	100.0	100.0	100.0	100.0
Fusarium + Rhizobia +Fungicide	100.0	100.0	100.0	100.0
Macrophomina	100.0	100.0	100.0	100.0
Macrophomina + Rhizobia	100.0	100.0	93.3	97.8
Macrophomina +Fungicide	100.0	100.0	100.0	100.0
Macrophomina + Rhizobia +Fungicide	100.0	100.0	100.0	100.0
Rhizoctonia	86.7	80.0	66.7	77.8
Rhizoctonia + Rhizobia	86.7	86.7	667	80.0
Rhizoctonia +Fungicide	93.3	86.7	80.0	86.7
Rhizoctonia + Rhizobia +Fungicide	93.3	86.7	73.3	84.4
Sclerotinia	93.3	80.0	86.7	85.7
Sclerotinia + Rhizobia	93.3	80.0	86.7	86.7
Sclerotinia +Fungicide	93.3	93.3	93.3	93.3
Sclerotinia + Rhizobia +Fungicide	93.3	93.3	93.3	93.3
Means	96.7	94.3	91.3	

$LSD_{0.05}$

Treatment	7.0
Legume	2.7
Treatment x Legume	NS
C.V (%)	8.0

Table 32: Mean percent post-emergence damping-off of grain legume species under pathogen, rhizobia and fungicide treatments.

	Legume species			
Treatment	Lablab	GLP 2	Green gram	Means
Control	0.0	0.0	0.0	0.0
Rhizobia	0.0	0.0	0.0	0.0
Rhizobia +Fungicide	0.0	0.0	0.0	0.0
Fungicide	0.0	0.0	0.0	0.0
Fusarium	6.7	13.3	8.3	9.4
Fusarium + Rhizobia	6.7	16.7	6.7	10.0
Fusarium + Fungicide	13.3	13.3	6.7	11.1
Fusarium + Rhizobia + Fungicide	6.7	6.7	6.7	6.7
Macrophomina	0.0	13.3	6.7	6.7
Macrophomina + Rhizobia	0.0	13.3	8.3	7.2
Macrophomina + Fungicide	6.7	13.3	8.3	9.4
Macrophomina + Rhizobia + Fungicide	6.7	13.3	13.3	11.1
Rhizoctonia	46.7	36.7	66.7	50.0
Rhizoctonia + Rhizobia	46.7	38.3	100.0	61.2
Rhizoctonia + Fungicide	15.0	15.0	45.1	25.0
Rhizoctonia + Rhizobia + Fungicide	20.0	15.0	62.6	32.5
Sclerotinia	13.3	30.0	25.0	22.8
Sclerotinia + Rhizobia	13.3	30.0	25.0	22.8
Sclerotinia +Fungicide	15.0	15.0	15.0	15.0
Sclerotinia + Rhizobia +Fungicide	15.0	15.0	16.7	15.6
Means	11.6	14.9	21.1	

$LSD_{0.05}$	
Treatment	12.61
Legume	4.88
Treatment x Legume	21.84
C.V (%)	25.2

5.3.2 Effect of fungicide treatment and rhizobia inoculation on nodulation

The interaction between the treatments and the legume species on number of nodules per plant was significant ($P<0.05$). In addition, significant differences were observed among the treatments and the legume species on number of nodules per plant. Rhizobia inoculation and its combination with fungicide and *Fusarium* significantly increased the number of nodules per plant in all the legume species except green gram which showed no effect with all the treatments with respect to the number of nodules per plant (Table 33). However, *Fusarium* and Rhizobia combination had no significant difference with *Fusarium*- rhizobia -fungicide combivation in lablab. Rhizobia inoculation on *Macrophomina* and *Rhizoctonia* inoculated seeds significantly increased the number of nodules per plant in common bean. Similarly, application of fungicide on Rhizobia inoculated seeds significantly reduced the number of nodules per plant on common bean but had no effect on lablab and green gram. In addition, application of fungicide on seeds inoculated with a combination of *Fusarium* and Rhizobia on common bean resulted in significantly lower number of nodules per plant compared to *Fusarium* and Rhizobia combination alone. However *Fusarium*- Rhizobia fungicide combination gave significantly higher number of nodules per plant than when fungicide alone was applied on *Fusarium* inoculated seeds. Similar treatment effect was observed with treatments inoculated with *Macrophomina* in common bean. However, Rhizobia inoculation and application of fungicide on *Macrophomina*, *Rhizoctonia* and *Sclerotinia* inoculated seeds and their combinations had no effect on number of nodules per plant in lablab and green gram. Among the legume species, common bean had significantly the highest number of nodules per plant and was different from all the legume species tested whereas green gram.

The interaction between the treatment and legume species was not significant ($P>0.05$). However, significant differences were observed among the treatment and the legume species. All the pathogens had no effect on nodule dry matter relative to the contro (Table 34). Rhizobia inoculation increased nodule dry matter of the legume species relative to the control when applied on seeds uninoculated with any of the pathogens. Rhizobia inoculation also increased nodule dry matter of *Macrophomina* treated plants but not for *Fusarium*, *Rhizoctonia* and *Sclerotinia*. Fungicide treatment had no effect relative to the control when applied on seeds inoculated or uninoculated with any of the pathogens. Combination of fungicide and rhizobia had no effect on nodule dry matter relative to the control. Also, the combination had no effect on *Fusarium*. *Macrophomina*,*Rhizoctonia* and *Sclerotinia* compared to the pathogens alone.

Table 33: Mean number of nodules per plant of grain legume species at 6WAE under pathogen, rhizobia and fungicide treatments.

	Legume species			
Treatment	Lablab	GLP 2	Green gram	Means
Control	2.6	3.8	0.0	2.1
Rhizobia	8.9	15.8	1.4	8.7
Rhizobia +Fungicide	7.7	12.4	0.0	6.7
Fungicide	2.4	2.8	0.0	1.7
Fusarium	3.0	4.3	0.0	2.4
Fusarium+ Rhizobia	7.7	14.6	0.0	7.5
Fusarium+ Fungicide	4.4	4.6	0.0	3.1
Fusarium+ Rhizobia + Fungicide	6.5	11.0	0.0	5.9
Macrophomina	2.4	3.7	0.0	2.0
Macrophomina + Rhizobia	6.6	15.4	0.0	7.4
Macrophomina + Fungicide	2.5	3.9	0.0	2.1
Macrophomina + Rhizobia + Fungicide	5.6	10.3	0.0	5.1
Rhizoctonia	2.9	3.8	0.0	2.2
Rhizoctonia + Rhizobia	4.7	12.4	1.3	6.1
Rhizoctonia + Fungicide	2.9	2.7	0.0	1.9
Rhizoctonia + Rhizobia + Fungicide	4.8	10.56	0.0	5.1
Sclerotinia	2.1	3.2	0.0	1.7
Sclerotinia + Rhizobia	7.1	10.48	0.0	5.9
Sclerotinia + Fungicide	2.3	3.3	0.0	1.9
Sclerotinia + Rhizobia + Fungicide	6.0	8.73	0.0	4.9
Means	5.2	9.64	0.1	
LSD$_{0.05}$				
Treatment	1.8			
Legume	0.7			
Treatment x Legume	3.1			
C.V (%)	38.2			

Table 34: Mean nodules dry weight (mg) per plant of grain legume species at 6WAE under pathogen, rhizobia and fungicide treatments.

	Legume species			
Treatment	Lablab	GLP 2	Green gram	Means
Control	18.1	12.0	0.0	10.0
Rhizobia	25.4	20.5	3.7	16.6
Rhizobia +Fungicide	19.4	14.6	0.0	11.3
Fungicide	11.5	10.1	0.0	7.2
Fusarium	13.9	13.6	0.0	9.2
Fusarium + Rhizobia	17.3	14.0	0.0	10.5
Fusarium + Fungicide	9.4	5.1	0.0	4.8
Fusarium + Rhizobia + Fungicide	13.4	11.6	0.0	8.3
Macrophomina	5.3	8.9	0.0	4.7
Macrophomina + Rhizobia	22.7	16.9	0.0	13.2
Macrophomina + Fungicide	3.2	8.6	0.0	3.9
Macrophomina + Rhizobia + Fungicide	14.0	13.3	0.0	9.1
Rhizoctonia	8.7	18.3	0.0	9.0
Rhizoctonia + Rhizobia	11.1	26.3	5.6	14.3
Rhizoctonia + Fungicide	11.7	25.7	0.0	12.4
Rhizoctonia + Rhizobia + Fungicide	18.1	16.5	0.0	11.5
Sclerotinia	9.5	10.6	0.0	6.7
Sclerotinia + Rhizobia	18.0	10.2	0.0	9.4
Sclerotinia +Fungicide	7.1	6.0	0.0	4.4
Sclerotinia + Rhizobia +Fungicide	12.6	9.4	0.0	7.3
Means	13.5	13.6	0.5	
$LSD_{0.05}$				
Treatment	6.2			
Legume	2.4			
Treatment x Legume	NS			
C.V (%)	72.1			

5.3.3 Effect of fungicide treatment and rhizobia inoculation on dry matter accumulation

The interaction between treatments and legume species on shoot and root dry matter was not significant. However, significant ($P<0.05$) differences were observed among the treatments and legume species for both shoot and root dry matter. All the pathogens had no effect on shoot dry matter of the legume species (Table 35). Rhizobia inoculation alone significantly increased shoot dry matter but not when applied in conjunction with the pathogens and fungicide. Fungicide alone had no effect on shoot dry matter however its combination with rhizobia improved this plant attribute on *Rhizoctonia* treated pants relative to the control. A combination of rhizobia and fungicide had no effect on shoot dry matter relative to the control but reduced this parameter relative to rhizobia alone and also on *Rhizoctonia* treated seeds compared to *Rhizoctonia* alone.

All the pathogens had no significant effect on root dry matter relative to the control although *Macrophomina, Sclerotinia and Rhizoctonia* treatments tended to result to lower root dry matter (Table 36). *Rhizoctonia* alone resulted in heavier roots although not significantly different from the control. However, rhizobia inoculation on *Rhizoctonia* treated seeds resulted in greater root dry matter compared to when *Rhizoctonia* was inoculated alone. Rhizobia had no effect the other pathogens. Fungicicide application had no effect relative to the control and when applied to pathogen inoculated seeds. Combination of rhizobia and fungicide had no effect compared to the control, rhizobia alone and with all the pathogens.

Table 35: Mean shoot dry weight per plant (g) of grain legume species at 6WAE under pathogen, rhizobia and fungicide treatments.

	Legume species			
Treatment	Lablab	GLP 2	Green gram	Means
Control	1.1	1.1	0.4	0.9
Rhizobia	1.3	1.4	0.7	1.1
Rhizobia +Fungicide	1.0	1.1	0.5	0.9
Fungicide	1.0	1.1	0.4	0.8
Fusarium	0.8	1.1	0.5	0.8
Fusarium + Rhizobia	1.1	1.2	0.4	0.9
Fusarium + Fungicide	1.0	1.2	0.5	0.9
Fusarium + Rhizobia + Fungicide	0.9	1.0	0.5	0.8
Macrophomina	0.8	1.2	0.5	0.8
Macrophomina + Rhizobia	1.1	1.4	0.5	1.0
Macrophomina + Fungicide	0.8	1.4	0.4	0.9
Macrophomina + Rhizobia + Fungicide	0.9	1.3	0.5	0.9
Rhizoctonia	1.1	0.8	0.5	0.8
Rhizoctonia + Rhizobia	0.8	1.5	0.6	1.0
Rhizoctonia + Fungicide	0.9	1.5	0.8	1.0
Rhizoctonia + Rhizobia + Fungicide	1.0	1.7	1.0	1.3
Sclerotinia	0.9	0.8	0.6	0.8
Sclerotinia + Rhizobia	1.2	1.2	0.5	0.9
Sclerotinia + Fungicide	0.9	1.3	0.3	0.8
Sclerotinia + Rhizobia + Fungicide	0.8	1.4	0.5	0.9
Means	1.0	1.2	0.5	

LSD0.05	
Treatment	0.2
Legume	0.1
Treatment x Legume	NS
C.V	26.8

Table 37: Mean root dry weight per plant (mg) of grain legume species at 6WAE under pathogen, rhizobia and fungicide treatments.

	Legume species			
Treatment	Lablab	GLP 2	Green gram	Means
Control	343	514	223	360
Rhizobia	377	867	287	510
Rhizobia +Fungicide	322	803	243	456
Fungicide	323	788	243	452
Fusarium	258	827	44	376
Fusarium + Rhizobia	288	790	187	422
Fusarium + Fungicide	294	603	235	378
Fusarium + Rhizobia + Fungicide	307	678	233	406
Macrophomina	220	478	54	251
Macrophomina + Rhizobia	73	577	127	326
Macrophomina + Fungicide	307	347	123	259
Macrophomina + Rhizobia + Fungicide	342	530	170	347
Rhizoctonia	333	596	42	324
Rhizoctonia + Rhizobia	657	557	306	506
Rhizoctonia + Fungicide	292	487	45	274
Rhizoctonia + Rhizobia + Fungicide	533	523	142	400
Sclerotinia	305	419	57	260
Sclerotinia + Rhizobia	323	470	119	304
Sclerotinia + Fungicide	268	437	138	281
Sclerotinia + Rhizobia + Fungicide	312	580	235	376
Means	334	594	163	

LSD0.05

Treatment	167.0
Legume	64.8
Treatment x Legume	NS
C.V (%)	14.2

5.4 Discussions

5.4.1 Effect of fungicide seed treatment and rhizobia inoculation on disease incidence

Inoculation of the grain legumes with *Rhizoctonia* and *Sclerotinia* pathogens significantly increased percent damping-off of the legume species whereas *Fusarium* and *Macrophomina* had no effect on damping-off. This indicated that of all *Rhizoctonia and Sclerotinia* were more pathogenic of all the pathogens at the conditions provided during the experiment. Similar findings were reported by Wong *et al.* (2003) on soybean. The insignificant effect of *Fusarium* and *Macrophomina* pathogens may be due to the unfavourable prevailing conditions which were characterized by moderate temperature and high moisture content provided through regular watering. According to Allen *et al*., (1996) these particular root rot pathogens thrive well under moisture stress and high temperature conditions. Results obtained by Ratnoo *et al.* (1997), in pot experiments in India on the effect of temperature and moisture on *Macrophomina* blight on cowpea indicated that high temperatures favour *Macrophomina* blight. They also found that disease development was low in flooded soil compared to drier soil. A similar study conducted in Niger by Afouda (1999) showed that when *Macrophomina* inoculated seeds were sown under stress conditions (daily temperature of 33^0C for 13 hours and 23°C for 11 hours and plants watered twice a week) the disease incidence was 92% and seedling mortality was 68%. By contrast, sowing inoculated seeds under apparently normal conditions (daily temperature cycle 28°C for 13 hours and 22°C for 11hours with plants watered regularly resulted in disease incidence of 15% and seedling mortality of only 5%. In the present study, application of fungicide significantly reduced both pre-and-post emergence damping-off on plants inoculated with *Rhizoctonia* and *Sclerotinia* pathogens. Combination of fungicide application and rhizobia inoculation on infected seeds gave results that were statistically similar with respect to pre-and post-emergence damping-off except with

Rhizoctonia inoculated plants.

5.4.2 Effect of fungicide seed treatment and rhizobia inoculation on nodulation

All the pathogens had no effect on both number of nodules per plant and nodule dry matter. Rhizobia inoculation significantly increased number of nodules and nodule dry weight. Application of fungicide significantly reduced number of nodules indicating that the fungicide used had some bactericidal effects on the rhizobia. Heweidy *et al.* (2005), reported that copper oxychloride was the most inhibiting to Bradyrhizobial strains. It however, significantly decreased the infection percentage with *Macrophomina phaseolina, Fusarium oxysporum* and *Sclerotium rolfisii* in comparison with either the control treatment or with the other tested fungicides. Combination of fungicide application and rhizobia inoculation on infected seeds gave results that were statistically similar with respect to number of nodules and nodule dry weight.

5.4.3 Effect of fungicide seed treatment and rhizobia inoculation on dry matter accumulation

Most of the treatments had no effect on shoot and root dry matter. However, rhizobia inoculation and its combination with fungicide on *Rhizoctonia* inoculated seeds improved the shoot dry matter of the legume species relative to the control.

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CHAPTER SIX

GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

The results of this study indicate that pesticides effectively used control insect pests and foliar fungal diseases of grain legumes. The significant interaction effect of legume species and pesticide spray on pest infestation is worth highlighting. Lablab and common bean were more susceptible to flower thrips compared to other legume species. In addition, lablab and chickpea were more susceptible to pod borer attack than the other legume species. ICRISAT (1988 and 1989) reported *Helilicorverpa armigera* Hubner as a major constraint to chickpea production in all chickpea production zones. In contrast, lima bean was less susceptible to both insect pests and foliar fungal diseases. This supports the reports by Wright (1993) and Wright *et al.* (1996) that pests of lima bean are minor with insignificant damage due to a bacterial chocolate spot and to root rot fungi. However, common bean and green gram tend to be more susceptible to foliar fungal diseases as was indicated by the high incidence of leaf blight, leaf rust and powdery mildew on the two species compared to the other legumes. However, the susceptibility to diseases by common bean is not translated into yield reduction. This suggests that GLP 2 is a susceptible but tolerant variety with respect to foliar fungal diseases. In general, high insect pest population damage was observed in the short rains than the long rains but the reverse was true for the diseases. This information indicates that priority may be given to insect pest than diseases in the short rains and vice versa when designing pest management programmes in grain legumes.

With respect to yield, the results show that the strategic use of pesticides in grain legumes pest management is probably inevitable. The results have shown that pests and diseases of caused up to 54, 67 and 70 percent in chickpea, lablab and green gram respectively per unit area if not protected. These results therefore advocate for pesticide application in grain legume production except for common bean and lima bean that did not respond to either pest infestation with respect to yield loss. Hence, application of pesticides to the two legumes may not be necessary. However, what is not clear from the present work is the optimum number of pesticide applications. It is therefore necessary to conduct studies to determine the frequency of pesticide application that would minimize excessive or unnecessary pesticide application for grain legume farmers.

The primary purpose of inoculating legumes is to enhance biological nitrogen fixation (BNF) and thereby improve the availability of this nutrient to the growing plant. This is particularly important if the soils are defiant in nitrogen. Rhizobia inoculation improved nodulation of the legume species but this was not translated into grain yield suggesting that increased nodulation does not necessarily result in increased grain yield. The presence on nodules on uninoculated plants suggests that the soils in the experimental sites have indigenous rhizobia that are equally active.

Manure application had no effect on nodulation; growth and grain yield of the legume during the long rains. This may be due o the slow mineralization hence slow nutrient release. However, during the short rains, manure treated plants showed improved yield relative to the control. This may have resulted from the high water retention capacity due to the high organic matter content in manure hence availing water to the root zone at the time the plants were experiencing drought stress.

Fertilizer application depressed nodulation but this did not affect plant growth and grain yields. However, it improved shoot dry matter and plant height in most species indicating the positive role of nitrogen on vegetative plant growth. However, the improved vegetative growth did not translate into grain yield in the long rains. Higher number of pods plant^{-1} of the grain legume species due to fertilizer N application relative to the control was observed in the long rains. A similar observation has been reported in pigeon pea following application of urea at a rate of 30 and 40 kg N ha^{-1}(Mukindia, 1993).

The insignificant interaction between legume species and the N source on most of the attributes measured suggests that the soil nitrogen in the experimental sites may have not be limiting as a result the legumes did not require external nitrogen inputs. The grain legumes did not substantially benefit in growth and yield from N application irrespective of the N source. It is possible that either the grain legumes were able to fix enough N to meet their requirements or these N requirements were met by from the soil supply. It has been reported that response to N is highly probable only when total soil N is low i.e. less than 0.2 %(Annon, 1991). Soil N at the study site was 0.40 and 0.28% in long rains and short rains (Appendix 2), respectively, hence medium (0.2 to 0.5%). Therefore response to added N was not expected. In addition, adequate soil moisture is important since uptake of mineral nutrients takes place via water films surrounding the soil particles. Consequently, in dry weather as in the short rains (Appendix 1), N uptake may have been low due to impaired absorption. Sheoran *et al.* (1981) reported that in pigeon peas, water deficit resulted in decreased water potential of the roots, nodules and leaves. This decreased water potential in the nodules resulted in decreased activities of nitrogenase, glytamine synthase, glutamate dehydrogense and uricase, The results of the greenhouse experiment showed that *Rhizoctonia* and *Sclerotinia* were more pathogenic than *Fusarium* and *Macrophomina*.This may be due to the fact that the conditions provided in the greenhouse were not favorable to the growth and survival of *Fusarium* and *Macrophomina* which require high temperatures and moisture stress in order ti thrive well (Allen *et al*., 1996). During the experiments, the temperatures were moderate and the plants watered regularly. Rhizobia seed inoculation had no effect on disease incidence although slightly lower post-emergence damping-off was recorded when rhizobia was inoculated together with the pathogens suggesting that rhizobia may have some fungicidal effects. Inoculation o the seeds with rhizobia improve nodulation and shoot dry matter. Fungicide application significantly reduced disease incidence but negatively impacted on nodulation. However, in combination with rhizobia, the disease incidence was significantly reduced and nodulation increased than when applied alone. Fungicide-rhizobia combinations stroke a balance between seedling mortality reduction and nodulation enhancement. Indicating that simultaneous use of rhizobia and fungicide for root rot management and nodulation enhancement is recommendable for use by farmers. However, studies to determine fungicides that are less toxic to rhizobia ought to be done.

Based on these results it is concluded that;

1. Pesticide spray provided a good protective cover against insect pests and diseases paving way for increase in yields and economically justified marginal returns for green grams, lablab and chickpea but not for common bean and lima bean.
2. Supplimental addition of nitrogen through rhizobia inoculation, fertilizer nitrogen and farm yard manure application on soils with sufficient nitrogen to support plant growth may not be necessary if the aim is to increase yields of the tested grain legumes.

3. Simultaneous fungicide seed treatment and rhizobia inoculation is beneficial for the tested grain legumes if the aim is to manage fungal root rots as well as enhancing nodulation than if each treatment is applied separately.

However, further studies are required for the following:

1. For reproducibility of the results, further studies needs to be done in the various agroecological zones due to site specificity of climatic factors and edaphic environment.
2. Determine other control measures that are ecologically viable for the management of the pests and diseases bearing in mind the prohibitive costs and negative impact to the environments of most pesticides.
3. On-farm experiments ought to be done to establish the effect of fungicide seed treatnment, rhizobia inoculation and their combination on the root rot pathogens, nodulation and dry matter accumulation of the grain legumes

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APPENDICES

Appendix 1: Weather data at Kabete Field Station during the experiment

Month	Mean Max Temp (^{0}C)	Mean Min Temp (^{0}C)	Mean Rainfall (mm)
March 2005	25.8	15.1	104.7
April 2005	22.3	14.9	276.4
May 2005	23.1	14.6	254.3
June 2005	20.9	12.8	27.2
July 2005	20.1	11.4	26.8
August 2005	20.9	11.6	8.5
September 2005	23.2	12.1	28.2
October 2005	24.8	13.5	32.7
November 2005	23.2	14.2	88.6
December 2005	24.8	13.5	0.5
January 2006	25.2	13.7	15.0
February 2006	26.5	14.3	25.9
March 2006	25.2	15.1	204.9

Appendix 2: Soil fertility results for the experimental site

Parameter	Long rains	Class	Short rains	Class
Soil Ph	5.82	Medium acid	5.77	Medium acid
Nitrogen (%)	0.40	Adequate	0.28	Adequate
Phosphorous (ppm)	33	Adequate	35	Adequate
Organic carbon (%)	1.52	Moderate	1.89	Moderate
Potassium (me%)	1.33	Adequate	1.28	Adequate
Calcium (me%)	5.0	Adequate	10.7	Adequate
Magnesium (me%)	4.46	High	4.04	High
Manganese (me%)	1.83	Adequate	1.64	Adequate
Copper (ppm)	6.96	Adequate	5.88	Adequate
Iron (ppm)	17.2	Adequate	21.4	Adequate
Zinc (ppm)	29.5	Adequate	35.8	Adequate
Sodium (me%)	0.30	Adequate	0.93	Adequate

Appendix 3: Chemical characteristics of manure used in the experiment

Parameter	Long rains	Short rains
Nitrogen (%)	2.3	1.65
Phosphorous (ppm)	0.34	1.11
Potassium (%)	4.28	1.70
Calcium (%)	0.48	1.01
Magnesium (%)	0.36	0.17
Iron (%)	1.35	-
Copper (mg/kg)	28	11.2
Manganese (mg/kg)	1060	838
Zinc (mg/kg)	197	138

Appendix 4a: Cost of pesticide application used in calculating marginal returns for the long rains

Item[1]	Cost (Kshs)[2]				
	GLP 2	Lima bean	Green gram	Lablab	Chickpea
Cost for r one spray (Kshs)					
Insecticide	600	600	600	600	600
Fungicide	750	750	750	750	750
Labour for spraying[3]	1740	1740	1740	1740	1740
Total number of sprays	5	8	5	12	10
Total cost/spray (Kshs.)	15450	24720	15450	37080	30900
Labour for harvesting + threshing additional yield[4]	0	0	0	2080	2080
Total cost/season (Kshs)	15450	24720	15450	39160	32980

1=Calculated per hectare

2=Free market price at the time of experiment, ha^{-1}

3=Labour for spraying was calculated at 1 man-day ha^{-1}

4=Labour for harvesting and threshing calculated at 10 man days ha^{-1}

Appendix 4b: Cost of pesticide application used in calculating marginal returns for the short rains

Item[1]	Cost (Kshs)[2]				
	GLP 2	Lima bean	Green gram	Lablab	Chickpea
Cost for one spray (Kshs)					
Insecticide	600	600	600	600	600
Fungicide	750	750	750	750	750
Labour for spraying[3]	1740	1740	1740	1740	1740
Total number of sprays	4	6	4	8	7
Total cost/spray (Kshs.)	12360	18540	12360	24720	21630
Labour for harvesting + threshing additional yield[4]	0	0	0	2080	2080
Total cost/season (Kshs)	12360	18540	12360	26800	23710

1=Calculated per hectare

2=Free market price at the time of experiment, ha^{-1}

3=Labour for spraying was calculated at 1 man-day ha^{-1}

4=Labour for harvesting and threshing calculated at 10 man days ha^{-1}

Appendix 5: Analysis of variance table (means square values) for the effect of insecticide spray on population of flower thrips, African bollworms and legume pod borers

Source of variation	DF	Flower thrips	Long rains African bollworms	Legume pod borers	Flower thrips	Short rains African bollworms	Legume pod borers
Block stratum	3	0.06067	0.00440	0.015563	0.09233	0.04292	0.09223
Block. Spraying stratum							
Spraying	1	14.88400*	2.78256*	0.451562*	80.0890*	4.69225*	1.38756*
Residual	3	0.01267	0.01773	0.001563	0.00967	0.01158	0.05173
Block. Spraying. Legume stratum							
Legume	4	16.14062*	1.17088*	0.223500*	10.2890*	5.62812*	0.55100*
Spraying. Legume	4	1.63213*	0.11225*	0.013750*	0.72025*	0.46537*	0.04162*
Residual	24	0.03521	0.01627	0.002625	0.04579	0.06642	0.01281
Total	39						

Where * is significant at *P*=0.05

Appendix 6: Analysis of variance table (means square values) for the effect of fungicide spray on leaf bight incidence

Source of variance	DF	4 WAE	Long rains 6 WAE	8 WAE	4WAE	Short rains 6 WAE	8 WAE
Block stratum	3	11.453	56.84	22.41	2.1667	19.300	52.4000
Block. Spraying stratum							
Spraying	1	455.625*	1296.18*	6819.93*	230.4*	409.6000*	1464.1000*
Residual	3	5.430	36.18	16.22	0.2*	0.6667	0.9000
Block. Spraying. Legume stratum							
Legume	4	654.919*	1523.08*	430.35*	23.65*	44.9000*	10.1000*
Spraying. Legume	4	41.855*	106.73*	70.23*	3.4*	4.1000*	19.1000*
Residual	24	5.025	21.58	18.66	0.4750	0.4000	0.9000
Total	39						

Where * is significant at *P*=0.05

Appendix 7: Analysis of variance table (means square values) for the effect of fungicide spray on leaf rust incidence

		Long rains			Short rains		
Source of variance	DF	4 WAE	6 WAE	8 WAE	4WAE	6 WAE	8 WAE
Block stratum	3	8.54	10.92	8.75	1.5000	15.5667	68.35833
Block. Spraying stratum							
Spraying	1	448.90*	1535.12*	2884.90*	36.1000*	122.500*	874.22500*
Residual	3	7.06	0.41	0.37	1.5000	0.1000	0.02500
Block. Spraying. Legume stratum							
Legume	4	618.56*	662.92*	407.27*	7.3500*	26.350*	526.22500*
Spraying. Legume	4	12.90*	20.15*	97.15*	7.3500*	3.7500*	150.72500*
Residual	24	11.18	10.86	13.37	0.2500	0.2500	0.02500
Total	39						

Where * is significant at *P*=0.05

Appendix 8: Analysis of variance table (means square values) for the effect of fungicide spray on powdery mildew incidence

		Long rains		Short rains
Source of variance	DF	6 WAE	8 WAE	8WAE
Block stratum	3	0.940	2.642	11.425
Block. Spraying stratum				
Spraying	1	201.152*	1442.401*	570.025*
Residual	3	4.106	3.298	5.292
Block. Spraying. Legume stratum				
Legume	4	587.618*	3857.126*	6579.225*
Spraying. Legume	4	124.959*	994.590*	570.025*
Residual	24	2.186	5.289	8.358
Total	39			

Where * is significant at *P*=0.05

Appendix 9: Analysis of variance table (means square values) for the effect of pesticide spray on percent pod and seed damage

		Long rains		Short rains	
Source of variance	DF	Pod damage	Seed damage	Pod damage	Seed damage
Block stratum	3	1.310	65.43	25.38	8.734
Block. Spraying stratum					
Spraying	1	2275.723*	1116.19*	2050.77*	3071.423*
Residual	3	7.593	40.51	3.77	5.583
Block. Spraying. Legume stratum					
Legume	4	160.426*	42.18*	528.02*	1177.648*
Spraying. Legume	4	160.287*	131.74*	293.60*	354.809*
Residual	24	4.551	39.73	55.44	4.913
Total	39				

Where * is significant at $P=0.05$

Appendix 10: Analysis of variance (mean square values) for the effect of pesticide spray on yield and yield components

							Long rains				
Source of variance	DF	Number of pods plant^{-1}	Number of seeds pod^{-1}	Grain yield	100 seed weight	Marketable yield	Number of pods plant^{-1}	Number of seeds pod^{-1}	Grain yield	100 seed weight	Marketal yield
Block stratum	3	116.57	0.1563	10119080	2.501	8.92	49.62	0.14267	21688	1.000	11.01
Block. Spraying stratum											
Spraying	1	5513.10*	7.3960*	151757*	2.116NS	608.79*	1907.99*	2.91600*	1651085*	7.930NS	256.69
Residual	3	156.42	0.2327	13326997	2.569	3.76	57.85	0.02267	80780.	0.927	15.67
Block. Spraying. Legume stratum											
Legume	4	21634.47*	53.4444*	16242964*	2235.305*	43.80NS	10615.32*	16.83000*	4598366*	1669.848*	109.45
Spraying. Legume	4	1506.11*	3.9104*	10080073*	0.049NS	98.31*	492.09*	0.82475*	138215*	0.505NS	39.54NS
Residual	24	98.45	0.2564	13387702.	2.727	24.61	35.24	0.04287	46666	2.707	21.53
Total	39										

Where * is significant and NS not significant at *P*=0.05

Appendix 11: Analysis of variance table (mean square values) for the effect of rhizobia inoculation, farmyard manure and fertilizer nitrogen on nodulation

		Long rains		Short rains	
Source of variation	DF	Number of nodules plant^{-1}	Nodule DM plant^{-1}	Number of nodules plant^{-1}	Nodule DM plant^{-1}
BLOCK stratum	2	1.707	301.3	5.4590	795.957
BLOCK. LEGUME. Stratum					
LEGUME	3	115.598*	6206.4*	157.8283*	68029.489*
Residual	6	0.939	405.9	0.6431	4.856
BLOCK.LEGUME.N_SOURCE stratum					
N_SOURCE	3	41.118*	3564.0*	18.2467*	3959.409*
LEGUME.N_SOURCE	9	4.329*	501.8NS	2.3028*	894.771*
Residual	24	2.901	465.6	0.2762	6.005
Total	47				

Where DM=dry matter, * is significant and NS not significant at *P*=0.05

Appendix 12: Analysis of variance table (mean square values) for the effect of rhizobia inoculation, farmyard manure and fertilizer nitrogen on shoot, root dry matter yield and plant height.

			Long rains			Short rains	
Source of variation	DF	Shoot DM	Root DM	Plant height	Shoot DM	Root DM	Plant height
	2	0.02744	7010.	84.92	0.1615	817.	8.373
BLOCK stratum							
BLOCK. LEGUME. Stratum	3	50.89055	55946.	2387.76	21.9058	67138.	197.259
LEGUME	6	0.00155*	2787*	102.47*	0.3731*	1487*	4.837*
Residual							
BLOCK.LEGUME.N_SOURCE stratum	3	1.57382	6066.	152.72	0.2808	2845.	5.040
N_SOURCE	9	0.08011*	2479.NS	26.10*	0.0636NS	1066.NS	1.954*
LEGUME.N_SOURCE	24	0.01.81NS	2786.NS	39.64NS	0.1019NS	1389.NS	1.725NS
Residual	47						
Total							

Where DM=dry matter, * is significant and NS not significant at *P*=0.05

Appendix 13: Analysis of variance (mean square values) for the effect of rhizobia inoculation, fertilizer nitrogen and manure on yield and yield components

		Long rains				Short rains			
Source of variation	DF	Pods plant^{-1}	Seeds pod^{-1}	100 seed weight	Grain yield	Pods plant^{-1}	Seeds pod^{-1}	100 seed weight	Grain yield
BLOCK stratum	2	413.37	2.5058	4.190	55232.	219.93	0.22021	0.051	42310.
BLOCK. LEGUME. Stratum									
LEGUME	3	62067.01	72.7497	3971.962	20371747	21589.33	30.98021	3149.764	10370387
Residual	6	455.42	3.2061	1.725	142516	50.79	0.08354	1.706	223398.
BLOCK.LEGUME.N SOURCE stratum									
N SOURCE	3	141.21	0.4519	2.420	47994	48.52	0.03132	1.460	155002.
LEGUME.N SOURCE	9	57.63	0.2598	2.067	47488	5.95	0.00947	0.769	36803.
Residual	24	35.66	0.4524	2.481	50052	20.61	0.03410	1.885	60544.
Total	47								

Appendix 14: Analysis of variance table (mean square values) for the effect of rhizobia inoculation and fungicide seed treatment on pre- and post-emergence damping off, nodulation and dry matter accumulation.

Source of variation	DF	Pre-mergence damping off	Post-emergence	No. of nodules plant^{-1}	Nodule dry weight plant^{-1}	Shoot dry weight plant^{-1}	Root dry weight plant^{-1}
Replicate stratum	2	108.89	37.0	0.723	27.63	0.00321	85428.
Replicate. Units stratum							
Treatment	19	511.23*	2431.8*	24.871*	106.27*	0.13464*	57390.
Legume species	2	428.89*	1384.0*	1358.5*	3426.44*	7.33349*	2823079.
Treatment. Legume species	38	59.30NS	347.6*	8.015*	50.56NS	0.08001NS	31411NS
Residual	118	56.91	182.4	3.647	43.91	0.05858	32088.
Total	179						

Where * is significant and NS not significant at *P*=0.05