EFFECT OF INTERCROPPING AND LEGUME DIVERSIFICATION ON INTENSITY OF FUNGAL AND BACTERIAL DISEASES OF COMMON BEAN

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DECLARATION

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

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DEDICATION

To my loving husband Mr. Jeff Njuguna for your love, patience, understanding and prayers during this study. God bless you.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic absorption spectrophotometer
ANOVA	Analysis of variance
BCMV	Bean common mosaic virus
CBB	Common bacterial blight
CIAT	International Center for Tropical Agriculture
CFU	Colony forming units
CGIAR	Consultative Group on International Agricultural Research
CV	Coefficient of variation
GLP 2	Global legume program two
GLP 92	Global legume program ninety two
GLP 1124	Global legume program eleven twenty four
Ha	Hectare
ICARDA	International Center for Agricultural Research in the Dry Areas
IITA	International Institute of Tropical Agriculture
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IPDM	Integrated Pest and Disease Management
ISTA	International Seed Testing Association
KALRO	Kenya Agricultural and Livestock Research Organization
KATX56	Katumani fifty six
Kg	Kilogram
KK8	Kakamega eight
K80	Katumani eighty
NARS	National Agricultural Research System
NEMA	National Environmental Management Authority
TSW	Thousand seed weight
UoN	University of Nairobi

ABSTRACT

Common bean (*Phaseolus vulgaris* L.) is an important grain legume cultivated in Kenya. Bacterial and fungal diseases are a major constrain in production of common bean in Western Kenya. This study assessed the effect of intercropping and legume diversification on the intensity of bacterial and fungal diseases of common bean in three cluster sites in lower midland one (LM1) in Butula and Teso South Divisions, Busia County, Western Kenya. The study was carried out during the long rains season of 2015 (April - July) where ten farms in each cluster were selected based on similarities in characteristics such as soil types, altitude, rainfall, temperature, land use, head of household, and farm typology. Planting was done at the start of long rains in April 2015 in which each farm per cluster was a replicate. Rose coco bean seeds from previous seasons, certified KK8 and KATX56 seeds from the market were planted. Each farm in the three clusters accommodated six experimental units, three measuring 10 x 10 m and the other three measuring 5 x 5m. In the 10 x 10 m plots, three treatments were included while the small plots (5 x 5 m) accommodated sole crops of each variety of common bean. Treatment one accommodated an intercrop of Rose coco and maize. Treatment two involved intercropping of three common bean varieties - Rose coco, KAT56 and KK8 - with maize, while treatment three involved intercropping Rose coco, KAT56 and KK8 bean varieties with groundnuts (Red Valencia), cow pea (K80) and maize. The other three sole treatments, on the small 5 x 5 m plots, accommodated pure bean stands of Rose coco, KATX56 and KK8. In each of the intercropped treatments, the legumes were planted in double rows between two maize rows. The spacing of maize was 75 × 30 cm while that of bean was 30 ×15 cm. Soil samples were collected for nutrient status analysis and for determination of the population and diversity of soil borne pathogens. Samples of common bean roots and above ground plant parts were collected for evaluation of root rot and foliar diseases, respectively. Seed samples were also collected before planting and after harvesting and were analyzed for purity, germination and bacterial contamination as outlined in International Seed Testing Association (ISTA). The soil samples had low nutrient levels and were highly acidic (pH range: 5.1-5.8). Major soil borne fungal pathogens isolated from the soil were *Fusarium solani, Fusarium oxysporum,*

Rhizoctonia solani, Macrophomina phaseolina and *Pythium* spp. Other fungal genera isolated in low frequency from the soil were *Aspergillus* spp., *Penicillium* spp., *Trichoderma* spp. and *Curvularia* spp. Root rot causing pathogens that were isolated from bean stem bases were *Fusarium solani, Fusarium oxysporum, Rhizoctonia solani, Macrophomina phaseolina* and *Pythium* spp. The intercrops had lower frequencies of root rot pathogens compared to the sole crops. Common bacterial blight was the major bacterial foliar disease while root rots were the most common fungal diseases. Foliar disease indices were lower in intercrop system compared to the sole crop system. Disease indices were much lower in intercrop systems where many legume species were inter-cropped. Seeds from all treatments had a lower physical purity standard (78.3 %) compared to the set ISTA standard (95 %); although, the seeds had the recommended germination standard (89.7 %). Certified KK8 was the only bean variety with the recommended physical purity standard of 99.7 %. Seeds obtained from intercrop and sole crop systems were significantly ($P \leq 0.05$) different in physical purity. Generally seeds obtained through the intercrop system were better in physical purity compared to those obtained through sole cropping. *Xanthomonas campestris* pv. *phaseoli* and *Pseudomonas savastanoi* pv. *phaseolicola* were the main bacterial pathogens isolated from bean seeds. The population of *Xanthomonas campestris* pv. *phaseoli* was significantly ($P \leq 0.05$) higher in pure stands (1223 CFU/seed) than in intercrops (696 CFU/ seed). Similarly, the population of *Pseudomonas savastanoi* pv. *phaseolicola* was significantly ($P \leq 0.05$) higher in pure stands (753 CFU/seed) compared to the intercrops (310 CFU/seed). The seed yield of sole crops (446 kg/ha) was significantly ($P \leq 0.05$) higher than yields obtained through the intercrop system (93 kg/ha). The results of this study showed that intercropping and diversification is a disease management strategy that can effectively manage soil borne and foliar diseases of common bean. The study also showed that good quality seeds can be produced through either cropping systems. Intercropping and legume diversification could be included in integrated pest and disease management (IPDM) strategies.

CHAPTER ONE: INTRODUCTION

1.1 Background

Common bean (*Phaseolus vulgaris* L.) is the number one grain legume that is grown in Kenya, with a very crucial input in dietary protein and soil fertility improvement (Chui and Nadar, 1984; Gicharu *et al*., 2013). CIAT (1986) documented that it provides 10 % proteins of human dietary needs with its consumption in Kenya being 100 % (Katungi *et al*., 2009). It is mainly grown in the highlands and midlands parts of Kenya, with 75 % of the produce annually coming from three regions; Nyanza, Rift valley and Eastern regions (Katungi *et al*., 2009). When sold, it gives more cash when compared with sale of cereals, such as maize (Kimiti *et al.,* 2009). It has been considered vital in improving soil fertility through their ability to fix atmospheric nitrogen in the soil, improve soil organic matter and the soil structure in general (Dyck, 1997; Maobe *et al*., 1998; National Academy of Science, 1994).

Common bean is mainly grown by small scale farmers in East Africa who have limited resources and usually its production is characterized by constraints such as marginal lands, low/ no input use and intercropping with crops that are highly competitive under low soil nutrients (Wortmann *et al*., 1998). Principal constraints to bean production in Kenya include diseases; low soil fertility, insect pests, low potential of cultivated varieties and variable rainfall (Katungi *et al*., 2009; Otsyula *et al*., 1998). Diseases are a main drawback to production of grain legumes (CGIAR, 2012; Wortmann *et al*., 1998). Major diseases of beans are caused by fungi, bacteria and viruses. The most important of these include anthracnose (*Colletotrichum lindemuthianum*), angular leaf sport (*Phaeoisariopsis griseola*), common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*), bean rust (*Uromyces appendiculatus),* halo blight (*Pseudomonas savastonoi* pv. *phaseolica),* bean common mosaic virus (BCMV), root rots, that are caused by a complex of pathogens (*Fusarium* spp., *Pythium* spp.,

Macrophomina spp., *Rhizoctonia* spp.) (Hillocks *et al.,* 2006; Medvecky *et al*., 2007; Mwang'ombe *et al*., 2007; Rusuku *et al*., 1997; Wortmann *et al.,* 1998).

1.2 Problem statement

Common beans is the most important and commonly produced legumes in the country but it's production is declining with yields being less than 0.5 t/ha compared to the expected yield of 1.5 t/ha (Hillocks *et al.,* 2006). Its production in the country has declined by 20 % from over 0.5 million tons in 2006 to below 0.3 million tons in 2008 (Akibode, 2011). That translates to a decrease from 6 bags/ha in 2006 to 2 bags/ha in 2008 (ICRISAT, 2013). In Western Kenya, yields are still low 400kg/ha, which is below the potential yield of 1350-1980 kg/ha according to KALRO (Audi *et al*., 1996).

Diseases have been identified one of the main constraints contributing to low bean yields (Kimiti *et al*., 2009; Makelo, 1997; Muthomi *et al*., 2007). Majority of these fungal and bacterial diseases are seed borne (Allen *et al*., 1998; Buruchara, 1990; Karavina *et al*., 2008, 2011; Kimiti *et al*., 2009). Use of clean seeds is an important step in management of seed borne diseases (Karavina *et al*., 2011 Makelo, 1997). Small scale farmers in bean production areas use their own saved seed; seeds borrowed from neighbors' or bought from nearby markets (Makelo, 2010). Farmers lack adequate information, resources or income to buy certified seeds (Katungi *et al*., 2009). Poor farming practices like continuous cropping without rotation and usage of farm saved seeds by farmers are some of the factors that have been identified to cause major disease epidemics of beans (Mahasi *et al*., 2010)

1.3 Justification of the study

Common bean production in Kenya has been on the decline. This is a major challenge with the current increase in demand in the country (Katungi *et al*., 2009). Early identification and evaluation of plant pathogens in an area can provide a timely and effective way of curbing plant diseases preventing epidemics that leads to huge losses in crop yields (Makelo, 1997). Previous studies have focused on screening different common bean varieties for grain yields (KALRO, 2011) and intercropping a single variety with maize in order to increase overall yields (Smithson and Lenne, 1996). Intercropping has been a common tool to manage diseases especially in cereals in the tropics (Sacred Africa, 2002). Intercropping has been incorporated in cropping systems in order to manage diseases of common bean by reducing the distance between crops belonging to the same family; thus spread of disease pathogen from one crop to another is reduced in a particular field (Fininsa and Yuen, 2001). Growing varietal mixtures of beans has been reported to reduce foliar disease incidences that have an overall effect on yield (Trutmann *et al*., 1993). In order to increase bean productivity in Kenya there is a need to understand how beans can be produced in conditions that make them less prone to attack by pathogens. There is a need to study the role of intercropping and legume diversification on bacterial and fungal disease intensity and their effects on crop yields.

1.4 Objectives

1.4.1 Broad objective

The broad objective of this study was to determine the effect of intercropping and legume diversity on intensity of fungal and bacterial diseases of common bean.

1.4.2 Specific objectives

i. To determine the effect of intercropping and legume diversity on soil-borne diseases of common bean.
ii. To evaluate the effect of intercropping and legume diversity on above ground fungal and bacterial disease pressure and bean seed quality.

1.5 Hypotheses

i. Intercropping and diversification of legumes reduce infection of common bean with soil borne pathogens.
ii. Intercropping of different legumes reduce foliar fungal and bacterial diseases on common bean and improves bean seed quality.

CHAPTER TWO: LITERATURE REVIEW

2.1 Bean production in Kenya

Common beans will remain crucially important as a cheap source of protein (Akibode and Maredia, 2011; Broughton *et al*., 2003). Beans are grown in a range of cropping systems as mixed, intercrops or in rotation with cereals (maize, sorghum or millet) or other crops (ICRISAT, 2013; Odhiambo and Ariga, 2001; Wanjekechee, 1997). Mostly beans are grown under rain fed and low input production (Akibode, 2011). The most common bean varieties produced in Kenya are Rose coco (GLP2), Mwitemania (GLP92), Nyayo or mwezi moja (GLP 1124) (Katungi *et al*., 2009). Beans are produced in small, medium and large scales. Farmers operating in smallholdings use a hand hoe, those in medium use an oxen and in large scale use tractors (Rusike *et al*., 2013). Beans are cultivated in several Counties countrywide that include: Machakos, Makueni, Embu, Nyeri, Kirinyaga, Murang'a, Uasin Gishu, Kericho, Baringo, Nakuru, Nandi, Kakamega, Vihiga, Busia, Siaya, Homabay, Kisii and Laikipia (Achieng *et al*., 2010; ICRISAT, 2013; Kimiti *et al*., 2009).Yields of beans are declining below 500kg/ha in arid and semi- arid regions of the country (Mathuva *et al*., 1996). Despite of the decline in production, common bean consumption is at 66 kg per person per year in rural parts of Kenya (Broughton *et al*., 2003).

2.2 Importance of common bean in Kenya

Many developing countries in the world, Kenya being in the list, derive the highest proportion of total dietary protein from grain legumes especially beans. Kenya is among the top five countries in sub-Saharan Africa in production of common bean, it contributes 20 % of protein consumption on common bean worldwide (Akibode and Maredia, 2011). Common beans play apart as sources of food and income, nutrition requirements plus natural resource management

(Rusike *et al*., 2013). Common bean production assist in reduction of poverty in several ways; farmers both consume and sell grain legumes that serve as some source of income, thus enabling them to carry on with other projects in their farms (Shiferaw *et al*., 2007). Common beans can be used in securing food supply programs since they can be fitted in different cropping systems to increase total food production per unit land area for small holders.

Common beans contribute highly to the human nutrition. Haas *et al.* (2010) reported that common beans are rich in protein, and micronutrients such as iron and zinc. High iron and zinc is beneficial in patients that are anemic, different minerals in beans have been shown to improve children health (Welch and Graham, 2000) They play a great role in sustainable intensification by fixing nitrogen, thus meeting much of their own N requirement while also leaving significant amounts of N in the soil for following crops thus reducing expenses for resource-poor farmers (Crews and People, 2005; Nyiraneza and Snapp, 2007). They also contribute to reduction in pollution by substituting for chemical N fertilizer (Crews and Peoples 2005; Nyiraneza and Snapp, 2007). They are also used in fodder, a benefit to livestock rearing farmers, reduces erosion by acting as cover crops and their use in different crop rotations where they act by breaking disease cycles of pathogens (Fininsa and Yuen, 2001).

2.3 Common bean production practices in western Kenya

Common bean is an important food crop in Western region of Kenya that contributes Ksh. 13.18 billion annually to the national economy (ICRISAT, 2013). Beans are produced by both large and small scale farmers, with a large proportion being small holder farmers especially women (ICRISAT, 2013; KALRO, 2011; Rusike *et al*., 2013). Farmers' bean sources in this region include: farmers saved seeds, purchase from local markets and a few of the farmers get seeds

from certified seed companies while the latter is not highly practiced due to financial constraints (ICRISAT, 2013; Makelo, 1997). Common beans are planted during either the short or long rainy periods in the region. Small holder farmers in Western Kenya cultivate legumes and cereals in continuous culture with no or little addition of replenishing inputs; this leads to overall nutrient depletion and generally low legume yields (Njeru *et al*., 2009; Odundo *et al*., 2009).

2.4 Constraints to bean production in Kenya

Common bean farmers face several challenges which are a deterrent to better yields of beans in the country. Key on farm production constraints on increasing bean yield include pests and diseases (Broughton *et al*., 2003; Kimiti *et al*., 2009; Ojiem *et al*., 2006), lack of certified seeds of improved varieties (Karanja *et al*., unpublished), poor agronomic practices that leads to pathogen build-up and low soil fertility (Buruchara, 1990; Okalebo *et al*.,2006; Scott *et al*., 2003). Ojiem *et al.* (2006) argues that high incidence of pests and diseases, low soil moisture and decreased soil fertility are some of the problems bean farmers face in Western Kenya. Many small holder farmers in Kenya practice continuous cropping with little or no addition of inputs like fertilizers to replenish the soil; this has led to decreased soil fertility and decline in overall productivity in the region (KALRO, 2011; Njeru *et al*., 2009; Odundo *et al*., 2009).

A study on cropping systems in Western Kenya by KALRO (2011) showed that not only does lack of fertilizer inputs increase stiff competition among plants but it also makes crops become prone to attack by disease pathogens. In order to realize higher bean yields in Western Kenya (over 1000 kg/ha) farm inputs like organic fertilizers need to be added to soils (Kibunja *et al*., 2000) however, rarely do small holder farmers use fertilization on bean crops (Thuita *et al*.,

2011). Lack of sufficient seeds and sufficient cash to purchase adequate and clean seeds is also a challenge, so farmers end up using their own saved seeds (Katungi *et al.*, 2010).

2.5 Diseases of common bean (*Phaseolus vulgaris* L.)

Common bean is a very important food crop worldwide. Apart from its use in nutrition, it also plays a role in improving soil fertility (Chui and Nadar, 1984). Common bean is affected by bacterial, fungal and viral diseases. These diseases not only affect bean yields but also reduce bean storability and marketability (CGIAR, 2012). Common Bacterial Blight is a very common disease of beans that is prevalent in many countries of the world (Karavina *et al*., 2011).The causal agent of this disease is *Xanthomonas axonopodis* pv. *phaseoli*. This is commonly seed borne and can overwinter in seed and infested bean straw and can survive in seed for over 15 years (Karavina *et al*., 2011). Symptoms first appear as water soaked spots that coalesce later to form regular brown necrotic lesions with lemon yellow margins. When lesions coalesce they produce extensive tissue damage. Infected pods show water soaked symptoms with dark lesions, the plant can wilt if the pathogen infects the vascular system (Allen *et al*., 1996; Hagedorn and Inglis, 1986).

Halo blight is a disease in common bean that is widespread especially in mid to high altitude areas. It causes major losses in beans in Africa specifically in Lesotho, Rwanda and Zimbabwe (Allen *et al*., 1996). The bacterium responsible for the disease is *Pseudomonas syringae* pv. *phaseolicola.* This disease is characterized by small water soaked lesions that appear on leaves which develop into green-yellow halos. Pods, stems and petioles show symptoms of water soaked lesions that at times produce white exudates. Chlorosis symptom is a sign of systemic infection. Seeds may be symptomless but may appear wrinkled bearing brown patches (Allen *et*

al., 1996) Seed infection is the main mode of spread of the pathogen; crop residues can also serve as a habitat for the survival of the pathogen; water splash through irrigation or rain splash serves as another method of the pathogen spread.

Bacterial wilt is a disease that affects beans worldwide. The bacterium *Curtobacterium flaccumfaciens* pv. *flaccumfaciens* can be borne on seeds. Infected plants have a wilted appearance during hot weather and then a normal appearance during cold weather (Hagedorn and Inglis, 1986). The leaves have necrotic regions that have bright yellow margins, the necrotic regions might be confused with necrosis caused by common bacterial blight; but the bacterial wilt necrosis is more wavy or irregular (Harveson *et al*., 2005).

Ascochyta blight is an important disease of beans that has been identified in Kenya, Burundi, Rwanda, Tanzania, Uganda and Zambia. This disease occurs throughout Africa particularly in cool and humid areas (Allen *et al*., 1996). The pathogen that elicits this disease is *Ascochyta phaseolum*. Dark grey-black ringed lesions form on leaves, stems, pods and petioles. In severe cases necrotic lesions are formed that causes extensive blights and premature defoliation. The fungus is seed borne and can also survive on crop debris, secondary spread is through rain splash (Allen *et al*., 1996).

Angular leaf spot is a primary disease in the tropics and subtropics that causes 10-50 % yield reduction (Hagedorn and Inglis, 1986). A fungus *Phaeoisariopsis griseola (*Sacc.) is the causative agent of the disease. The disease is characterized by grey lesions that later become dark brown or black. As they increase in size, several may coalesce and large portions of the leaf

surface become necrotic and chlorotic after 9 days of infection. The necrotic regions are angular in shape (Hagedorn and Inglis, 1986; Saettler *et al*., 1984). The pods are circular in color with reddish brown centers and dark margins, the fungus may infect seeds, with seeds having a characteristic shriveling, and the fungus may be carried on or in seeds (Saettler *et al.*, 1984).

Anthracnose caused by *Colletotrichum lindemuthianum* is a bean disease that causes massive losses in crop yields. Dark brown-black lesions along the veins on the underside of the leaf occurs, symptoms on the pods appear as brick red to dark brown sunken lesions that become dark brown with enlargement of lesions. In moist weather, gelatinous masses of pinkish spores of the fungus may develop in infected areas. The fungus spores may penetrate the pods causing discoloration and distortion of seeds. If the fungus infects seeds, this serves as a primary source of inoculum of the pathogen (Hagedorn and Inglis, 1986; Saettler, 1983).

Powdery mildew is a disease that occurs worldwide but rarely causes huge losses on yields (Kiss and Szentivanyi, 2001), the fungus *Erysiphe polygoni*, elicits the disease. The fungus can be seed-borne. The first symptoms are darkened and discolored areas on the leaf that develop into tiny white powdery spots. These spots enlarge rapidly, coalesce and finally cover the entire leaf. If infection occurs in early seasons, leaves may become dwarfed, turn yellow and fall off. On pods, small moist looking circular spots develop into white powdery masses of the pathogen mycelium and spores (Kiss and Szentivanyi, 2001).

Bean rust occurs worldwide and is most severe when plants are infected during the pre-flowering and flowering stages. The fungus *Uromyces phaseoli* causes bean rusts that usually affects

leaves, stems and pods. The first symptoms appear on the undersurface of leaves as tiny, white raised spots (Harveson *et al*., 2007). These spots gradually enlarge and forms reddish brown pustules, which eventually erupt to release rusty masses of spores. These spores can re-infect other plants under favorable conditions (Harveson *et al.,* 2007).

Root rots are caused by a single pathogen or a combination of several fungal pathogens which include; *Fusarium solani, Pythium ultimum, Macrophomina phaseolina* and *Rhizoctonia solani* (Medvecky *et al*., 2007; Mwang'ombe *et al*., 2007). Symptoms of disease differ from one pathogen to another, *Rhizoctonia* spp. symptoms are reddish brown lesions on the root and the lower hypocotyl. Symptoms due to *Pythium* species are water soaked spots on roots and hypocotyls, these spots coalesce to give the root a tan-brown appearance. Finally, *Fusarium* spp. symptoms are small tan red lesions on the lower hypocotyl and the entire root system that later coalesce to form reddish brown necrosis (Abawi *et al.,* 2011; Hagedorn and Inglis, 1986).

2.6 Factors affecting the spread of common bean diseases

Several factors influence the spread of fungal and bacterial diseases of common bean. The usage of unclean seeds for planting, presence of infested crop debris and environmental factors that facilitate the survival and spread of disease pathogens, are factors that contribute high disease incidences in an area over time. Majority of legume diseases are seed borne (Makelo, 1997). Common bacterial blight survives for over 15 years on seeds (Karavina *et al.,* 2011). Farmers in Western Kenya plant own-saved seeds, or they buy the seeds from the local markets or borrow from neighbors with a few of them buying seeds from a certified seed company (Makelo, 1997; Katungi *et al*., 2009). There is need for farmers to use clean seeds that are free from pathogens in

order to prevent epidemics that could be caused by planting seeds that are infested with pathogens (Makelo, 1997). Mahasi *et al*. (2010) argues that continuous cropping of the same plant without crop rotation can lead to disease persistence in a region. He adds that mixed cropping without nutrient inputs makes them prone to attack by pathogens. Some pathogens overwinter in crop debris, for instance common bacterial blight has been known to overwinter in crop debris for a long period of time (Karavina *et al*., 2011). There is need for farmers to discard crop debris that had or have been seen to have disease symptoms.

Insects play a major role in spread of plant diseases directly or indirectly. Many insects facilitate entry of pathogens into a new host either through wounds or natural openings like the stomata; insects carry plant bacterial, fungal or viral pathogens in their legs, mouthparts and bodies, where they serve as a source of inoculum to a new host in the same field, neighboring field or some field miles away (Agrios, 1997). Plant debris and weeds have been sources of inoculum for some pathogens that overwinters in these plants; for instance, *Isariopsis griseola* and *Colletotrichum lindemuthianum* that causes angular leaf spot and anthracnose in beans respectively is spread through this manner (Hagedorn and Inglis, 1986). Environmental aspects like wind, temperature and rain play a major role in transmission of some diseases. Some pathogens requires some amount of temperature and humidity in order to multiply and be spread, for example, the pathogen responsible for *Aschochyta* leaf blight proliferates between 16-24 $^{\circ}$C (Hagedorn and Inglis, 1986). Rain and wind are important agents of some foliar diseases like rusts, powdery mildews, Aschochyta blights where pathogenic spores are blown by wind or splashed by rain water to new hosts a distance away (Hagedorn and Inglis, 1986). The farmers working in the field also play a part in transmission of legume diseases by creating wounds while cultivating

that serve as entry route to pathogens; often farmers transfer the pathogen in whole or in parts in their clothes or hands while working in the farm (Hagedorn and inglis, 1986).

2.7 Role of intercropping on bacterial and fungal diseases of common bean

Intercropping involves growing of more than one crop species in a piece of land. Beans are mainly intercropped with cereals (maize, sorghum or millet), bananas and tuber crops (Katungi *et al*., 2009). In Kenya small holder farmers mainly grow maize in association with other crops in order to produce enough food on their small pieces of land (KALRO, 2011). Cropping systems affect how a plant responds to disease pathogens. Intercropping is a farming strategy that replenishes soil fertility, improves soil structure, suppresses weeds, reduces diseases incidence and generally increases crop yields (Njeru *et al*., 2009; Odhiambo and Ariga, 2001; Odundo *et al*., 2009). Beans grown in association with maize have showed low incidences of common bacterial blight, halo blight, anthracnose, mildews and scab (Rheenen *et al*., 1981). Intercropping systems delays disease epidemics onset and slows down disease progress as documented by Fininsa and Yuen (2002) working on Common bacterial blight of beans. Intercropping may reduce impact of pests and disease outbreaks by creating habitat for predatory insects and increasing distant between crops of the same species, reduce soil erosion and increase in yields (Carlson, 2008).

2.8 Importance of seed quality in bean production

Quality of bean seeds is an important factor in relation to diseases and yield (Icishahayo *et al*., 2009; Rubyogo *et al.*, 2007). According to ISTA (1999), tests that should be done to determine quality status of a seed lot include seed purity test, germination test and health test. Good quality seeds have reasonable physical purity, high germination capacity and are pathogen free (ISTA,

1999). ISTA has set these standards at 95 % for physical purity, 0.95 % inert matter, 0.05 % other crop seeds, 85 % germination percentage and 14 % maximum moisture (ISTA, 1999). Many bacterial and fungal diseases of common bean are seed borne. For instance, *Xanthomonas axonopodis* pv. *phaseoli,* the cause of common bacterial blight can survive on seeds for over 15 years (Karavina *et al*., 2011). Small holder farmers in Kenya use farm saved seeds that they have recycled over the years, borrow from neighbors or purchase from nearby markets (Opole *et al*., 2003; Makelo, 2010). Farmers prefer using their own saved seeds as it is considered more economical and readily available (Opole *et al*., 2003). Use of these seeds from season to season encourages build-up of pathogens that increases crop losses through diseases epidemics (Buruchara, 1990; Opole *et al*., 2006). Infection of seeds by seed-borne pathogens results in seed rots, seedling decay, and pre and post emergence mortality. Seeds borne diseases therefore affect seed germination, seedling emergence and establishment in a negative way. These diseases in later stages causes leaf blights, leaf spots, stem rots, discolorations and fruit infections (Icishahayo *et al*., 2009). Seed borne diseases carry over infections from season to season and cause poor stand, low yields that leads to poor returns (Icishahayo *et al*., 2009). Therefore, disease free seeds should be able to germinate well, give rise to healthy vigorous growing plants with high yielding capacity.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of the study area

The study was carried out in Butula and Teso South divisions, Busia County, specifically in Lower Midland one (LM1) (Figure 1). Busia County is found within Lake Victoria basin hence the characteristic high humidity throughout the year. The area has two rainy seasons; between March and June, and between August and October. Lower midland 1 of Busia County has an annual mean temperature of 21-22.2 ºC, annual average rainfall of 1800-2000 mm and altitude between 1200-1440 m above sea level (Jaeztold *et al*., 2005; Kerstin *et al*., 2013; NEMA, 2013). The soils in Busia County are moderately deep, generally rocky and stony, well drained red clay soils that have low fertility (Jaeztold *et al*., 2005). Soils in Butula area are sandy well drained, deep, brownish with moderate water holding capacity (NEMA, 2013) while those of Teso South are poorly drained with under laying hard pans and have low content of soil nutrients (Jaeztold *et al*., 2005). Maize intercropped with legumes such as beans, cowpea or soybeans is the main cropping system in this region (Jaeztold *et al.,* 2005).

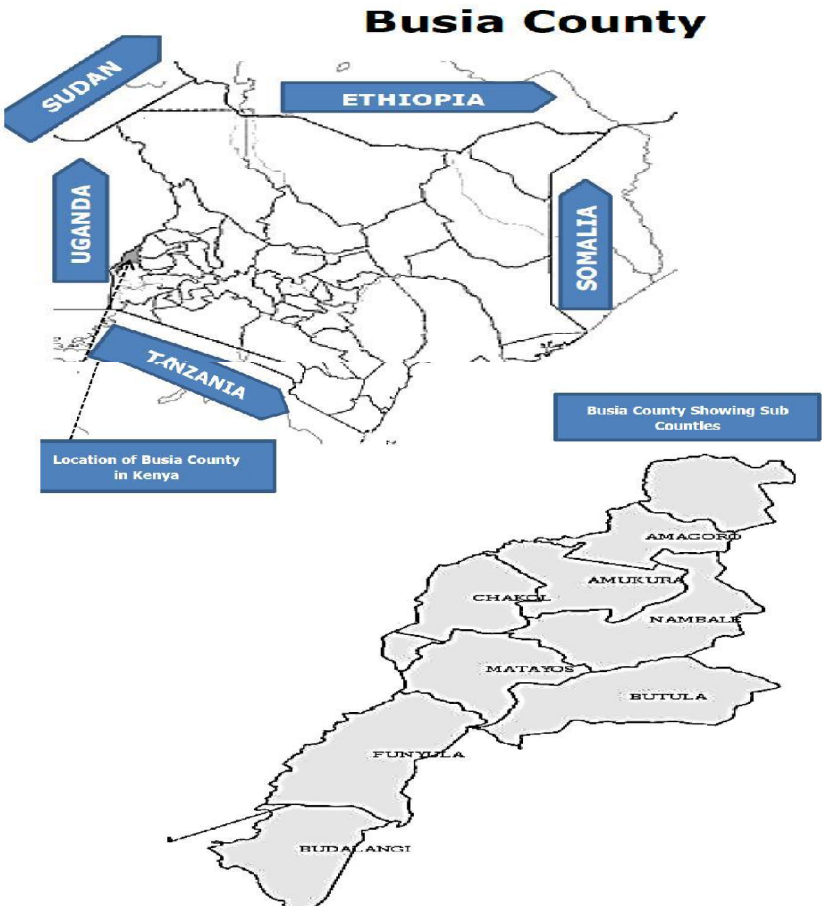

Figure 1: Map showing Busia County where the study was conducted.

Source: Lake Victoria North Water Services Board, 2013.

3.2 Selection of experimental sites and source of planting seeds

Three clusters, Alupe, Bujumba and Madola in LM1 in Butula and Teso South division of Busia County were selected on which the experiment was conducted. Ten farms in each cluster were selected based on similarities in characteristics such as soil types, altitude, rainfall, temperature, land use, head of household and farm typology. A field experiment was conducted between March and June, during the long rains of 2015. Planting took place at the start of long rains in April 2015 in which each farm per cluster was a replicate. Farmer saved Rose coco seeds from previous seasons, seeds of KATX56 variety bought from market and certified seeds of KK8 variety obtained from the Kenya Agricultural and Livestock Research Organization (KALRO) were planted.

3.3 Experimental layout and design

Each farm in the three clusters accommodated six experimental units, three measuring 10 x 10 m and the other three measuring 5 x 5 m. In the 10 x 10 m plots, three treatments were included while the small plots (5 x 5 m) accommodated sole crops of each variety of the common bean. Treatment 1 involved intercropping Rose coco, a common bean variety that is commonly grown by farmers in the region with maize (H517) (Low diversity). Treatment 2 involved intercropping of three common bean varieties - Rose coco, KATX56 and KK8 - with maize (Medium diversity), while treatment 3 involved intercropping Rose coco, KAT56 and KK8 bean varieties with groundnuts (variety Red Valencia), cow pea (variety K80) and maize (High diversity). The other three treatments on the small 5 x 5 m plots - accommodated pure bean stands of Rose coco, KATX56 and KK8.

In each of the intercropped treatments, the legumes were planted in double rows between two maize rows. The spacing of maize rows was 75 × 30 cm while that of bean was 30 × 15 cm. Each plot (intercropped/sole) was separated from another by 1 m distance. Artificial soil amendments were not added either to beans or maize at planting but top dressing of maize crop with CAN fertilizer was done during the V6 developmental stage of maize as described by Berglund *et al*. (1999). The experimental plots were weeded thrice at 3 weeks after crop emergence, before and after flowering of common bean.

3.4 Determination of the effect of intercropping and legume diversity on soil borne bean diseases

3.4.1 Collection of soil samples

Soil was sampled before planting. Approximately 1 kg of soil from the top 10 - 15 cm layer of each plot was collected at five points in each plot; at four corners and in the middle area of each plot for both the pure stands and the intercrops. The five sub samples from each plot were thoroughly mixed in a paper bag to make a composite mixture. Approximately 0.5 kg of the composite sample was drawn and placed in a polyethylene bag, labeled and transported to the laboratory within three days after sampling. The samples were air dried on laboratory benches for five days prior to isolations and nutrient analysis. The soil samples were collected from three farms per cluster that were randomly selected in each of the three clusters.

3.4.2 Determination of soil nutrient status

Soil samples were analyzed for pH, level of macro and micro nutrients at the National Agricultural Research laboratories (NARL). Soil pH was determined in a 1:1 (w/v) soil-distilled water suspension with a pH meter. Available nutrients potassium (K), sodium (Na), calcium (Ca), magnesium (Mg) and manganese (Mn) were determined using Mehlich Double Acid Method (Hinga *et al*., 1980; Mehlich *et al*., 1962). Sodium, calcium and potassium were determined with flame photometer while phosphorus (P), magnesium (Mg) and manganese (Mn) were determined by spectrophotometry. Total organic carbon was determined by calometric method (Anderson and Ingram, 1993) where 1 g of the soil sample was oxidized by acidified dichromate at 150 °C for 30 minutes, barium chloride was added to cool digests. The digests were allowed to stand overnight and carbon concentration was read on the spectrophotometer at 600 nm. Total nitrogen was determined using Kjeldahl method (Page *et al*., 1982; Hinga *et al*., 1980) where 1 g of the soil

sample was digested with concentrated sulphuric acid containing potassium sulphate, selenium and copper sulphate hydrated at approximately 350 °C. Total nitrogen was determined by distillation followed by titration with dilute standardized sulphuric acid. Available trace elements (iron, zinc and copper) were determined with Atomic Absorption Spectrophotometer (AAS) (Hinga *et al*., 1980; Mehlich *et al*., 1962). The soil samples were oven dried at 35 °C for 5 hours and elements were extracted from the soil in 1:10 ratio (w/v) with 0.1 M hydrochloric acid.

3.4.3 Isolation and identification of soil borne pathogens

3.4.3.1 Isolation of soil borne pathogens

A sub sample weighing 100 g of the composite soil sample was passed through a 0.5 mm standard sieve. Ten grams of the fine sieved soil was then suspended in 100 ml of autoclaved distilled water, mixed on a mechanical shaker for 30 minutes and 1 ml of the dilution transferred to another 9 ml sterile water to make the second dilution. The mixture was serially diluted by mixing 1 ml aliquot in 9 ml sterile distilled water up to $10^{3.}$

3.4.3.2 Preparation of potato dextrose agar amended with antibiotics

The media was prepared by dispensing 39 g of potato dextrose agar powder in 1 litre distilled water, the mixture was swirled gently to dissolve the solid and then autoclaved at 121 ºC for 15 minutes at 15 psi. The media was cooled to approximately 45 ºC, mixed with 50 mg/L streptomycin and 40 mg/L tetracycline. The media was maintained in a water bath (45 °C) to prevent solidification and approximately 20 ml dispensed in 9 cm Petri dish in aseptic conditions in a biological safety cabinet.

3.4.3.3 Preparation of synthetic nutrient agar

This media was prepared by mixing 1 g Potassium di-hydrogen phosphate (KH_2PO_4), 1 g Potassium Nitrate (KNO_3), 0.5 g Magnesium Sulphate ($MgSO_4$), 0.5 g Potassium Chloride (KCl), 0.2 g glucose and 20 g agar (Nirenberg, 1981) in 1 litre distilled water and autoclaved at 121 °C for 15 minutes. The media was cooled to about 45 °C and approximately 20 ml poured in sterile Petri dishes in a biological safety cabinet and allowed to solidify.

3.4.3.4 Preparation of nutrient agar

This media was prepared by dispensing 28 g of Nutrient agar in 1 litre of distilled water and autoclaved at 121 °C for 15 minutes. The media was cooled to 45 °C and approximately 20 ml poured in sterile Petri dishes and allowed to solidify.

3.4.3.5 Culturing of soil- borne fungal pathogens

One milliliter (1 ml) of 10^2 and 10^3 dilutions was pipetted into sterile Petri dishes and approximately 20 ml molten PDA media amended with antibiotics was dispensed, swirled and allowed to set. Three replicates of each dilution were pipetted and the plates incubated for 5 - 7 days at room temperature (23 ± 2 °C). The number of each fungi type growing on the media was counted immediately as colony forming units per plate, which was then used to calculate colony forming units/gram of soil as follows (Bollman *et al*., 2010):

$$\text{CFU/ g} = \frac{Average\ count}{Dilution\ factor} \times Volume\ plated$$

Fungal colonies were sub cultured on PDA incubated at room temperature (23 ± 2 °C) for 5 - 7 days. Isolated *Fusarium* colonies were sub-cultured on PDA and synthetic nutrient agar. *Fusarium* cultures on SNA were incubated near UV-light at 25 °C for 14 - 21 days to allow for sporulation.

Riddell slide cultures of *Fusarium* were prepared by placing block edges of SNA on a sterile microscope slide placed on a sterile bent glass rod covered with a sterile filter paper at the bottom. A sterile cover slip was placed on SNA culture blocks mounted on microscope slides and the filter paper wetted with sterile distilled water and the plate sealed with parafilm and incubated at 25 °C for 14 - 21 days (Riddell, 1950). Slides for light microscopy were prepared by removing the cover slip from the agar block and placing it on a slide with a drop of lactophenol cotton blue. The slide preparations were used for identification and taking photos of morphological characteristics of common fungi isolated at × 1000 magnification using a light microscope (LEICA DM 500, Leica Microsystems, Wetzler, Germany) fitted with a camera (LEICA ICC 50, Leica Microsystems, Wetzler, Germany).

Fungal genera were identified based on morphological and cultural characteristics like color of the colony, growth type, colony pigmentation, spore shape, septation and sporophores. The incidence of each fungal genera was determined by counting the number of colony forming units per plate. *Fusarium* species were identified to species level using manuals by Leslie and Summerell (2006) and Nelson *et al.* (1983). *Fusarium* cultures on PDA were identified based on cultural characteristics such as mycelial color, presence of aerial mycelia and reverse mycelial color. Cultures on SNA were identified based on microscopic characteristics: macroconidia morphology;size, shape, apical or basal cell morphology, microconidia; shape, aerial mycelial presentation, present or absent, chlamydospores; present or absent.

3.4.4 Assessment of germination rate and plant stand

Seedling emergence date was marked as from two weeks after planting in which about 70 % of the seedlings in each plot had emerged. Plant stand was determined by counting the number of surviving plants in each plot. The data was collected from two inner double rows of each bean

variety from each plot. Plant stand was determined at 2nd and 4th week after emergence and was expressed as a percentage of the total number of plants over the total seeds planted per plot.

3.4.5 Assessment of distribution, incidence and severity of root rots

Assessment of root rot distribution, incidence and severity was carried out at 2nd and 4th weeks after emergence. Distribution of root rots was assessed on a scale of 0 - 2, where 0 = no disease, 1 = spots, 2 = whole field. Incidence of root rots was determined by counting the number of plants showing root rot symptoms from two inner double rows of each bean variety. Root rot infected plants were identified based on symptoms such as yellowing of leaves, wilting, dark or brown colored lesions on the root system. Root rot incidence per plot was expressed as the number of plants showing symptoms over the total number of plants in the plot. Severity of root rot was assessed on a scale of 0 - 3 where 0 = no disease, 1 = mild infection, 2 = moderate infection and 3 = severe infection. Root rot indices were calculated by summing up scores of distribution, incidence and severity.

3.4.6 Isolation and identification of root rot pathogens

Ten symptomatic and ten non-symptomatic bean plants for each variety in each treatment from each farm were sampled, placed in Kraft bags, labeled and stored in a cool box and transported to the laboratory within two days of sampling. In the laboratory, stem bases were washed in running tap water to remove any soil particles, each plant base cut into five pieces measuring approximately 1cm, then surface sterilized with 1.3 % sodium hypochlorite solution and rinsed thrice with sterile distilled water in a bio safety cabinet. The five pieces of plant samples from each treatment were placed on molten PDA amended with antibiotics (Section 3.4.3.2) and incubated at room temperature (23 ± 2 °C) for 5 - 10 days. The fungi isolated were sub cultured on PDA and incubated at room temperature for 7 days. Fungi that resembled *Fusarium* spp. were

sub cultured from PDA to SNA and incubated at room temperature for 14 - 21 days (Section 3.4.3.5). Pure cultures of *Fusarium* spp. were identified based on cultural and morphological characteristics with the guide of *Fusarium* identification manuals (Nelson *et al*., 1983; Summerell and Leslie, 2006). Other fungal genera were identified based on morphological and cultural characteristics of the fungal pathogens such as type, shape and color of sexual or asexual spore formed, by microscopic examination with the guide of pictorial atlas of soil and seed fungi (Bhale *et al*., 2001).

3.5 Determination of the effect of intercropping and legume diversity on bean foliar diseases and seed quality

3.5.1 Determination of distribution, incidence and severity of foliar diseases

Distribution, incidence and severity of foliar diseases was assessed at flowering and early podding stage i.e. 4^{th} and 6^{th} week after emergence respectively (Section 3.4.5). Disease indices were calculated by summing up distribution, incidence and severity index for each disease. In each farm, five legume plants showing symptoms of specific diseases were sampled based on the plant part showing symptoms, put in Kraft bags, labeled, stored in a cool box and transported to the laboratory for fungal and bacterial isolations.

3.5.2 Isolation and identification of fungal pathogens from above ground plant parts

In the Laboratory, the symptomatic plant parts were washed in running tap water, cut into small pieces approximately 1 cm long and surface sterilized in 1.3 % sodium hypochlorite solution. The plant parts were rinsed in three changes of sterile distilled water, placed in Potato Dextrose Agar amended with antibiotics and incubated at room temperature (23 ± 2 °C) for 5 - 10 days. All the fungi isolated were sub cultured on PDA amended with antibiotics and incubated at room

temperature for 5 - 10 days. Identification of specific fungi was done based on cultural and morphological characteristics described using photographs in the Atlas of Soil Manual (Bhale *et al*., 2001).

3.5.3 Isolation and identification of bacterial pathogens from above ground plant parts

Small sections at the boundary of the lesions and healthy tissue on above ground plant parts were cut and surface sterilized in 1.3 % sodium hypochlorite for three minutes and rinsed in three changes of sterile water. The pieces were aseptically macerated in 10 ml of sterile distilled water using a sterile glass rod. The suspension was left to stand for 10 minutes in order to free bacterial cells from plant parts. The suspension was streaked on nutrient agar (NA) plates which were incubated in an inverted position at 26 ºC for 48 hours. Pure bacteria cultures were identified based on cultural and morphological characteristics (Section 3.5.6).

3.5.4 Determination of seed physical purity

A seed sample of 50 g replicated thrice was used in determination of common bean seed purity (ISTA, 2013). Seed samples were separated into pure seeds, discolored/shrivelled seeds, insect damaged seeds, other bean varieties, other crop seeds, inert matter and weed seeds. Each component was weighed separately and the percentage fraction calculated as follows:

$$\text{Component (\%)} = \frac{\text{Weight of each component fraction}}{\text{Total test sample weight (50 g)}} \times 100$$

3.5.5 Determination of seed germination and seedling infection

Seed germination test was conducted on 50 seeds replicated three times per sample (ISTA, 2013). The seeds were surface sterilized in 1.3 % sodium hypochlorite and then rinsed in three changes of sterile distilled water. Five seeds were placed on a wet blotter paper in a row and others placed against the five seeds to make rows of five seeds and columns of ten seeds.

Another layer of blotter paper was placed on top of the seeds and wetted with sterile distilled water. The seeds were rolled and placed inside a clear polythene bag incubated at room temperature (23 ± 2 °C) for 7 days, the blotter paper were sprayed daily with sterile distilled water to maintain the moisture. Data on the number of germinated seeds, hard seeds, mouldy seeds,seedlings showing infection and number of abnormal seedlings was recorded after 7 days. Germination percentage was calculated according to ISTA (1999):

$$\text{Percentage germinated seeds} = \frac{\text{Germinated seedlings}}{50} \times 100$$

3.5.6 Determination of seed borne bacterial pathogens in bean seeds

Bacterial pathogens were isolated using liquid assay technique/seed wash test (ISTA, 2014). Sterile saline solution was prepared by dissolving 8.5 g sodium chloride in 1000 ml distilled water amended with 0.2 ml plus Tween 20. The solution was autoclaved at 121 °C at 15 psi for 15 minutes. The number of seeds in 50 g were counted and the seed weight of the sample based on thousand seed weight (TSW) which was estimated as:

$$\text{TSW} = \frac{\text{Weight of seed (50 g)}}{\text{Number of seeds in 50 g}} \times 1000$$

Fifty grammes of each sample was suspended in sterile saline plus Tween 20 (0.02 % v/v) in a conical flask (volume of the saline was 1.0 x TSW) and soaked overnight at 4 ºC.The flasks were placed in a mechanical shaker (Artisan Technology Group, Illinois, USA) for 30 minutes to make the extract homogenous. The extract was subjected to a 10-fold dilution series upto 10^4 by pipetting 1 ml of the extract into 9 ml sterile saline. One milliliter of the 10^2 and 10^3 dilution was pippeted into sterile Petri plates and about 20 ml of Nutrient agar added. Once solidified the Petri plates were incubated at 28 °C for 48 hours in an inverted position. Each dilution was replicated thrice. Colony forming units per Petri plate of *Xanthomonas campestris* pv. *phaseoli* and

Pseudomonas savastonoi pv. *phaseolicola* were counted and recorded. The number of colony forming units per seed were calculated as follows:

$$\text{CFU/ seed} = \frac{\text{Calculated CFU}}{\text{Number of seeds in 50g}}$$

Selected bacterial colonies were sub-cultured on fresh nutrient agar for identification based on presence of yellow, mucoid, convex colonies which is a positive identity for *Xanthomonas axonopodis* pv. *phaseoli* (Karavina *et al*., 2011). Cream mucoid colonies surrounded by zone of hydrolysis were identified as *Pseudomonas savastonoi* pv. *phaseolicola* (Remeeus and Sheppard, 2006).

3.5.7 Determination of pod number and seed yield

Determination of pod number per plant was carried out at late podding stage. The number of pods was counted randomly from ten plants from the inner bean rows. After harvesting, grain legumes were sun dried for seven days, threshed manually and seed yield from each plot weighed in grams. The yield per hectare in each plot was determined as follows (FAO, 1995):

$$\text{Grain yield (kg/ha)} = \frac{\text{plot yield (kg} \times 1000)}{\text{plot size in square metres (M2)}}$$

3.6 Data analysis

Total disease indices were obtained by summing disease distribution (0 - 2), severity (0 - 3) and incidence (0 - 1). Data on bacterial and fungal isolations, disease indices, seed quality parameters and yield attributes was subjected to Analysis of Variance (ANOVA), using the PROC ANOVA procedure of GENSTAT version 12 and differences among treatments compared using Fisher's protected LSD at 5 % probability level.

CHAPTER FOUR: RESULTS

4.1 Effect of intercropping and legume diversity on intensity of soil borne diseases of common bean

4.1.1 Nutrient status of the soil

The levels of pH were significantly ($p \leq 0.05$) different among the three sites (Table 1). The levels of Carbon (C) were significantly different ($p \leq 0.05$) in the three sites and were highest and lowest in Bujumba and Madola, respectively. In general the levels of macronutrients were not significantly different ($p \geq 0.05$) in the three sites although the levels of Nitrogen varied significantly with the lowest levels being in Madola. The levels of Calcium, Copper and Iron varied significantly ($p \leq 0.05$) in the three sites. Calcium levels were lowest in Bujumba and highest in Alupe. The levels of copper were lowest in Madola while those of Iron were lowest in Bujumba.

Table 1: Nutrient status of soil samples collected from three sites in Busia County

Site	PH	N	C	P	K	Ca	Mg	Mn	Cu	Fe	Zn	Na
Alupe	5.80a	0.16a	1.72a	11.7a	0.4a	3.1a	1.4a	0.5a	6.4b	37.4b	8.1a	0.6a
Bujumba	5.10b	0.16a	1.79a	10.0a	0.2a	0.9b	1.3a	0.7a	14.3a	28.0c	5.0a	0.1a
Madola	5.3ab	0.11b	1.10b	16.7a	0.3a	1.3b	1.2a	0.8a	2.6c	45.3a	3.8a	0.2a
Mean	5.40	0.14	1.54	12.7	0.3	1.7	1.3	0.6	7.8	36.9	5.6	0.3
LSD ($p \leq 0.05$)	0.50	0.02	0.22	10.8	0.3	1.6	0.5	0.4	2.5	7.2	4.4	0.6
CV (%)	5.00	6.10	7.30	73.8	42.3	45.1	18.2	31.3	16.2	9.8	39.5	104.5

Means followed by the same letter(s) in each column are not significantly different ($p \geq 0.05$); LSD: Least difference at ($p \leq 0.05$); CV: Coefficient of variation

4.1.2 Root rot pathogens isolated from the soil

The major fungal pathogens isolated from soil samples in decreasing incidence were: *Fusarium solani*, *F. oxysporum*, *Pythium* spp., *Rhizoctonia solani* and *Macrophomina* spp. (Figure 2; Table 2). Other fungal genera isolated in low incidence from the soil were *Aspergillus* spp., *Curvularia* spp., *Penicillium* spp. and *Trichoderma* spp.

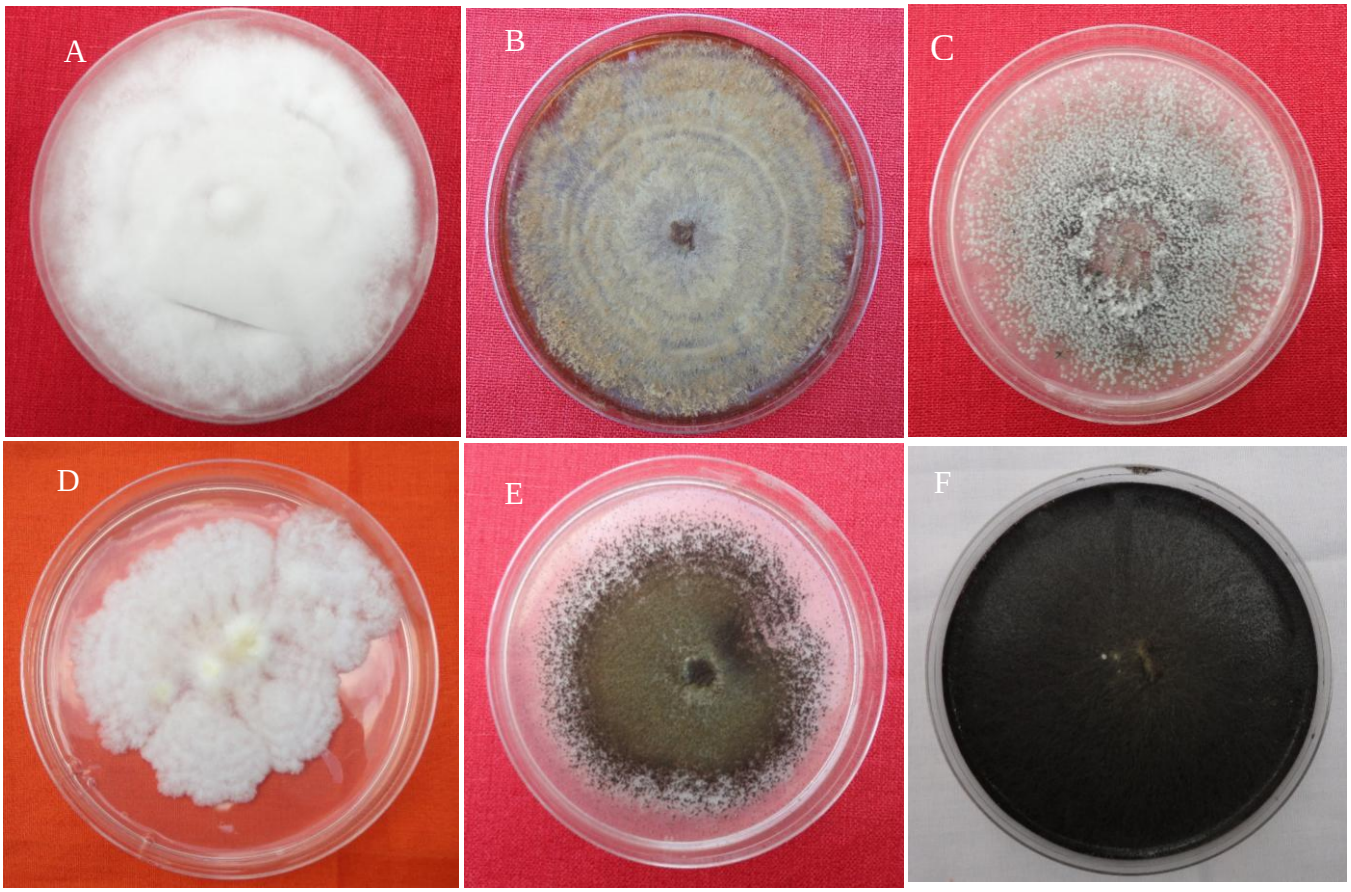

Figure 2: Cultures of major fungal species isolated from soil and common bean stem bases. A: *Fusarium solani*, B: *Rhizoctonia solani*, C: *Colletotrichum* spp., D: *Pythium* spp., E: *Aspergillus* spp., F: *Macrophomina phaseolina.*

The population and the isolation frequency of fungal pathogens in the soil significantly ($p \leq 0.05$) varied among the sites (Table 2; Table 3). *F. oxysporum* and *F. solani* were the most prevalent in Bujumba while *Pythium* spp. and *Macrophomina* spp. and *R. solani* were the most prevalent in Alupe.

Table 2: Population (CFU/g soil) of different fungal pathogens in soil sampled from three sites in Busia County

Site	*F. solani*	*F. oxysporum*	*Pythium* spp.	*R. solani*	*Macrophomina* spp.
Alupe	11,630b	12,259b	11,074a	9,000a	5,593a
Bujumba	14,722a	13,444a	10,481a	8,465b	4,833b
Madola	12,500b	11,537c	5,370b	8167b	2,111c
Mean	13,556	11,809	8,975	8,543	4,179
LSD ($P \leq 0.05$)	1416	653	1159	384	396
CV (%)	27.5	14.5	34.0	11.8	24.9

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; LSD: Least significant difference at $p \leq 0.05$; CV: Coefficient of variation

Table 3: Isolation frequency (%) of different fungal pathogens from soil in three sites in Busia County

Site	*F. solani*	*F. oxysporum*	*Pythium* spp.	*R. solani*	*Macrophomina* spp.
Alupe	29.6b	23.0a	9.5a	11.5a	5.4a
Bujumba	48.9a	23.4a	3.9b	6.9ab	0.2b
Madola	32.7b	26.6a	7.4ab	2.0b	0.1b
Mean	37.1	24.3	7.0	6.8	1.9
LSD ($P \leq 0.05$)	9.2	9.3	4.7	5.4	2.1
CV (%)	64.9	100.2	179.6	207.1	268.1

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation.

4.1.3 Root rot pathogens isolated from bean stem bases

The major root rot pathogens isolated from symptomatic and non-symptomatic common bean stem bases in decreasing incidence were; *F. solani, F. oxysporum, Rhizoctonia solani, Macrophomina* spp. and *Pythium* spp. (Table 4; Table 5). The frequency of isolation of root rot pathogens varied significantly ($p \leq 0.05$) between samples collected from intercrops and those from pure stands. There was a higher incidence of root rot pathogens in pure stands (31.6 %) compared to the intercrops (14.1 %) in all the sites. Treatment that had maize intercropped with beans, cow pea and groundnuts had the lowest frequencies (9.6 %) of all root rot pathogens isolated in all the sites (Table 4; Table 5).

Table 4: Percentage of stem bases infected with root rot pathogens from symptomatic plants of different bean treatments at four weeks after emergence in three sites in Busia County

Treatment	*F. solani*	*F. oxysporum*	*Macrophomina* spp.	*R. solani*	*Pythium* spp
Alupe					
Rose coco + maize	38.7bc	48.2ab	13.3b	18.0a	3.3b
Rose coco + mixed varieties	33.0 bc	16.0c	16.7ab	0.0c	4.7b
Rose coco + mixed species	22.8c	25.2bc	0.0c	0.0c	0.0b
Rose coco	66.7a	53.3a	20.0ab	0.0c	17.8a
KK8	71.1a	60.0a	11.1b	6.7b	8.9ab
KATX56	51.1ab	68.9a	24.4a	0.0c	17.8a
Mean	47.2	45.3	12.6	4.1	8.8
LSD ($p \leq 0.05$)	24.0	25.8	10.7	5.6	9.7
CV (%)	39.1	43.7	81.8	259.8	67.5
Treatment	*F. solani*	*F.oxysporum*	*Macrophomina* spp.	*R. solani*	*Pythium* spp.
Bujumba					
Rose coco + maize	32.6b	40.0ab	11.1a	20.0a	1.3cd
Rose coco + mixed varieties	15.3b	33.3b	6.7a	0.0c	6.7a
Rose coco + mixed species	18.3b	20.0b	0.0b	1.3c	0.0d
Rose coco	44.4ab	66.7a	6.7a	13.3ab	4.4b
KK8	53.3ab	51.1ab	0.0b	6.7bc	2.2c
KATX56	73.3a	53.3ab	0.0b	4.4bc	2.2c
Mean	39.5	44.0	4.1	7.6	2.8
LSD ($p \leq 0.05$)	30.6	32.8	5.6	10.9	1.4
CV (%)	55.2	59.1	259.8	137.7	251.6
Treatment	*F. solani*	*F. oxysporum*	*Macrophomina* spp.	*R. solani*	*Pythium* spp.
Madola					
Rose coco + maize	38.8ab	66.7ab	6.7b	18.3a	0.0a
Rose coco + mixed varieties	25.2bc	58.1b	11.1ab	13.3a	8.9a
Rose coco + mixed species	22.8c	33.0c	18.3a	1.3b	6.7a
Rose coco	49.0a	64.4ab	4.4b	15.5a	4.4a
KK8	37.8ab	86.7a	6.7b	0.0b	6.7a
KATX56	44.4a	84.4a	4.4b	4.4b	4.4a
Mean	36.3	65.6	8.6	8.8	5.2
LSD ($p \leq 0.05$)	14.3	24.8	9.0	6.4	4.0
CV (%)	80.7	32.5	178.0	203.3	178.0

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Table 5: Percentage of stem bases infected with root rot pathogens from asymptomatic plants of different bean treatments at four weeks after emergence in three sites in Busia County

Treatment	*F. solani*	*F. oxysporum*	*Macrophomina* spp.	*R. solani*	*Pythium* spp.
Alupe					
Rose coco + maize	13.3b	38.8c	6.7b	2.2b	1.3b
Rose coco + mixed varieties	20.0b	33.0cd	6.7b	1.3b	0.0b
Rose coco + mixed species	6.7b	13.3d	8.9b	1.3b	0.0b
Rose coco	68.9a	82.0a	20.0a	0.0b	8.9a
KK8	60.0a	51.1bc	13.3ab	0.0b	8.9a
KATX56	60.0a	60.0b	8.9b	8.9a	8.9a
Mean	38.2	46.4	10.8	2.3	4.7
LSD ($p \leq 0.05$)	27.6	19.9	9.9	2.9	5.3
CV (%)	45.0	31.7	72.4	205.4	118.6
Treatment	*F. solani*	*F.oxysporum*	*Macrophomina* spp.	*R. solani*	*Pythium* spp.
Bujumba					
Rose coco + maize	15.3b	8.9b	1.3b	4.4bc	0.0b
Rose coco + mixed varieties	25.2b	11.1b	1.3b	1.7c	0.0b
Rose coco + mixed species	18.3b	6.7b	0.0c	1.7c	1.3b
Rose coco	44.4ab	66.7a	2.2a	6.7b	1.3b
KK8	53.3a	60.0a	0.0c	15.6a	1.3b
KATX56	60.0a	57.8a	0.0c	4.4bc	6.7a
Mean	36.1	35.1	0.8	5.8	1.8
LSD ($p \leq 0.05$)	30.1	32.5	0.7	4.3	2.2
CV (%)	58.9	54.3	52.0	100.8	137.6
Treatment	*F. solani*	*F.oxysporum*	*Macrophomina* spp.	*R. solani*	*Pythium* spp.
Madola					
Rose coco + maize	11.1ab	32.8b	6.7a	1.3d	6.7a
Rose coco + mixed varieties	22.8ab	22.8b	0.0b	15.2a	1.3b
Rose coco + mixed species	6.7b	13.3b	0.0b	4.4cd	0.0b
Rose coco	35.6a	64.4a	2.2b	11.1ab	2.2b
KK8	20.0ab	88.2a	2.2b	4.4cd	2.2b
KATX56	20.0ab	73.3a	0.0b	6.7bc	0.0b
Mean	19.4	49.1	1.9	7.2	2.1
LSD ($p \leq 0.05$)	21.7	24.6	3.3	4.7	2.3
CV (%)	129.2	34.5	167.4	104.6	127.4

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

4.1.4 Bean seedling stand count

The percentage of emerged seedlings among treatments at two weeks after emergence varied significantly ($p \leq 0.05$) across the three sites (Table 6). Generally, the intercrops had approximately 50 % higher seedling stand count across the three sites than that of pure stands. Bean seedling stand count in Alupe was not significantly different ($p \geq 0.05$) among treatments; in Bujumba and Madola the intercrops had higher stand counts compared to the pure stands. Among the three sites, there was no significant difference ($p \geq 0.05$) in stand counts among treatments.

The stand count of seedlings at four weeks after emergence varied significantly ($p \leq 0.05$) among treatments in the three sites (Table 7). The intercrops had a higher seedling stand count compared to the pure stands. The intercrops had a 30 % higher stand count than that of pure stands. In Alupe, the seedling stand counts were not significantly different ($p \geq 0.05$) among the six treatments. The percentage seedling stand count was higher in the intercrops compared to pure stands in Bujumba and Madola. Among the three sites, Bujumba and Madola had the highest seedling stand count while the lowest was in Alupe.

Table 6: Percentage bean seedling stand count at two weeks after emergence at three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	56.0a	49.6a	60.3a	55.3
Rose coco + mixed varieties	44.4a	54.1a	58.1a	52.2
Rose coco + mixed species	51.5a	53.6a	61.3a	55.5
Rose coco	28.3b	26.2c	34.8b	29.8
KK8	26.5b	41.9ab	36.0 b	34.8
KATX56	27.6b	33.4c	28.7b	27.6
Mean	37.9a	43.1a	46.5a	42.5
LSD ($p \leq 0.05$) treatment	14.0	13.9	17.4	
LSD ($p \leq 0.05$) site	10.2			
LSD ($p \leq 0.05$) site* treatment	25.0			
CV (%)	60.7	18.1	21.0	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Table 7: Percentage bean seedling stand count at four weeks after emergence at three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	25.2a	37.8ab	41.7a	34.9
Rose coco + mixed varieties	28.5a	40.9a	32.2ab	33.9
Rose coco + mixed species	29.7a	43.1a	30.3ab	34.4
Rose coco	18.6a	27.4bc	27.8ab	24.6
KK8	27.4a	39.1a	30.7ab	27.4
KATX56	20.5a	25.5c	24.0b	20.5
Mean	21.1b	35.6a	31.1a	29.3
LSD ($p \leq 0.05$) treatment	20.2	11.3	14.0	
LSD ($p \leq 0.05$) site	5.6			
LSD ($p \leq 0.05$) site* treatment	14.5			
CV (%)	53.8	17.8	25.4	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

4.1.5 Intensity of root rots

Root rot indices were significantly ($p \leq 0.05$) different among treatments across the three sites at two weeks after emergence (Table 8). Seedlings from the intercrop system had higher root rot intensities compared to the sole crop system. The intensity of root rots was significantly different ($p \leq 0.05$) among the sites. Root rot index was highest in Madola and lowest in Alupe. At four weeks after emergence, there was significant difference ($p \leq 0.05$) among treatments in the three sites (Table 9). Treatments differed significantly ($p \leq 0.05$) in Alupe with the pure stands having a higher percentage root rot index compared to the intercrops. Percentage root rot indices among treatments were not significantly ($p \geq 0.05$) different in Bujumba and Madola. Root rot indices differed significantly ($p \leq 0.05$) among the three sites, Madola had the highest root rot indices while Bujumba had the lowest.

Table 8: Percentage of root rot indices of different bean treatments at two weeks after emergence in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	40.2a	38.5ab	70.9a	49.9
Rose coco + mixed varieties	32.8ab	49.3ab	65.6ab	49.2
Rose coco + mixed species	30.9ab	44.0ab	63.2ab	46.4
Rose coco	11.6b	29.8b	51.4b	31.0
KK8	28.6ab	23.3b	65.7ab	39.2
KATX56	11.9b	59.1a	54.4ab	41.8
Mean	26.0b	40.8b	61.9a	42.9
LSD ($p \leq 0.05$) treatment	21.9	26.1	19.4	
LSD ($p \leq 0.05$) site	16.9			
LSD ($p \leq 0.05$) site* treatment	41.4			
CV (%)	46.3		35.1	17.2

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$), CV: Coefficient of variation

Table 9: Percentage of root rot indices of different bean treatments at four weeks after emergence in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	22.8b	51.0a	61.7a	60.6
Rose coco + mixed varieties	64.1a	49.1a	68.7a	60.6
Rose coco + mixed species	64.7a	49.7a	67.2a	61.6
Rose coco	65.0a	49.0a	69.3a	55.2
KK8	55.0a	53.5a	69.7a	45.2
KATX56	47.8ab	45.1a	72.6a	59.4
Mean	53.2b	49.6b	68.2a	57.0
LSD ($p \leq 0.05$) treatment	30.9	37.1	36.0	
LSD ($p \leq 0.05$) site	13.2			
LSD ($p \leq 0.05$) site* treatment	32.4			
CV (%)	32.6	42.3	29.6	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

4.2 Effect of intercropping and legume diversity on foliar diseases and seed quality

4.2.1 Common foliar diseases of common bean in Busia County

The common foliar bacterial diseases affecting beans were common bacterial blight and halo blight while major foliar fungal diseases included Angular leaf spot, Ascochyta blight, Anthracnose and web blight (Figure 3).

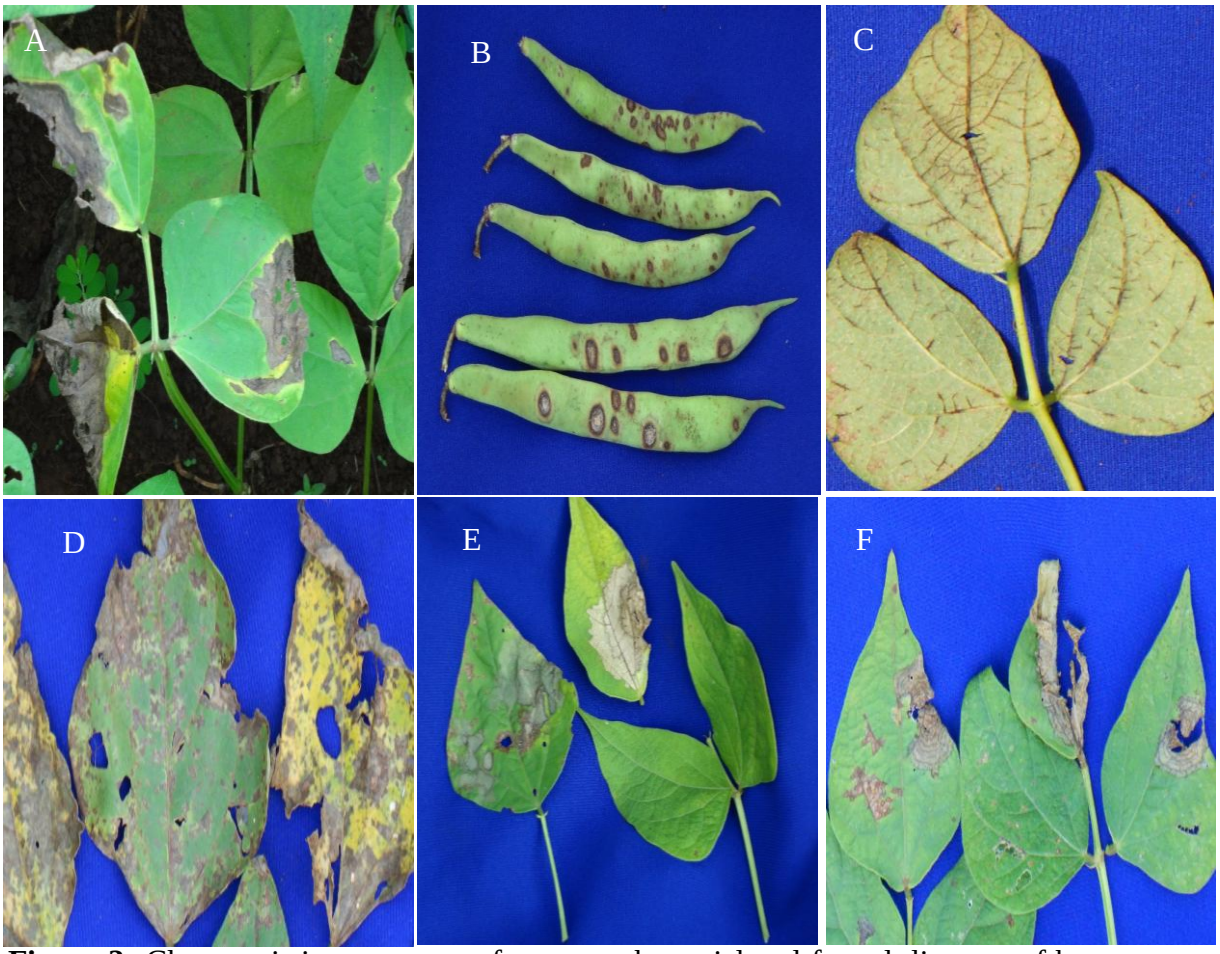

Figure 3: Characteristic symptoms of common bacterial and fungal diseases of beans grown in Busia County Kenya during long rain season of 2015.
A: Common bacterial blight, B: Anthracnose on pods, C: Anthracnose on leaves, D: Angular leaf spot, D: Web blight, E: Ascochyta blight.

4.2.2 Effect on foliar diseases at flowering stage

The mean percentage index of common bacterial blight (CBB) varied significantly ($p \leq 0.05$) among treatments in the three sites at flowering stage (Table 10). The intercrops had a lower CBB index compared to the pure stands across the three sites. The intercrops and the pure stands were significantly different ($p \leq 0.05$) in Alupe and Bujumba, with the intercrops having a lower CBB index in Alupe while the intercrops in Bujumba had a higher CBB index compared to the pure stands (Table 10). The CBB index for both intercrops and the pure stands were not significantly different ($p \geq 0.05$) in Madola. The highest CBB index of both the intercrops and the pure stands among the sites was in Madola followed by Alupe and Bujumba.

The mean percentage indices of Angular leaf spot (ALS) were not significantly different ($p \geq 0.05$) among the intercrops and the pure stands in the three sites (Table 11). The ALS indices were significantly different ($p \leq 0.05$) in the three sites with Alupe and Madola with the highest and Bujumba with the lowest. Percentage foliar disease indices at flowering stage were not significantly different ($p \geq 0.05$) between intercrops and pure stands in the three sites. However, the percentage disease index in the three sites was significantly different ($p \leq 0.05$) with Madola having the highest disease index followed by Alupe and Bujumba (Table 12).

Table 10: Percentage common bacterial blight disease indices of different bean treatments at flowering stage (six weeks after emergence) in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	37.1a	37.1a	40.2a	38.1
Rose coco + mixed varieties	24.4b	33.8a	36.9a	31.7
Rose coco + mixed species	33.3ab	23.3ab	43.5a	33.4
Rose coco	38.4a	23.6ab	44.0a	35.4
KK8	35.2ab	11.6b	46.3a	31.0
KATX56	38.0a	37.1a	64.8a	46.6
Mean	34.4b	27.7b	46.0a	36.0
LSD ($p \leq 0.05$) treatment	11.1	20.4	27.9	
LSD ($p \leq 0.05$) site	7.8			
LSD ($p \leq 0.05$) site*treatment	19.2			
CV (%)	17.7	40.5	33.4	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; Mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties; CBB: Common bacterial blight; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Table 11: Percentage angular leaf spot disease indices of different bean treatments at flowering stage (six weeks after emergence) in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	36.6a	23.1a	34.7a	31.5
Rose coco + mixed varieties	28.2a	23.9a	16.5a	22.9
Rose coco + mixed species	23.8a	23.9a	25.8a	24.5
Rose coco	37.1a	11.6a	35.7a	28.1
KK8	23.6a	11.6a	27.8a	21.0
KATX56	25.0a	12.1a	37.5a	24.9
Mean	29.0a	17.1b	29.6a	25.5
LSD ($p \leq 0.05$) treatment	27.7	12.6	21.7	
LSD ($p \leq 0.05$) site	10.4			
LSD ($p \leq 0.05$) site* treatment	25.6			
CV (%)	53.6	32	41.2	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Table 12: Percentage of root rot and foliar disease indices of different bean treatments at flowering stage (six weeks after emergence) in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	37.9a	32.9a	39.8a	39.8
Rose coco + mixed varieties	28.6a	35.7a	16.5b	34.6
Rose coco + mixed species	29.4a	30.7ab	25.8ab	34.8
Rose coco	29.0a	21.7ab	35.7ab	31.5
KK8	29.2a	15.5b	27.8ab	30.4
KATX56	25.1a	36.1a	37.5a	37.8
Mean	29.9b	28.8b	45.8a	34.8
LSD ($p \leq 0.05$) treatment	21.0	14.8	20.4	
LSD ($p \leq 0.05$) site	7.2			
LSD ($p \leq 0.05$) site* treatment	17.6			
CV (%)	39.5	28.8	25	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

4.2.3 Effect on foliar diseases at pod filling stage

Common bacterial blight index was significantly different ($p \leq 0.05$) across the three sites between intercrops and pure stands at eight weeks after emergence (Table 13). The pure stands

had a higher mean percentage of CBB index compared to the intercrops. Bean variety KK8 was tolerant to common bacterial blight (Table 13). There was no significance difference ($p \geq 0.05$) of CBB index among the sites.

Table 13: Percentage common bacterial blight disease indices of different bean treatments at pod filling stage (eight weeks after emergence) in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	13.3c	32.8a	35.6bc	27.2
Rose coco + mixed varieties	27.1bc	25.9ab	29.4bc	27.5
Rose coco + mixed species	45.4b	29.7ab	13.9c	29.7
Rose coco	76.1a	21.1ab	76.1a	57.7
KK8	0.0c	0.0b	10.9c	3.64
KATX56	56.7ab	45.0a	55.6ab	52.4
Mean	36.4a	25.8a	36.9a	33.0
LSD ($p \leq 0.05$) treatment	29.8	28.7	30.5	
LSD ($p \leq 0.05$) site	11.3			
LSD ($p \leq 0.05$) site* treatment	27.6			
CV (%)	46.0	62.6	46.5	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties; CBB: Common bacterial blight; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Angular leaf spot disease indices were not significantly different ($p \geq 0.05$) between the intercrops and the pure stands across the three sites (Table 14). There was significant difference ($p \leq 0.05$) in ALS disease index among the three sites with Madola having the highest index while Bujumba had the lowest (Table 14). Mean percentage indices of alternaria leaf spot disease were significantly different ($p \leq 0.05$) between the intercrops and the pure stands across the three sites (Table 15). Generally, the intercrops had lower alternaria leaf spot index in comparison to the pure stands. The mean percentage disease indices of anthracnose and

ascochyta blight diseases were not significantly different ($p \geq 0.05$) between intercrops and pure stands in the three sites (Table 16; Table 17). Web blight disease indices were higher in intercrops compared to that of sole crops (Table 18). Percentage mean index of anthracnose was highest in Alupe and lowest in Madola (Table 16) while mean index for Ascochyta blight was highest in Alupe and lowest in Bujumba (Table 17). Mean index of web blight disease was not significantly different ($p \geq 0.05$) in the three sites (Table 18). The mean percentage indices of foliar diseases at eight weeks after emergence were not significant ($p \geq 0.05$) among the treatments in the three sites (Table 19). The percentage mean disease index was significantly different ($p \leq 0.05$) among the three sites being highest in Alupe and lowest in Bujumba.

Table 14: Percentage angular leaf spot disease indices of different bean treatments at pod filling stage (eight weeks after emergence) in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	63.9a	43.9a	62.2a	56.7
Rose coco + mixed varieties	29.8ab	42.8a	75.0a	49.2
Rose coco + mixed species	55.4a	33.9a	59.6a	49.6
Rose coco	72.8a	37.2a	64.4a	58.2
KK8	27.8b	32.2a	57.8a	39.3
KATX56	67.8a	36.7a	63.3a	55.9
Mean	52.9a	37.8b	63.7a	51.5
LSD ($p \leq 0.05$) treatment	43.2	26.5	32.1	
LSD ($p \leq 0.05$) site	13.2			
LSD ($p \leq 0.05$) site* treatment	32.3			
CV (%)	45.9	39.5	28.4	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties; ALS: Angular Leaf Spot; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Table 15: Percentage alternaria leaf spot disease indices of different bean treatments at pod filling stage (eight weeks after emergence) in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	45.0a	12.2ab	0.0b	19.1
Rose coco + mixed varieties	28.9ab	0.0b	7.8b	12.2
Rose coco + mixed species	38.0a	12.0ab	4.1b	18.0
Rose coco	0.0b	0.0b	12.8ab	4.3
KK8	0.0b	12.8a	24.4a	12.4
KATX56	12.2ab	0.0b	0.0b	4.1
Mean	20.7a	6.2ab	8.2a	11.7
LSD ($p \leq 0.05$) treatment	33.5	12.6	15.4	
LSD ($p \leq 0.05$) site	13.4			
LSD ($p \leq 0.05$) site* treatment	32.8			
CV (%)	118.2	98.1	43.4	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties, LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Table 16: Percentage anthracnose disease indices of different bean treatments at pod filling stage (eight weeks after emergence) in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	27.8a	18.3a	0.0a	15.4
Rose coco + mixed varieties	18.9a	18.5a	10.2a	15.6
Rose coco + mixed species	27.8a	22.9a	8.3a	19.7
Rose coco	19.4a	18.9a	0.0a	12.7
KK8	11.7a	0.0a	11.7a	7.8
KATX56	26.1a	19.4a	0.0a	15.2
Mean	20.7a	16.4ab	5.0b	14.4
LSD ($p \leq 0.05$) treatment	15.1	19.3	5.7	
LSD ($p \leq 0.05$) site	15.1			
LSD ($p \leq 0.05$) site* treatment	36.9			
CV (%)	95.6	169.5	116.0	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Table 17: Percentage Ascochyta blight disease indices of different bean treatments at pod filling stage (eight weeks after emergence) in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	0.0a	0.0b	0.0b	1.9
Rose coco + mixed varieties	8.5a	0.0b	10.2a	5.0
Rose coco + mixed species	10.2a	0.0b	8.3a	6.2
Rose coco	26.7a	12.2a	0.0b	13.0
KK8	28.9a	0.0b	11.7a	9.6
KATX56	0.0a	12.2a	0.0b	8.1
Mean	12.4a	4.1b	5.0b	7.3
LSD ($p \leq 0.05$) treatment	10.5	6.7	8.4	
LSD ($p \leq 0.05$) site	3.2			
LSD ($p \leq 0.05$) site* treatment	22.4			
CV (%)	118.4	100.2	129.1	

Means followed by same letter(s) in each column are not significantly different at $p \geq 0.05$, Mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties, LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Table 18: Percentage web blight disease indices of different bean treatments at pod filling stage (eight weeks after emergence) in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	0.0b	0.0b	12.2b	4.1
Rose coco + mixed varieties	3.9a	4.1a	6.1bc	4.7
Rose coco + mixed species	0.0b	4.1a	10.2b	4.7
Rose coco	0.0b	0.0b	0.0c	0.0
KK8	0.0b	0.0b	25.0a	8.3
KATX56	0.0b	0.0b	0.0c	0.0
Mean	0.7a	1.4a	8.9a	3.6
LSD ($p \leq 0.05$) treatment	0.9	2.2	6.5	
LSD ($p \leq 0.05$) site	4.2			
LSD ($p \leq 0.05$) site* treatment	20.2			
CV (%)	124.3	98.8	130.1	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Table 19: Percentage of root rot and foliar disease indices of different bean treatments at pod filling stage (eight weeks after emergence) in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	33.7a	22.6a	31.1a	29.1
Rose coco + mixed varieties	25.9a	20.1a	29.1a	25.0
Rose coco + mixed species	34.5a	21.8a	24.5a	26.9
Rose coco	28.2a	19.8a	26.0a	24.7
KK8	17.6a	14.1a	28.5a	20.1
KATX56	30.1a	22.6a	29.1a	27.3
Mean	28.3a	20.2b	28.1a	25.5
LSD ($p \leq 0.05$) treatment	24.5	16.5	14.7	
LSD ($p \leq 0.05$) site	6.2			
LSD ($p \leq 0.05$) site* treatment	15.1			
CV (%)	17.4	46.1	29.4	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cow pea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

4.2.4 Physical quality of bean seeds

The percentage of pure seeds at planting varied significantly ($p \leq 0.05$) among the bean varieties with KK8 and Rose coco having the highest and lowest mean percentages of pure seeds, respectively (Table 20). The percentage of other bean seeds varied significantly ($p \leq 0.05$) among the three bean varieties. Seeds from Rose coco and KK8 varieties had the highest and lowest percentages of other bean seed varieties, respectively. The percentage of other crop seeds also varied significantly ($p \leq 0.05$) among the three varieties with Rose coco having the highest and KK8 having the lowest percentages. The percentage of inert matter was not significantly different ($p \geq 0.05$) among the three bean varieties. The percentage of discolored, shriveled and insect damaged seeds was significantly different ($p \leq 0.05$) among the three bean varieties with Rose coco having the highest while KK8 had the lowest.

Table 20: Percentage of pure seeds, other bean varieties, other crop seed, inert matter, shriveled seeds and insect damaged seeds in three bean varieties at planting in Busia County

Treatment	Pure seeds	Other bean variety	Other crop seed	Inert matter	Discolored seeds	Shrivelled seeds	Insect damaged seeds
Rose coco	71.0c	15.0a	1.2a	1.2a	5.3a	1.4a	4.4a
KK8	99.7a	0.0b	0.0b	0.1b	0.0b	0.2b	0.0b
KATX56	85.6b	4.8b	0.0b	0.7ab	4.3a	1.9a	3.0ab
Mean	85.4	6.6	0.4	0.7	3.3	1.2	2.5
LSD ($p \leq 0.05$) treatment	5.7	8.2	1.1	0.9	3.5	1.1	3.2
CV (%)	2.9	54.8	126.0	160.6	47.5	40.4	56.9

Means followed by the same letter(s) in each column are not significantly different at ($p \leq 0.05$); Rose coco, KK8 and KATX56 – bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

The percentage of pure seeds at harvesting was significantly different ($p \leq 0.05$) among treatments in the three sites. In general, the percentage of pure seeds from intercrops was higher than that of pure stands (Table 21). Samples from Alupe had a significantly ($p \leq 0.05$) higher percentage of pure seeds for intercrops compared to the pure crops. There was no significant difference ($p \geq 0.05$) in percentage of pure seeds between the intercrops and pure stands in Bujumba. Pure stands had a higher percentage of pure seeds compared to the intercrops in Madola.

Figure 4: Seeds of common bean varieties that were planted (A, B, C) and quality of common bean seed samples at harvest.
A: KK8 bean variety; B: KATX56 bean variety; C: Rose coco farm- saved; D: Insect damaged seeds; E: pure seeds; F: other bean seed varieties; G: inert matter; H: other crop seeds; I: shriveled seeds; J: Discolored seeds.

Table 21: Percentage of pure seeds of different bean treatments at harvest in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	96.4a	64.1b	57.5c	72.7
Rose coco + mixed varieties	78.7b	87.1a	74.0b	79.8
Rose coco + mixed species	79.7b	90.5a	74.0b	81.5
Rose coco	69.3c	66.1b	61.3c	65.5
KK8	73.1c	90.1a	80.7a	81.3
KATX56	94.8a	89.0a	82.8a	88.9
Mean	82.0a	81.1a	71.7b	78.3
LSD ($p \leq 0.05$) treatment	5.1	7.0	4.8	
LSD ($p \leq 0.05$) site	2.1			
LSD ($p \leq 0.05$) site* treatment	5.1			
CV (%)	3.4	4.7	3.7	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cowpea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Percentage weight of other bean varieties (Figure 4) in the harvested seeds was significantly different ($p \leq 0.05$) among the treatments in the three sites (Table 22). Seeds from the intercrops had a higher percentage of other bean varieties as compared to the pure stands. The seeds from intercrops in Madola and Alupe had the highest percentage of other bean varieties (Table 22). There was no significant difference ($p \geq 0.05$) between intercrops and pure stands in Bujumba.

The percentage of inert matter (Figure 4) was not significantly different ($p \geq 0.05$) among treatments in the three sites (Table 23). In general, the intercrops had a higher percentage of inert matter compared to the pure stands at 1.6 % and 1.3 % respectively. Intercrops in Alupe and Madola had a higher percentage of inert matter compared to the pure stands. There was no significant difference ($p \geq 0.05$) in percentage inert matter among treatments in Bujumba.

Table 22: Percentage of other bean varieties at harvest in different treatments in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	1.7b	27.1a	28.7a	19.2
Rose coco + mixed varieties	7.1a	8.3b	12.0c	9.2
Rose coco + mixed species	7.9a	5.6b	8.8cd	7.4
Rose coco	9.0a	29.4a	22.5b	20.3
KK8	3.5b	3.5b	6.1de	4.4
KATX56	2.1b	2.4b	3.3e	2.6
Mean	5.2a	12.7a	13.6a	10.5
LSD ($p \leq 0.05$) treatment	3.5	7.1	4.9	
LSD ($p \leq 0.05$) site	1.9			
LSD ($p \leq 0.05$) site* treatment	4.7			
CV (%)	36.6	30.7	19.8	

Means followed by same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and, cowpea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Table 23: Percentage of inert matter at harvest from different bean treatments in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	0.5c	0.7a	2.4ab	1.2
Rose coco + mixed varieties	1.7a	0.3a	3.3a	1.8
Rose coco + mixed species	1.1ab	0.9a	3.9a	1.9
Rose coco	1.3ab	0.9a	0.9b	1.1
KK8	1.2ab	0.9a	2.3ab	1.4
KATX56	0.7bc	1.1a	2.3ab	1.4
Mean	1.1b	0.8b	2.5a	1.5
LSD ($p \leq 0.05$) treatment	0.7	0.9	1.7	
LSD ($p \leq 0.05$) site	0.5			
LSD ($p \leq 0.05$) site* treatment	1.2			
CV (%)	37.1	68.8	36.2	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and, cowpea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

The percentage of discolored seeds (Figure 4) among the treatments in the three sites was significantly ($p \leq 0.05$) different (Table 24). Seeds from Alupe and Bujumba had the highest and lowest percentage of discolored seeds, respectively. The pure stands had higher percentages of discolored seeds than the intercrops across the three sites. In Alupe and Madola the percentage of discolored seeds in the pure stands was higher than that of the intercrops. There was no significant difference ($p \geq 0.05$) in percentage of discolored seeds among treatments in Bujumba.

Table 24: Percentage of discolored seeds at harvest for different bean treatments in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	3.5c	7.9a	8.2b	6.6
Rose coco + mixed varieties	13.9b	3.5a	8.5b	8.6
Rose coco + mixed species	10.9b	3.9a	8.3b	7.7
Rose coco	19.3a	3.7a	12.7a	11.0
KK8	23.3a	6.1a	10.9ab	13.5
KATX56	2.5c	8.0a	10.1ab	6.9
Mean	12.2a	5.5c	9.8b	9.2
LSD ($p \leq 0.05$) treatment	4.8	5.3	4.1	
LSD ($p \leq 0.05$) site	0.6			
LSD ($p \leq 0.05$) site* treatment	4.1			
CV (%)	21.5	53.2	23.0	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and, cowpea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

4.2.5 Germination capacity and seedling infection of bean seeds

The percentage of germinated seeds (Figure 5) at planting was significantly different ($p \leq 0.05$) in the three varieties (Table 25). KK8 seeds had the highest germination rate KATX56 had the lowest. Percentage of normal seedlings (Figure 5) in the three varieties differed significantly ($p \leq 0.05$); KK8 and KATX56 had the highest and lowest percentage of normal seedlings, respectively (Table 25). KATX56 had significantly higher ($p \leq 0.05$) percentage of abnormal seedlings than the other varieties while KK8 had the lowest. The percentage of moldy seeds (Figure 5) also differed significantly ($p \leq 0.05$) among the three bean varieties with Rose coco and KK8 having the highest and lowest percentages, respectively (Table 25). There was no significant difference ($p \leq 0.05$) in seedlings with infection among the three varieties.

Figure 5: Germination features of common bean seed samples collected from different regions in Busia Kenya.

A: Seedlings germinated on moist blotter paper; B: Seedlings showing infection; C: Moldy seeds; D: Normal germinated seed; E: Germinated abnormal seedling; F: Seedling showing infection; G: Dead and moldy seed; H: Moldy seed.

Table 25: Percentage of germinated, normal, abnormal seedlings, moldy seeds and seedlings with infection of different bean treatments at planting in Busia County

Treatment	Germinated seeds	Normal seedlings	Abnormal seedlings	Moldy seeds	Infected seedlings
Rose coco	93.3b	90.0b	2.7ab	7.3a	47.3a
KK8	99.3a	98.7a	0.7b	0.7b	52.0a
KAT	89.3b	84.0b	6.7a	5.3a	67.3a
Mean	95.3	90.9	3.3	4.4	55.6
LSD ($p \leq 0.05$) treatment	5.2	8.2	4.5	4.4	28.5
CV (%)	2.4	4.0	60.0	43.7	22.6

Means followed by the same letter(s) in each column are not significantly different at ($p \geq 0.05$); Rose coco, KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Germination rate of seeds sampled from intercrops and pure stands was not significantly different ($p \geq 0.05$) among the three sites (Table 26). Generally, seeds from intercrops had a higher germination rate (90.7 %) as compared to the pure stands (88.7 %). There was a significant difference ($p \leq 0.05$) among treatments in Bujumba and Madola with seeds from intercrops having a higher germination rate than seeds from pure stands. Seeds of both intercrops and pure stands harvested from Alupe had no significant difference ($p \geq 0.05$) in germination rates. There was significant difference ($p \leq 0.05$) in the percentage of normal seedlings after germination among treatments in Alupe and Bujumba (Table 27). The percentage of normal seedlings was lower in the intercrops compared to the pure stands in Alupe while in Bujumba, the percentage of normal seedlings was higher in pure stands than the intercrops.

Table 26: Germination rate (%) of bean seeds sampled from different treatments at harvest in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	88.7a	94.0a	90.7a	91.1
Rose coco + mixed varieties	89.3a	97.3a	86.7ab	91.1
Rose coco + mixed species	90.0a	96.0a	84.0ab	90.0
Rose coco	92.7a	88.0b	78.7b	86.4
KK8	84.7a	96.0a	86.7ab	89.1
KATX56	91.3a	94.7a	86.0ab	90.7
Mean	89.4b	94.3a	85.4c	89.7
LSD ($p \leq 0.05$) treatment	10.5	5.0	11.2	
LSD ($p \leq 0.05$) site	3.3			
LSD ($p \leq 0.05$) site* treatment	8.1			
CV (%)	6.5	2.9	7.2	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and, cowpea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Table 27: Percentage of normal seedlings at harvest for different bean treatments in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	88.0a	89.3ab	76.0a	84.4
Rose coco + mixed varieties	81.3b	92.7a	83.3a	85.8
Rose coco + mixed species	85.3ab	91.3a	78.7a	85.1
Rose coco	88.7a	82.0b	70.7a	80.4
KK8	81.3b	94.0a	82.7a	86.0
KATX 56	86.0a	90.7a	84.7a	87.1
Mean	85.1b	90.0a	79.3c	84.8
LSD ($p \leq 0.05$) treatment	4.2	7.4	16.4	
LSD ($p \leq 0.05$) site	4.2			
LSD ($p \leq 0.05$) site* treatment	10.2			
CV (%)	48.7	4.5	11.3	

Means followed by same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and, cowpea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

The percentage of abnormal seedlings was significantly different ($p \leq 0.05$) in samples from the three sites (Table 28). Seeds from pure stands had a higher percentage of abnormal seedlings in Alupe while seeds from intercrops had a higher percentage of abnormal seedlings than those obtained from pure stands in Bujumba. The mean percentage of moldy seeds in the three sites was significantly ($p \leq 0.05$) different among treatments (Table 29). In general, seeds obtained from intercrops had lower percentage of moldy seeds in Alupe and Bujumba compared to seeds obtained from pure stands. The highest and lowest percentage of moldy seeds among the three sites was in Madola and Bujumba, respectively.

Table 28: Percentage of abnormal seedlings at harvest for different bean treatments in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	0.7c	4.7ab	6.0a	3.8a
Rose coco + mixed varieties	8.0a	6.0a	3.3a	5.8a
Rose coco + mixed species	7.3ab	4.7ab	6.0a	6.0a
Rose coco	4.0abc	6.0a	8.0a	6.0a
KK	3.3bc	2.0b	4.0a	3.1a
KATX56	5.3ab	4.0ab	1.3a	3.6a
Mean	4.8a	4.6a	4.8a	4.7
LSD ($p \leq 0.05$) treatment	4.2	3.4	7.0	
LSD ($p \leq 0.05$) site	1.9			
LSD ($p \leq 0.05$) site* treatment	4.7			
CV (%)	6.5	40.6	80.0	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and, cowpea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Table 29: Percentage of moldy seeds at harvest for different bean treatments in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	3.3c	3.3b	8.7abc	5.1
Rose coco + mixed varieties	11.3ab	2.7b	7.3bc	7.1
Rose coco + mixed species	9.3abc	4.7b	13.3ab	9.1
Rose coco	6.7bc	10.6a	14.0a	10.4
KK8	14.7a	4.0b	10.0abc	9.5
KATX56	8.7abc	4.7b	4.0c	5.8
Mean	9.0a	5.0b	9.6a	7.6
LSD ($p \leq 0.05$) treatment	7.1	5.4	6.6	
LSD ($p \leq 0.05$) site	2.3			
LSD ($p \leq 0.05$) site* treatment	5.6			
CV (%)	43.3	59.8		38.0

Means followed by same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and, cowpea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

The percentage of hard seeds after germination was not significantly different ($p \geq 0.05$) among treatments in the three sites (Table 30). There was no significant difference ($p \geq 0.05$) in the percentage of hard seeds in the respective sites. There was significant difference ($p \leq 0.05$) in the percentage of infected seedlings among treatments across the three sites (Table 31). Seeds obtained from the intercrop system produced seeds that had lower infection rates compared to those from pure stands in Alupe and Bujumba. Seedlings obtained from intercrop system had the highest percentage of infected seedlings by around 36 % compared to the pure stands in Madola. The percentage of infected seeds varied significantly ($p \leq 0.05$) among the three sites with Bujumba having the highest percentage and lowest in Alupe.

Table 30: Percentage of hard seeds sampled at harvest from different bean treatments in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	2.7a	2.7a	2.7a	2.7
Rose coco + mixed varieties	2.7a	0.7bc	2.7a	2.0
Rose coco + mixed species	2.0ab	0.7bc	2.0ab	1.6
Rose coco	0.7bc	2.0a	2.0ab	1.6
KK8	0.7bc	0.0c	0.0c	0.9
KATX56	0.0c	0.7bc	0.7bc	0.4
Mean	1.4a	1.1a	2.0a	1.5
LSD ($p \leq 0.05$) treatment	1.3	0.8	1.9	
LSD ($p \leq 0.05$) site	1.1			
LSD ($p \leq 0.05$) site* treatment	2.8			
CV (%)	86.3	129.9	108.0	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cowpea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Table 31: Percentage of infected seedlings sampled at harvest from different bean treatments in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	4.0b	12.7d	44.0a	20.2
Rose coco + mixed varieties	10.7ab	36.7bc	11.3b	10.7
Rose coco + mixed species	9.3ab	49.3ab	10.7b	9.3
Rose coco	12.7ab	30.7c	16.0b	12.7
KK8	17.3a	59.3a	8.7b	17.3
KATX56	8.7ab	60.7a	11.3b	8.7
Mean	10.4c	41.6a	17.0b	23.0
LSD ($p \leq 0.05$) treatment	11.0	13.5	14.6	
LSD ($p \leq 0.05$) site	5.3			
LSD ($p \leq 0.05$) site* treatment	13.1			
CV (%)	57.6	17.9	47.1	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cowpea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

4.2.6 Bacterial infection of bean seed samples

Xanthomonas campestris pv. *phaseoli* and *Pseudomonas savastanoi* pv. *phaseolicola* were the main bacterial pathogens isolated from the bean seed samples (Figure 6). Varieties Rose coco and KK8 bean had higher population of *Pseudomonas savastanoi* pv. *phaseolicola* of up to 2500 CFU/ seed and 500 CFU/seed, respectively compared to the population of *Xanthomonas campestris* pv. *phaseoli* of up to 2300 CFU/seed and 250 CFU/ seed, respectively (Figure 7). In variety KATX56, the population (2300 CFU/seed) of *Xanthomonas campestris* pv. *phaseoli* was higher than that of *Pseudomonas savastanoi* pv. *phaseolicola* (2000 CFU/seed) (Figure 7).

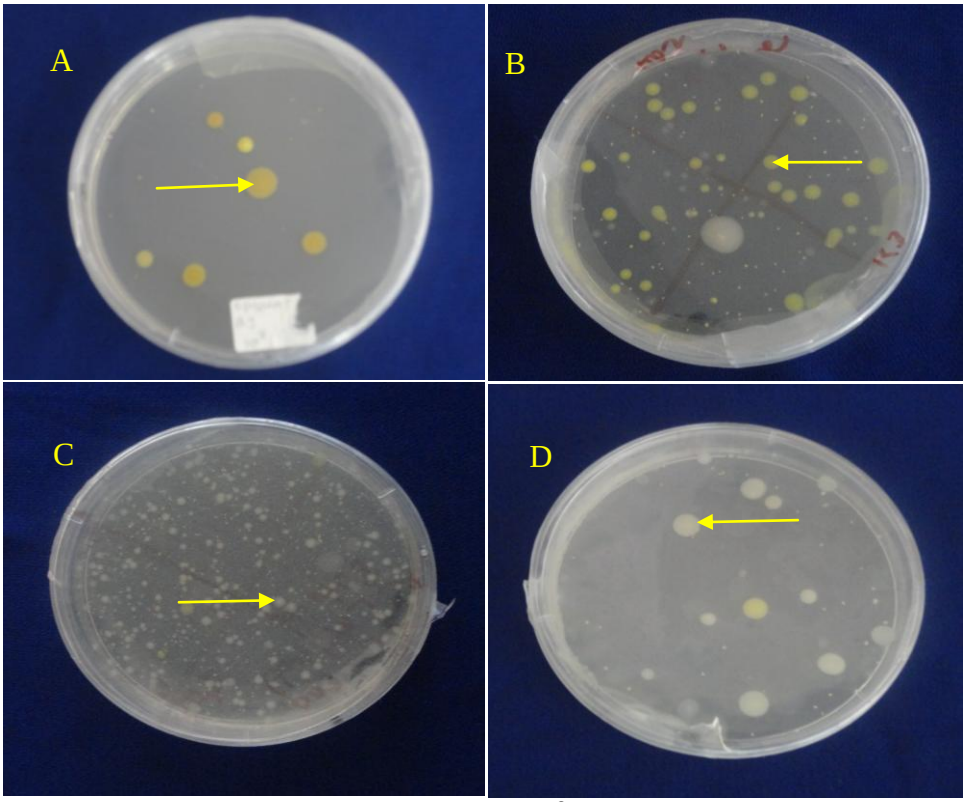

Figure 6: Common bacterial pathogens isolated from bean seeds.
A: *Xanthomonas campestris* pv. *phaseoli* (yellow colonies) from a sample with low population of the pathogen; B: *Xanthomonas campestris* pv. *phaseoli* (yellow colonies) from a sample with high population of the pathogen; C: Sample with high population of *Pseudomonas savastanoi* pv. *phaseolicola* (cream colonies); D: Sample with low population of *Pseudomonas savastanoi* pv. *phaseolicola*.

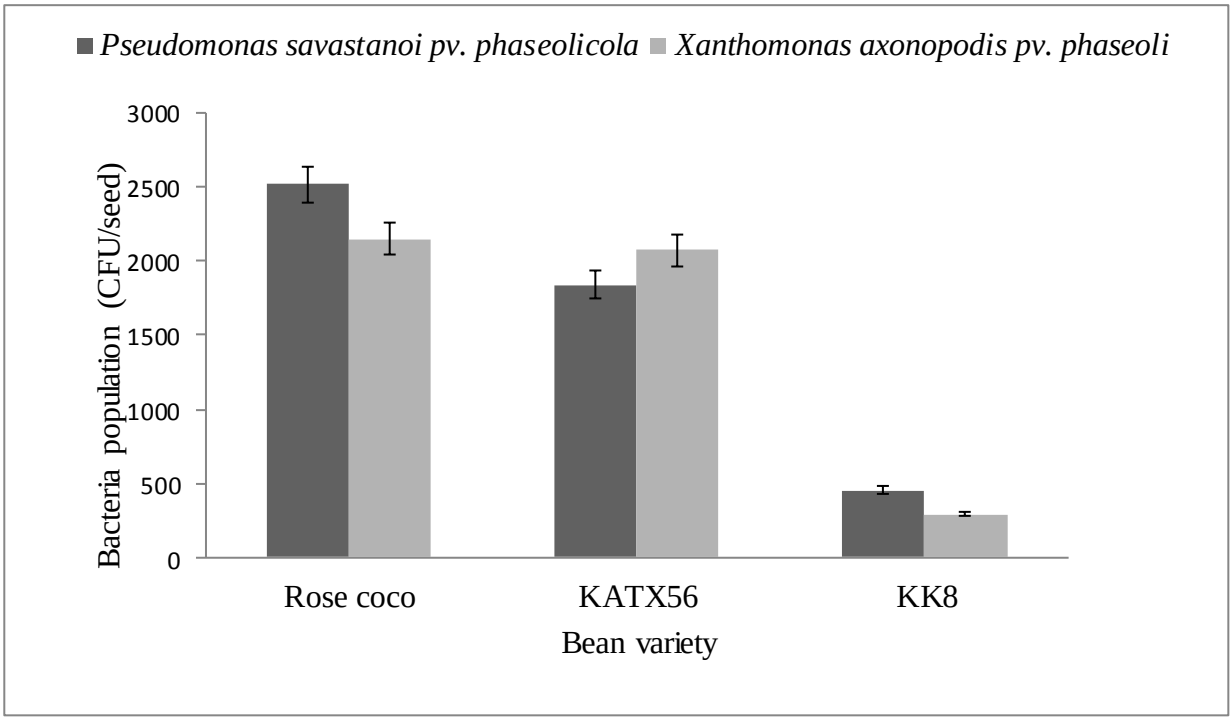

Figure 7: Population (CFU/seed) of *Xanthomonas campestris* pv. *phaseoli* and *Pseudomonas savastanoi* pv. *phaseolicola* in bean seeds sampled at planting**.**
Bars accompanied by standard error of the means

There was significant variation ($p \leq 0.05$) in the population of *Xanthomonas campestris* pv. *phaseoli* and *Pseudomonas savastanoi* pv. *phaseolicola* in seed samples obtained from intercrops and those from pure stands in the three sites (Table 32). Generally, the inoculum of *Xanthomonas campestris* pv. *phaseoli* and *Pseudomonas savastanoi* pv. *phaseolicola* was higher in seeds from pure stands than in intercrops in all the sites.

Table 32: Population (CFU/ seed) of *Xanthomonas campestris* pv. *phaseoli* and *Pseudomonas savastanoi* pv. *phaseolicola* in bean seeds sampled at harvest from different treatments in three sites in Busia County

Treatment	Alupe		Bujumba		Madola	
	PSP	XAP	PSP	XAP	PSP	XAP
Rose coco + maize	222c	209c	272cd	442c	524ab	1735ab
Rose coco + mixed varieties	206c	732b	500bc	546bc	95c	265c
Rose coco + mixed species	187c	653b	213d	213c	574ab	1472ab
Rose coco	782a	1000b	1861a	1093a	667a	1234b
KK8	396bc	1796a	694b	546bc	415b	1483ab
KATX56	704ab	1490a	708b	385c	552ab	1979a
Mean	416	980	708	606	471	1361
LSD ($p \leq 0.05$) treatment	361	348	281	427	218	528
LSD ($p \leq 0.05$) site	111.2	58.3	111.2	58.3	111.2	58.3
LSD ($p \leq 0.05$) site* treatment	272.4	142.9	272.4	142.9	272.4	142.9
CV (%)	48.8	19.9	22.3	39.6	26.0	21.8

Means followed by the same letter(s) in each column are not significantly different at ($p \geq 0.05$); Rose coco, KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation; PSP: *Pseudomonas savastanoi* pv. *phaseolicola;* XAP*: Xanthomonas campestris* pv. *phaseoli*

4.2.7 Yield and yield attributes

There was no significant difference ($p \geq 0.05$) in the number of pods per plant among treatments in the three sites (Table 33). There was significant difference ($p \leq 0.05$) in yield among treatments in the three sites with Alupe and Madola having the highest and lowest amount of seed yield, respectively (Table 34). The pure stands had a higher seed yield/ha than the intercrops across the three sites. Yield from pure stands was higher by 32 % than that of intercrops in all the three sites. Biomass per hectare was significantly different ($p \leq 0.05$) in the three sites with Alupe and Bujumba having the highest and lowest biomass respectively (Table 35). In general, pure stands had a higher biomass per hectare in each site except in Madola where

there was no significant difference ($p \geq 0.05$) between the biomass in pure stands and the intercrops.

Table 33: Average number of pods of 10 plants of different bean treatments in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	6.0a	4.0b	2.0a	4.0
Rose coco + mixed varieties	5.0a	4.0b	4.0a	4.0
Rose coco + mixed species	6.0a	4.0b	3.0a	4.0
Rose coco	7.0a	6.0a	3.0a	5.0
KK8	7.0a	5.0ab	2.0a	5.0
KATX56	8.0a	5.0ab	4.0a	6.0
Mean	7.0a	5.0ab	3.0b	5.0
LSD ($p \leq 0.05$) treatment	3.0	1.5	2.0	
LSD ($p \leq 0.05$) site	1.1			
LSD ($p \leq 0.05$) site* treatment	2.8			
CV (%)	36.3	18.1	77.8	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and cowpea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Table 34: Yield (kg/ha) of different bean treatments in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	220.0b	98.0b	99.0c	139.0
Rose coco + mixed varieties	126.0b	90.0b	50.0c	89.0
Rose coco + mixed species	66.0b	63.0b	22.0c	50.0
Rose coco	432.0ab	436.0a	423.0a	430.0
KK8	479.0ab	626.0a	160.0bc	421.0
KATX56	795.0a	357.0ab	313.0ab	488.0
Mean	353.0a	278.0ab	178.0b	270.0
LSD ($p \leq 0.05$) treatment	425.0	289.0	208.0	
LSD ($p \leq 0.05$) site	172.4			
LSD ($p \leq 0.05$) site* treatment	222.2			
CV (%)	83.6	58.6	160.8	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and, cowpea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

Table 35: Total biomass (kg/ha) of different bean treatments in three sites in Busia County

Treatment	Alupe	Bujumba	Madola	Mean
Rose coco + maize	240.0b	89.0c	134.0a	154.0
Rose coco + mixed varieties	124.0b	92.0c	69.0a	95.0
Rose coco + mixed species	98.0b	60.0c	48.0a	69.0
Rose coco	380.0ab	378.0b	949.0a	569.0
KK8	435.0ab	651.0a	400.0a	496.0
KATX56	664.0a	303.0b	230.0a	399.0
Mean	324.0a	262.0b	305.0a	297.0
LSD ($p \leq 0.05$) treatment	380.6	168.0	977.1	
LSD ($p \leq 0.05$) site	233.0			
LSD ($p \leq 0.05$) site* treatment	370.9			
CV (%)	66	36	180	

Means followed by the same letter(s) in each column are not significantly different at $p \geq 0.05$; mixed varieties: Rose coco, KK8 and KATX56; mixed species: Rose coco, KK8, KATX56, groundnuts and, cowpea; KK8 and KATX56: bean varieties; LSD: Least significant difference at ($p \leq 0.05$); CV: Coefficient of variation

4.3 Relationship among soil nutrient status, diseases and yield

There was a highly significant ($p \leq 0.05$) positive correlation (r = 0.92**) between the levels of Phosphorus and yield (Table 36). The level of Carbon was positively correlated (r = 0.97**) to the levels of Nitrogen. The intensity of root rots was positively correlated (r = 0.83**) to the intensities of foliar diseases. The population of soil borne pathogens was positively correlated (r = 0.80**) to intensity of root rot disease. There was a significant ($p \leq 0.05$) negative correlation between Nitrogen levels (r = -0.57*) and Carbon levels (r = -0.67*) to the intensity of root rot disease. The population of soil borne pathogens was negatively correlated (r = -0.66*) to seedling stand count. The soil borne pathogens population and root rot disease intensities were negatively correlated (r = -0.58*) and (r = -0.55*) to the seed yield respectively (Table 36).

Table 36: Correlation among soil pH, macronutrients, foliar diseases intensities, root rot intensities, stand count, soil borne pathogens and yield**.**

	Soil pH	Phosphorus	Nitrogen	Carbon	Foliar disease intensity	Root rot disease intensity	Stand count	soil borne pathogens	Seed Yield
Soil pH	-								
Phosphorus	0.3196	-							
Nitrogen	0.2538	-0.1923	-						
Carbon	0.1857	-0.1475	0.9665**	-					
Foliar disease intensity	0.1957	-0.2921	-0.2774	-0.4204	-				
Root rot disease intensity	-0.2290	-0.2909	-0.5652*	-0.6687*	0.8275**	-			
Stand count	-0.4460	-0.2296	-0.3675	-0.2371	0.1755	-0.1612	-		
Soil borne pathogens	0.0851	-0.1958	0.3323	0.1720	0.4171	0.8040**	-0.6640*	-	
Seed yield	0.4031	0.9253**	0.0802	0.1533	-0.4209	-0.5532*	-0.1627	-0.579*	-

*indicates significant correlation **indicates highly significant correlation at $p \leq 0.05$.

CHAPTER FIVE: DISCUSSION

5.1 Effect of intercropping and legume diversity on intensity of soil borne diseases of common bean

5.1.1 Soil nutrient status

The soils sampled at the three sites were acidic, had low levels of available Nitrogen, Phosphorus, Carbon, Potassium and organic matter for crops growth. These findings agree with the report of a study by Okalebo *et al*. (2003) who found that soils in Western Kenya are acidic with low levels of Potassium and organic matter content. This is in comparison to the adequate and recommended levels of these nutrients in the soil for crops growth; Nitrogen (0.2-0.5 %), Phosphorus (30-80 ppm), Carbon (2.66-5.32 %) and Potassium (0.24-1.5 %) and pH (5.5-6.5) (Anderson and Ingram, 1993; Hinga *et al*., 1980; Mehlich *et al*., 1962; Page *et al*., 1982).

Depletion of these nutrients and organic matter could be as a result of continuous cultivation without replenishing the soil with the necessary nutrients. In a study by Opole *et al*. (2003), common bean farmers in Busia County hardly used fertilizers to replenish their soils. Similar findings have been documented in a report by Abawi and Widmer (2000) who noted that reduction of organic matter in the soil without replenishment influences soil fertility, water availability, soil erosion and soil compaction and increases build-up of insects and makes plants more prone to attack by disease causing pathogens. Low soil fertility enhances chances of plant disease epidemics. Studies by Duffy and Defago (1999) and Medvecky *et al.* (2007) showed that adequate soil fertility and good soil management skills reduce attack of crops by root rot pathogens and improve the vigor of a crop.

5.1.2 Root rot pathogens isolated from the soil

Root rot disease is caused either by a single pathogen or a complex of pathogens. In the current study, major root rot pathogens isolated from the soils in the three sites were *F. solani, F. oxysporum, Rhizoctonia* spp., *Pythium* spp. and *Macrophomina* spp. Similarly, findings from an earlier study by Okoth and Siameto (2010) documented *Fusarium* spp., *Pythium* spp., *Rhizoctonia* spp., *Sclerotinia* spp., and *Macrophomina* spp. as the major root rot causing pathogens. *Fusarium* spp. was the most predominant of all the other species. Similar to the findings of the current study, Abawi and Pastor-Corrales (1990) reported that *Fusarium* spp. are the major root rot pathogens that constrain bean production in Latin America and Africa.

Soil is the most important inoculum source of *Fusarium* spp. and other root rot causing pathogens (Saremi and Burgess, 2000; Saremi *et al.,* 2001). Presence of these pathogens in the soil could be attributed to poor farming practices like lack of appropriate rotation programs due to lack of enough farming space (Gichangi *et al*., 2012). Crop rotation has been documented to be one of the strategies used to reduce severity and damage by many fungal root rot pathogens (Abawi and Widmer, 2000). In addition, majority of farmers do not use clean and certified bean seeds but rather recycle seeds from previous seasons that are possible carriers of pathogen inoculum from season to season (Gichangi *et al*., 2012). Similar studies by Opole *et al*. (2003) have showed that bean farmers in Busia and Siaya Counties hardly use certified seeds but instead use their own saved seeds or seeds bought from neighbors or local market from year to year. Usage of these uncertified seeds leads to build up of root rot pathogens in the seeds and soil over the years.

5.1.3 Root rot pathogens isolated from bean stem bases

Root rot pathogens isolated from bean stem bases were *F. solani, F. oxysporum, Rhizoctonia solani, Macrophomina* spp. and *Pythium* spp. These results concur with the findings by Mwang'ombe *et al*. (1997) on major root rot pathogens of bean found in Kenya. Similarly, these findings were in agreement with other reports that documented *Fusarium* spp. as the major and common pathogen that causes root rots in various crops (Saremi and Burgess, 2000; Saremi *et al*., 2001). *Fusarium* spp. which was the most abundant fungal pathogen causes major destruction in low fertility soils, in hot weather, moderate soil moisture and high acidic soils (Naseri and Marefat, 2014). Damage by root rot pathogens is common in regions with lower soil fertility (Abawi and Pastor-Corrales, 1990) conditions prevalent in LM1 (Jaeztold *et al*., 2005). Gautam *et al*. (2014) reported that *Macrophomina phaseolina,* also isolated from the stem bases, is a common root rot causing pathogen that is most infectious in long rainy season and concurrent heat; conditions prevalent when the field trial was undertaken (Appendix I).

In this study, the frequency of root rot pathogens in intercrops was lower compared to the pure stands. Maize intercropped with common beans, cow pea and groundnuts had the lowest frequencies of the root rot pathogens. Growing crops in mixtures lowers disease progress and assists a crop escape disease epidemics (Dane and Laugale, 2014; Skelsely *et al*., 2005). Studies elsewhere have shown that host diversity reduces disease progress (Garret *et al*., 2001; Andrivon *et al*., 2003); for instance, host diversity has been reported to reduce late blight epidemics of potatoes in France and United states (Garret and Mundt, 1999). The mechanisms involved in reduction of frequency of root rot pathogens in an intercrop system include abundance of predators and parasites which prevent build-up of disease causing pathogens, delay of disease

introduction by reduction of spread of disease carrying spores and modification of environmental conditions that are less favorable to spread of disease causing pathogens (Dwivedi *et al*., 2015). Intercropping promotes biodiversity of microorganisms that prevent disease outbreaks by bringing back populations of pathogens into low levels that have no major effect on crop growth (Altieri, 1994).

5.1.4 Bean seedling stand count

Bean seedling stand count differed significantly between the intercrops and the pure stands. The intercrops had a higher stand count compared to the sole crops at two and four weeks after emergence. Stand count of bean seedlings reduced drastically for both cropping system from 42.5 % to 29.3 % in two weeks. This could be attributed to death of plants as a result of infection by root rot pathogens and acidic conditions prevalent in the soils. These results are in agreement with studies by Medvecky *et al.* (2007) who reported increase in bean seedlings mortality from second, fourth up to sixth week after emergence as a result of root rot pathogens and high soil acidity. Another study by Naseri and Marefat (2011) showed that root rot pathogens are responsible for post emergence damping off that causes major seedling loss. A study by Farooq *et al*. (2011) showed that soil-borne pathogens cause major losses in crops by reducing the crop stand and lowering quality of the crops.

5.1.5 Disease intensity of root rots

There was no statistical difference in root rot disease intensity between intercrops and sole crops although disease intensity for sole crops was slightly lower than that of intercrops. These findings could be attributed to presence of root rot pathogens in other crops that had been intercropped with beans i.e. cow peas and groundnuts. These crops could have acted as reservoirs or alternate hosts for root rot pathogens. A study by Gichuru *et al*. (Unpublished) in

South Western Uganda linked diverse crops included in bean intercrop to root rot outbreaks in the region. Total disease index for root rots increased drastically in sole crop system between the second and fourth week after emergence in comparison to the intercrop system where disease progress was reduced. It is known that growing crops in mixtures assists crops escape epidemics (Skelsey *et al*., 2005). Studies elsewhere indicate that host diversity reduces disease progress (Garret *et al*., 2001; Andrivon *et al*., 2003).

5.2 Effect of intercropping and legume diversity on foliar diseases and seed quality

5.2.1 Foliar diseases at flowering and pod filling stages

There was high prevalence of bacterial and fungal diseases in the three sites. This might have been due to favorable weather conditions in LM 1 agro-ecological zone. Common bacterial blight was the most prevalent foliar disease in all the sites. These results are in agreement with Saettler (1989), who reported that common bacterial blight is an important foliar disease in hot and humid weather conditions in East Africa. The three sites differed significantly in distribution, incidence and severity of foliar diseases. Differences in altitude, relative humidity and precipitation affect the occurrence of pests and diseases in a region (Fininsa and Tefera, 2006).

Total disease index of common bacterial blight was higher in pure stands than in intercrops. These results concur with other findings by Fininsa (1996); Fininsa and Yuen (2001); Fininsa and Yuen (2002) and Rheenen *et al*. (1981), who concluded that intercropping beans with other crops reduces the severity and incidence of common bacterial blight and increases yields.

Common bacterial blight infection could have been reduced in intercropping system due to changes in the microclimate (Gomez-Rodriguez *et al*., 2003), specifically shading by maize that

lowered the temperatures and delayed CBB development by reducing bacterial multiplication thus lowering the levels of inoculum (Fininsa and Yuen, 2002). The maize plants act by shielding rain droplets thus reducing the spread of pathogens and consequently reduces rate of infection (Fininsa and Yuen, 2002). Reduced host density in intercropping system in addition to induced host resistance brought by competition could explain reduction in common bacterial blight. Stress induced to a crop through competition in an intercrop system could induce a plant to alter its physiology such that it becomes less nutritious or more toxic to the pathogen (Dwivedi *et al*., 2015). A study by Boudreau and Mundt (1992) reported that maize competition with beans in a maize-bean intercrop system led to reduction in spread of bean rust.

KK8 bean variety was less affected by common bacterial blight. This shows that usage of clean certified seeds could reduce epidemics of the disease in bean growing areas. Common bacterial blight mainly spreads through seed and use of certified seeds (for example, KK8) is one strategy that ought to be embraced by farmers in management of the disease (Karavina *et al*., 2011). Many farmers in Western Kenya use farmer saved seeds, seeds borrowed from neighbors or bought from the market (Makelo, 2010; Opole *et al*., 2003). They rarely use certified seeds as they are considered not readily available and expensive (Opole *et al*., 2003). Usage of unclean seeds from one season to another leads to build up of soil borne pathogens in the seeds and soils; which is responsible for major disease epidemics (Opole *et al*., 2006).

Total disease indices did not differ statistically between intercrops and the pure stands; although disease intensities were lower in intercrops compared to sole crops between flowering and podding stage. Among the intercrops, maize-Rose coco-KK8 and KATX56 intercrop had the

lowest disease indices. Increased mixtures of bean varieties could be the reason for lower disease indices in this intercrop system. These results concur with the findings by Hauggaard- Nielsen *et al*. (2008) who reported reduction in foliar diseases in legume (pea, faba bean and lupin)–barley intercropping system and Jensen *et al*. (2005) who reported a 20 % foliar disease decrease in many intercrop systems. Disease reduction in intercropped systems could also be attributed to interference in the spread of pathogen by varietal mixtures, in which one variety tolerant to a disease blocks movement of inoculum to susceptible varieties (Trutmann *et al*., 1993).

5.2.2 Physical purity of bean seeds

Physical purity of seeds of the three varieties that were planted did not meet the minimum pure seed standard of 95 % ISTA (1999) except for KK8 variety that had a pure seed standard of 99.7 %. The minimum pure seed standard was not met by seeds obtained from pure stands except for seeds from the maize-bean intercrop which was at 96.4 % in one site. Seeds obtained through intercrop system were higher in percentage of pure seeds compared to the seeds obtained through sole crop system. These results are contrary to findings by Oshone *et al*. (2014) who reported that seeds obtained from intercrop system were not different in physical purity from those obtained from sole crop system. The percentage of pure seeds, inert matter and discolored seeds also varied significantly among the three sites. These results are consistent with Oshone *et al*. (2014) who reported differences in physical purity of seeds from three districts in Eastern Ethiopia.

Pure stands had higher percentage of discolored seeds than the intercrops. Seed discoloration is an indication of poor seed quality, mostly caused by presence of a seed borne pathogen inoculum on seed surface (Icishahayo *et al.,* 2009; ISTA, 1999). Reduction in disease intensities in

intercropping system could explain the reduced percentages of discolored seeds in this system. Variation in seed discoloration among the three sites could be attributed to a higher prevalence of bean diseases in a particular zone compared to others due to favorable weather conditions as observed by Makelo, (2010).

5.2.3 Seed germination and fungal seedling infection

Poor seed germination leads to low plant population and low bean yields (ISTA, 1999). Seeds that were produced under intercrop system were slightly better in germination (90.7 %) compared to those produced in sole cropping system (88.7 %) though not significant. These findings were similar with those of Oshone *et al*. (2014) who found that seeds that originated from an intercrop system had a higher germination rate (84 %) compared to those produced under sole cropping system (75 %). In addition, Ogutu *et al*. (2012) working on beans in Western Kenya reported that bean seeds produced under maize-bean intercrop were not affected in germination rates. The higher germination rate of seeds from intercrops compared to sole crops could be attributed to reduced disease intensities in intercrop system that translates to better quality seeds. Seed borne diseases are known to negatively affect seed germination, seedling emergence and vigor and initial stand establishment (Icishahayo *et al*., 2009).

The germination rate of seeds from both the intercrops and the pure stands was high, above the minimum germination standard of 85 % according to ISTA (1999), contrary to Oshone *et al*. (2014) who found out that common bean in Eastern Ethiopia did not fulfill the recommended germination standard. This high germination capacity of seeds shows that both cropping systems can be adopted in production of good quality seeds. Germination capacity of seeds from both cropping systems was different among the three sites. Variations in moisture content, stage of

seed maturity at harvest, poor post- harvest handling and poor storage could be attributed to differences in germination capacities of seeds in different sites

Seedling infection with fungal pathogens was not significantly different among the two cropping systems but it was different among the three sites, corroborating a previous study by Oshone *et al*. (2014) who reported similar fungal seedling infection in both intercrop and sole crop systems. Fungal seedling infection differences among sites could have been attributed to differences in temperature. In her study, Makelo (2010) reported higher pathogen load in seed samples obtained from cooler regions than in seeds obtained from warmer regions in various crops.

5.2.4 Bacterial infection of bean seeds

Rose coco and KATX56 had high infection levels with *Xanthomonas campestris* pv. *phaseoli* and *Pseudomonas savastanoi* pv. *phaseolicola* compared to the certified KK8 variety. Presence of seed- borne pathogens in certified seeds could be attributed to storage of this seeds for long duration before use. Studies have documented presence of *Xanthomonas campestris* pv. *phaseoli* in certified seeds that have been retained for a long time (Karavina *et al.,* 2008). Many farmers in Africa obtain seeds from informal sectors i.e. they use farm saved seeds that are recycled over years, from neighbors or buy from nearby markets. These seeds harbor microorganisms that are transferred from one cropping season to another (Oshone *et al*., 2014).

Seeds from intercrops had lower populations of *Pseudomonas savastanoi* pv. *phaseolicola* and *Xanthomonas campestris* pv. *phaseoli* compared to the sole crops consistent with Oshone *et al*. (2014) who reported low proportions of *Xanthomonas campestris* pv. *phaseoli* in bean samples obtained from intercropping system. These findings are also in agreement with other studies (Fininsa, 2003) who reported reduction in common bacterial blight incidence in beans produced

under intercropping system. Similarly, other studies by Fininsa (1996), Fininsa (2001; 2002; 2003); and Rheneen *et al.* (1981) reported that intercropping system reduces disease incidence and severity of common bean. This suggests that diseases that have an overall effect on seed quality can be better managed in an intercrop system.

5.2.5 Yield and yield attributes

Common bean seed yield obtained from the three sites for the intercrops was way below the potential grain yield of about 450 kg per hectare in mono crop and 370 kg per hectare when produced under intercrop with maize (Katungi *et al*., 2010). Katungi *et al*. (2009) documented an average bean yield of 298 kg/ha in Kenya between 2001 and 2007. In the current study, seed yield was higher in pure stands (446 kg/ha) than in intercrops (93 kg/ha). These results are in agreement with previous studies by Atuahene-Amankwa and Micheals (1997), Odhiambo and Ariga (2001) and Smithson and Lenne (1996) who reported comparative yield. Rheneen *et al*. (1981) reported that beans grown in association with maize yield less considerably than when grown as mono-crops. Fininsa (2003) attributed higher yields in sole cropping to higher bean crop density compared to intercrop system. However, Trutmann *et al*. (1993) concluded that varietal mixtures of bean in an intercrop system were preferred by farmers as they provided better yield and better stability than the individual varieties. Interspecific and intraspecific competitions for space and nutrients could have resulted in reduced yields of intercrops compared to the pure stands. In a legume-cereal intercrop system, the cereal component has a higher competitive ability because of higher growth rate, extensive root system and height advantage (Ofori and Stern, 1987).

High prevalence of root rot and foliar diseases could have been attributed to the low common bean yields in all sites. Fininsa (2003) reported a bean yield loss of 38.8 kg/ha in pure stands and 71.1 kg/ha in intercrops due to common bacterial blight. Similarly, Lemessa *et al.* (2011) working on common bean in South western Ethiopia noted a decrease in yield of 18-124.5 kg/ha due to Angular leaf spot. Nutritional limitations could also have played a role in reduction of yields in intercrop system (Haggaard-Nielsen *et al*., 2007). Findings from a study by Odendo *et al*. (Unpublished) attributed decline in bean production in Kenya to diseases associated with long standing soil fertility in major bean producing areas in the country. Thuita *et al*. (2011) reported that small holder farmers rarely used fertilizers on bean crops.

The highest yield was obtained from the pure stand of variety KATX56 in Alupe (795 kg/ha) and the lowest was in maize/beans/groundnuts and cowpea intercrop in Madola (22 kg/ha). This observation on yielding capacity of KATX56 bean variety is in agreement with studies by Karanja *et al*. (Unpublished) who reported that the variety has stable yields even in stressful conditions and is therefore one of the common bean varieties being adopted in Western Kenya.

The number of pods per plant did not differ significantly among the intercrops and the pure stands. Bean crops in both cropping systems could have received similar adequate gradient of sunlight for photosynthesis. Studies by Wortmann *et al*. (1991) showed that beans and maize have no serious competition for sunlight in a bean-maize intercrop system. Biomass on the other hand was higher in pure stands than in the intercrops. Higher biomass in pure stands compared to intercrops could have been due to higher plant density in the sole crop system. Higher biomass

yield is important for nutrient utilization, kernel development, allows for efficient use of light and for reduction of weeds population (Abulo *et al*., 2005; Olupot *et al*., 2004).

5.2.6 Relationship among soil nutrient status, diseases and yield

The level of Phosphorus was highly correlated to the amount of yield. These results are in consistent with reports by Rao *et al*. (1999) who documented a 60-75 % decrease in yields in Phosphorus deficient soils in Latin America and Africa. The population of soil borne pathogens was highly correlated to root rot disease intensities. Root rot disease intensity was also positively correlated to the intensity of foliar diseases. Nitrogen and Carbon levels were negatively correlated to root rot disease intensity. This could be attributed to good soil fertility suitable for crops growth that allows crops to compete favorably for the available nutrients and to counter attacks by soil borne pathogens. A study by Altieri and Nicolls (2003) showed that the ability to tolerate diseases in crops was positively correlated to soil biology, chemistry and physics. In this study, the population of soil borne pathogens was negatively correlated to seedling stand count and overall yield. Soil borne diseases are destructive to plants and this can cause huge economic losses. Death of plants could have been caused by soil borne pathogens that resulted to lower seedling stand count. A study by Abawi and Widmer (2000) showed that soil-borne pests and diseases of vegetables are known to have negative effects on yield and vegetable quality.

Root rot disease intensity and yield were negatively correlated concurring with findings by Naseri and Marefat (2011) who reported a decrease in bean yields was associated with higher *Fusarium* root rot incidence and severity. Bean root rot caused by a single pathogen or a complex of pathogens cause pre emergence and post emergence damping off that leads to poor

plant stand which leads to total yield loss when susceptible varieties are used (Nzugize *et al*., 2011).

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Soils in Busia County, Western Kenya have low nutrient status and high acidity which poses a challenge to growth of common beans. Diverse fungal pathogens known to cause root rots i.e. *Fusarium* spp., *Pythium* spp., *Macrophomina* spp., *and Rhizoctonia* spp. were isolated from these soils in high incidence. *Fusarium* spp. was the most prevalent fungal pathogen isolated.

Root rot disease intensity was lower in sole crops compared to the intercrops although disease progress was lower in intercrops. Seedling stand count was higher in intercrops compared to sole crops.

There was high prevalence of fungal and bacterial diseases of common bean in Busia County. Intercropping beans with other crops reduced intensities of foliar diseases with the system that had the highest diversity of other crops having the lowest disease intensities. The rate of infection of bean crops grown from certified seeds was significantly lower compared to planting farmer saved seeds.

Bean seeds produced under intercrop system had higher percentages of pure seeds compared to sole cropping system. Seeds obtained from both cropping systems had similar percentage of germinated seedlings and met the minimum germination percentage standard (85%).

The population of *Xanthomonas campestris* pv. *phaseoli* and *Pseudomonas savastanoi* pv. *phaseolicola* was lower in seeds from intercrops compared to those from sole crops. Certified

KK8 variety had the lowest levels of the two bacterial species compared to KATX56 and Rose coco that had been saved by farmers.

Although intercropping system performed better in curbing diseases and producing better quality seeds, the sole crop system on the other hand resulted in higher biomass production and seed yield. This implies that farmers need to strike a balance on the best method to use in bean production and the best bean variety to cultivate while keeping disease levels low.

6.2 Recommendations

Based on the findings of this study, the following are recommended:

i. Farmers of common bean should be trained in good soil management skills and good agronomic practices like; crop rotation, removal of crop debris after harvest and usage of certified seeds and seed treatments in order to reduce build-up of pathogens in the seeds and soil.

ii. Farmers should embrace diversification of legumes that allows production of beans in conditions that make them less prone to soil borne and foliar diseases.

iii. Further research should be carried out to determine the effect varying soil nutrient status on intensities of bacterial and fungal diseases, seed quality and yields in intercropping and sole cropping systems of common bean.

iv. Further research on legume diversification should be conducted in other agro-ecological zones in order to determine the suitability of this technology and bean varieties to specific zones.

REFERENCES

Abawi G.S., Porch T.G. and Kelly J.D. (2011). Field evaluation of promising breeding lines and varieties of common bean for tolerance to soil borne pathogens. Michigan State University, Michigan, USA.

Abawi, G.S. and Pastor-Corrales, M.A. (1990). Root rot beans in Latin America and Africa. Diagnosis, research methodologies and management strategies. CIAT, Cali, Colombia.

Abawi G.S. and Widmer T.L. (2000). Impact of soil health management practices on soil borne pathogens, nematodes and root diseases of vegetable crops. *Applied Soil Ecology* 15: 37–47.

Abulo P., Olupot G., Ochwoh V.A. and Adipala E. (2005). Effect of phosphate fertilizer and pesticide application on the yield of groundnuts in Central Uganda. African Crop Science Conference proceedings 7: 37-40.

Achieng J., Kanampiu F., Chauhan Y. and Rodriquez D. (2010). Sustainable intensification of maize bean production among small holder farmers in Western Kenya. Farming system design.http://aciar.gov.au/files/node/13992/sustainable_intensification_of_maize_bean_producti_14479.pdf, Accessed 29th January 2015.

Agrios G.N. (1997). Plant Pathology 4th edition. Academic Press. San Diego. California.

Akibode S. (2011). Trends in production, trade and consumption of food legume crops in Sub-Saharan Africa. M. Sc. Thesis, Michigan State University, Michigan, USA.

Akibode S. and Maredia M. (2011). Global and regional trends in production, trade and consumption of food legume crops. Report Submitted to CGIAR Special Panel on Impact Assessment, 27 March 2011. 83 pp. http://impact.cgiar.org/sites/default/files/images/Legumetrendsv2.pdf, Accessed 13th October 2015.

Allen D.J., Ampofo J.K.O. and Wortmann C.S. (1996). Pests, diseases and nutritional disorders of the common bean in Africa: a field guide. International Center for Tropical Agriculture (CIAT), Cali, Colombia.

Allen D.J., Thottapilly G., Emechebe A.M. and Singh B. (1998). Diseases of cowpea. In Pathology of food and pasture legumes of cow pea, Allen D.J. and Lenne J.M (Eds). CAB International, Wallingford, UK. pp 267-286.

Altieri M.A. (1994). Biodiversity and Pest Management in Agroecosystems. Food Products Press, New York, USA.

Altieri M. and Nicholls C. (2003) Soil Fertility Management and Insect Pests: Harmonising Soil and Plant Health in Agroecosystems. *Soil and Tillage Research* 72: 203-211.

Amadi J.E. (1995). Chemical control of *Cercospora* leaf spot disease of cow pea (*Vigna unguiculata*). *Agriculture Search* 1: 101-107.

Anderson J.M. and Ingram J.S.I. (1993). Tropical soil biology and fertility: A handbook of methods. CAB International, Wallingford, Oxoforshire, UK.

Andrivon D., Lucas J. M., and Ellisseche D. (2003). Development of natural plots of potato cultivars with different hosts of partial resistance. *Plant Pathology* 52: 586-594.

Atuahene-Amankwa G. and Michaels T.E. (1997). Genetic variances, heritabilities and genetic correlations of grain yield, harvest index and yield components for common bean (*Phaseolus vulgaris* L.) in sole crop and in maize × bean intercrop. *Canadian Journal of Plant Science* 77: 537–538.

Audi P.O., Ngugi C.K., Wandera F.P., Ndegwa R. (1996). Dryland farming research, extension and development project. Dryland farming: Recommendations for smallholder farmers. Proceedings of a workshop held in KARI-Katumani, Machakos, Kenya. Pp. 47.

Bhale M.S., Khare D., Raut N.D. and Singh D. (2001). Seed borne diseases objectionable in seed production and their management. Scientific Publishers, India, Jodhpur. pp. 2-182.

Berglund D.R., Endres G.J. and McWilliams D.A. (1999). Corn growth and management-quick guide. North Dakota State University, Fargo, Darkota. http://www.ag.ndsu.edu/pubs/plantsci/crops/a1173.pdf, Accessed 18th March 2016.

Bollmann A., Palumbo A.V., Lewis K. and Epstein S. (2010). Isolation and physiology of bacteria from contaminated subsurface sediments. *Applied Environmental Microbiology* 76: 7413-7419.

Boudreau M.A. and Mundt C.C. (1992) Mechanisms of alterations in bean rust epidemiology due to intercropping with maize. *Phytopathology* 82: 1051–1060.

Broughton W.J., Hernandez M.B., Beebe S., Gepts P. and Vanderleyden J. (2003). Beans (*Phaseolus* spp.)- Model food legumes. *Plant and Soil Journal* 252: 55-128.

Buruchara R.A. (1990). Preliminary information on seed borne fungi of beans (*Phaseolus vulgaris*) in Kenya. In Proceedings of the second workshop on bean research in East Africa. CIAT Africa workshop series No. 7, Nairobi, Kenya. pp 257-269.

Carlson D.J. (2008). Intercropping with maize in sub- arid Regions. Community planning and Analysis. A Technical Brief. Pp 1-6.

Chui J.N. and Nadar M. (1984). Evaluation of effects of *Rhizobium phaseoli* strains on nodulation, dry matter and grain yield of two bean (*Phaseolus vulgaris*) varieties. *East African Agricultural and Forestry Journal* 44: 109-112.

Consultative Group on International Agricultural Research (CGIAR) (2012). Leveraging legumes to combat poverty, hunger and malnutrition and environmental degradation. A

CGIAR Research Program submitted by ICRISAT, CIAT, ICARDA and IITA. http://www.icrisat.org/crp/CRP3.5_Grain_Legumes_15Aug12.pdf, Accessed 17th December, 2015.

Crews] T.E. and Peoples M.B. (2005). Can the synchrony of nitrogen supply and crop demand be improved in legume and fertilizer based agro ecosystems? : A review. *Nutrient Cycling Agro ecosystems* 72: 101-120.

Dane S. and Laugale V. (2014). Influence of intercrop on plant growth and yield. *Research for Rural Development* 1: 14-18.

Duffy B. and Defago G. (1999). Macro- and micro element fertilizers influence the severity of *Fusarium* crown and root rot of tomato in a soilless production system. *Horticulture Science Journal* 34: 287-291.

Dwivedi A., Dev I., Kumar V., Yadav S.R., Yadav M., Gupta D., Singh A. and Tomar S.S. (2015). Potential role of maize-legume intercropping systems to improve soil fertility status under smallholder farming systems for sustainable agriculture in India. *International Journal of Life Sciences, Biotechnology and Pharmacy Research* 4: 145-157.

Dyck E. (1997). Screening legumes for potential for soil productivity improvement in Kenya. International Workshop on Green Manure -cover crop systems for smallholder in tropical and sub-tropical regions, held 6th to 12th April 1997 at Chepaco, Santa Catarina, Brazil, 8pp.

Farooq M., Jabran K., Cheema Z.A., Wahid A. and Siddiquec H.M. (2011). The role of allelopathy in agricultural pest management. *Pest Management Science* 67: 493–506.

Fininsa C. (1996). Effect of intercropping bean with maize on bean common bacterial blight and rust diseases. *International Journal of Pest Management* 42: 51‑54.

Fininsa C. (2003). Relationship between common bacterial blight severity and bean yield loss in pure stand and bean - maize intercropping systems. *International Journal of Pest Management* 49: 177-185.

Fininsa C. and Yuen J. (2001). Association of bean rust and common bacterial blight epidemics with cropping systems in Hararghe highlands, Eastern Ethiopia. *International Journal of Pest Management* 47: 211-219.

Fininsa C. and Yuen J. (2002). Temporal progression of bean common bacterial blight (*Xanthomonas campestris* pv. *phaseoli*) in sole and intercropping systems. *European Journal of Plant Pathology* 108: 485–495.

Fininsa, M. and Tefera T. (2006). Multiple disease resistance in common bean genotypes and their agronomic performances in Eastern Ethiopia. *International Journal of Pest Management* 52: 291-296.

Food and Agriculture Organization (1995). Farming systems approach development and appropriate technology generation. http://www.fao.org/docrep/v5330e/V5330e00.htm#Contents, Accessed 18th April 2015.

Garret K.A. and Mundt C.C. (1999). Epidemiology in mixed host populations. *Phytopathology* 89: 984-990.

Garret K.A., Nelson R.J., Mundt C.C., Chacon G., Jaramillo R.E. and Forbes G.A. (2001). The effects of host diversity and other management components on epidemics of potato late blight in the humid highland tropics. *Phytopathology* 91: 993-1000.

Gautam R., Singh S.K. and Sharma V. (2014). RAPD and Nuclear rDNA ITS polymorphism within *Macrophomina phaseolina* isolated from arid legumes of Western Rajasthan. National Academy of Sciences 84: 171-181.

Gichangi A., Maobe S.N., Karanja D., Getabu A., Macharia C.N., Ogecha J.O., Nyang`au M.K., Basweti E. and Kitonga L. (2012). Assessment of production and marketing of climbing beans by smallholders farmers in Nyanza region, Kenya. *World Journal of Agricultural Science* 8: 293-302.

Gicharu G.K., Gitonga N.M., Boga H., Cheruiyot R.C. and Maingi J.M. (2013). Effects of inoculating selected climbing bean cultivars with different rhizobia strains on nitrogen fixation. *Online International Journal of Microbiology Research* 1: 25-31.

Gichuru V., Okori P., Buruchara R. and Opio F. (Unpublished). The role of mixed cropping systems on bean root rot epidemics in South Western Uganda.

Gomez-Rodriguez O., Zavaleta-Mejia E., Gonzalez-Hernandez V.A., Livera-Munoz M. and Cardenas-Soriano E. (2003). Allelopathy and microclimatic modification of intercropping with marigold on tomato early blight disease development. *Field Crops Research* 83: 27–34.

Graham P.H. and Vance P.C. (2003). Legumes; importance and constraints for greater use. *Plant Physiology* 131: 872-877.

Haas J.D., Villalpando S., Shamah T., Beebe S., and Boy E. (2010). The effect of consuming bio fortified beans on the iron status of Mexican school children. Poster presented at the Bioavailability 2010 Conference, 26-30 Sep 2010. University of California, Davis, California.

Hagedorn D.J and Inglis D.A (1986). Handbook of Bean diseases. University of Wisconsin-Extension. http://learningstore.uwex.edu/assets/pdfs/A3374.pdf , Accessed on 6th January 2015.

Harveson M.R, Steadman J.R and Schwartz H.F (2007). Rust of dry bean. University of Nebraska- Lincoln Extension, Institute of Agriculture and Natural Resources. http://ianrpubs.unl.edu/live/g1766/build/g1766.pdf, Accessed on 13th January 2016.

Harveson M.R., Urrea C.A., and Schwartz H.F. (2005). Bacterial wilt of dry beans in Western Nebraska. University of Nebraska-Lincoln Extension, Institute of Agriculture and Natural Resources. http://ianrpubs.unl.edu/live/g1562/build/g1562.pdf, Accessed on 18th January 2015.

Hauggaard-Nielsen H., Jornsgaard B., Kinane J. and Jensen E.S (2008). Grain legume–cereal intercropping: The practical application of diversity, competition and facilitation in arable and organic cropping systems. *Renewable Agriculture and Food Systems* 23: 3–12.

Hillocks R., Madata C., Chirwa R., Minja E., and Msolla S. (2006). *Phaseolus* bean improvement

http://impact.cgiar.org/sites/default/files/images/Legumetrendsv2.pdf, Accessed on 28th November 2015.

Hinga G., Muchena F.N. and Njihia C.N. (1980). Physical and Chemical methods of soil analysis. National Agricultural Laboratories, Nairobi, Kenya.

Icishahayo D., Sibiya J., Dimbi S., Madakadze I., Manyangarrwa and Chipindu B. (2009). Assessment of quality and health of field bean seeds home saved by smallholder farmers. *Africa Crop Science* 9: 609–615.

International Center for Tropical Agriculture (CIAT) (1986). Proceedings of a Pan African workshop on bean fly. Arusha, Tanzania. Series No.1. CIAT, Cali, Colombia.

International Center for Tropical Agriculture (CIAT) (1987). Standard system for evaluation of bean germplasm. Schoonhaven A. and Pastor Corrales M.A. (compilers). Cali, Colombia 54pp.

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) (2013). A bulletin of tropical legumes II project. http://www.icrisat.org/tropicallegumesII/pdfs/Flyer_A%20Bulletin%20of%20the%20Tropical%20October.pdf, Accessed on 29th January 2015.

International Seed Testing Association ISTA. (1999). International Rules for seed testing – Rules 1999. Seed Science and Technology Supplement Rules No. 27.

International Seed Testing Association (ISTA). (2013). Rules proposal for the international Rules for seed Testing 2013 edition. International Seed Testing Association (ISTA), Bassersdorf, Switzerland.

International Seed Testing Association (ISTA). (2014). Seed health testing methods. Detection of *Xanthomonas axonopodis* pv *phaseoli* and *Xanthomonas axonopodis* var. *fuscans on Phaseolus vulgaris*. International Seed Testing Association (ISTA), Bassersdorf, Switzerland.

Jaeztold R., Schmidt H., Hortez B., Shisanya C. (2005). Farm Management Handbook of Kenya volume II. Natural conditions and farm management 2nd Edition, Part A, West Kenya subpart A1 Western Province. Ministry of Agriculture, Kenya.

Jensen E.S., Hauggaard-Nielsen H., Kinane J., Mette K.A. and Jornsgaard B. (2005). Intercropping – the practical application of diversity, competition and facilitation in arable organic cropping systems. ISOFAR: Proceedings of the Conference "Researching Sustainable Systems", Adelaide 2005.

Karanja D.R., Kavoi J., Sperling L., Rubigyo J.C. and Ogecha J. (Unpublished). Promotion of improved bean varieties in Nyanza, Western and Central Rift Valley Provinces of Kenya. http://www.pdfdrive.net/promotion-of-improved-bean-varieties-in-nyanza-western-e7478149.html, Accessed 16th January 2016.

Karavina C., Chihiya J. and Tigere T.A. (2008). Detection and characterization of *Xanthomonas phaseoli* in common bean (*Phaseolus vulgaris* L.) seeds collected in Zimbabwe. *Journal of Sustainable Development in Africa* 10:105–119.

Karavina C., Mandumbu R., Parwada C. and Tibugari H. (2011). A Review of the occurrence, biology and management of Common Bacterial Blight (CBB). Journal of *Agricultural Technology* 7: 1459-1474.

Katungi E., Farrow A., Chianu J., Sperling L. and Beebe S. (2009). Common bean in Eastern and Southern Africa: A situation and outlook analysis. International Centre for Tropical Agriculture (CIAT). http://www.icrisat.org/what-we-do/mip/projects/tl2-publications/regional-situation-outlook-reports/rso-common-bean-esa.pdf, Accessed 20th January 2015.

Katungi E., Farrow A., Mutuoki T., Gebeyehu S., Karanja D., Alemayehu F., Sperling L., Beebe S., Rubyogo J. and Buruchara R. **(**2010**).** Improving common bean productivity. An analysis social-economic factors in Ethiopia and Eastern Kenya, baseline report. Tropical legume II. International Centre for Tropical Agriculture (CIAT), Cali, Columbia. www.icrisat.org/what-wedo/impi/projects/tl2-publications/research-reports/rr-common-bean-esa.pdf, Accessed on 12th December 2015.

Kenya Agricultural and Livestock Research Organization (KALRO) (2011). Legumes project; Annual Progress Report.

http://www.ccrp.org/sites/default/files/legumes__year_1___multipurpose_legumes_for_health_and_productivity_of_smallholder_farming_systems.pdf, Accessed 15th December 2015.

Kerstin Linne, Joab Osamba and Petra Jacobi (2013). Climate risk and vulnerability profiles for Homabay and Busia Counties, Kenya. www.ACCI_Homa-bay-and-Busia-Risk-profile_1-13.pdf, Accessed 12th February 2016.

Kibunja C.N., Gikonyo E.W., Thuranira E.G., Wamaitha J., Wamae D.K, Nandwa S.M. (2000) Sustainability of long-term bean productivity using maize using maize stover incorporation, residual fertilizers and manure. Soil Science Society of East Africa, Nairobi, Kenya.

Kimiti J.M., Odee D.W. and Vanlauwe B. (2009). Area under Grain Legume cultivation and problems faced by small Holder farmers in legume production in Semiarid Eastern Kenya. *Journal of Sustainable Development* 11: 101-118.

Kiss L. and Szentivanyi O. (2001). Infection of bean with cucumber powdery mildew, *Podosphaera fusca*. *Plant Pathology* 50: 411.

Lake Victoria North Water Services Board (2013). Water Point Mapping Report

Busia County.

https://www.google.co.ke/url?sa=t&rct=j&q=&esrc=s&source=books&cd=1&cad=rja&uact=8&ved=0ahUKEwjajKKewv7LAhWBsiwKHVK0CJEQFggaMAA&url=http%3A%2F%2Fmaps.virtualkenya.org%2Fdocuments%2F739%2Fdownload&usg=AFQjCNGVH_hodU93gdudduCKGmrNc-o8vA&sig2=GnrrpYFYrCwY1ihOZeTh8A&bvm=bv.118817766,d.bGg.pdf, Accessed on 8th April 2016.

Lemessa F., Sori W. and Wakjira M. (2011). Association between Angular Leaf Spot (*Phaeoisariopsis griseola* (Sacc.) Ferraris) and common bean (*Phaseolus vulgaris* L.) Yield loss at Jimma, South Western Ethiopia. *Plant Pathology Journal* 10: 57-65.

Leslie J. F. and Summerell B. A. (2006). The *Fusarium* laboratory manual. Ames, Iowa, Blackwell Professional, USA.

Lowenberg-DeBoer J. and Ibro G. (2008). A study of the cowpea value chain In Kano State, Nigeria from a pro-poor and gender perspective. Washington, DC: USAID, Nigeria, GATE Project,http://www.nigeriamarkets.org/files/GATE_Cowpeas_Final%5B1%5D.pdf, Accessed 10th December 2015.

Maas B.L., Knox M.R., Venkatesha S., Tefera T.A., Ramme S. and Pengelly C.B. (2010). *Lab lab purpureus*, A crop lost for Africa? *Tropical Biology* 3: 123-125.

Mahasi J.M., Vanlauwe B., Mursoy R.C. and Mbehero P., and Mukalama J. (2010).Increasing productivity of soybean in Western Kenya through evaluation. 12th KARI Scientific Proceedings. http://www.kari.org/biennialconference/conference12/docs/increasing%20productivity%20of%20soybean%20in%20western%20kenya%20through%20evaluation.pdf, Accessed 23rd December 2014.

Makelo M.N. (1997). Assessment of seed-borne pathogens for some important crops in Western Kenya,A report. KARI, Katumani. http://www.kari.org/biennialconference/conference12/docs/ASSESSMENT%20OF%20SEEDBORNE%20PATHOGENS%20FOR%20SOME%20IMPORTANT%20CROPS%20IN%20WESTERN%20KENYA.pdf, Accessed 23rd December 2014

Makelo M. N. (2010). Assessment of seed-borne pathogens for some important crops in western Kenya. 12th KARI scientific conference proceedings held on 8-12th, Nov. 2010, doc 747. Nairobi, Kenya.

Maobe S.N., Dyck E.A. and Mureithi J.G. (1998). Screening of soil improving herbaceous legumes for inclusion into smallholder farming systems in Kenya. In: Soil Fertility Research for Maize-based Farming systems in Malawi and Zimbabwe. Soil Fertility Network. . Waddington S.R., Murwira H.K., Kumwenda J.D., Hikwa D. and Tagwira F. (Editors). pp 105 -112.

Mathu R.W., Nandokha T., Riungu T.C. Matere S. and Bendera N.K. (2009). The potential of soybean to increase Agricultural productivity in dry areas of Central Kenya. KARI, Kenya. http://www.kari.org/biennialconference/conference12/docs/THE%20POTENTIAL%20OF%20SOYBEAN%20TO%20INCREASE%20AGRICULTURAL%20PRODUCTIVITY%20IN%20DRY%20AREAS.pdf, Accessed 20th January 2015.

Mathuva M. N., Rao M. R., Smithson P. C., Coe R. (1996). Improving maize (*Zea mays*) yields in semiarid highlands of Kenya: agroforestry or inorganic fertilizers? *Field Crops Research* 55: 57-72.

Medvecky B.A., Ketterings Q.M, and Nelson E.B. (2007). Relationships among soil borne bean seedling diseases, *Lablab purpureus* L. and maize stover residue management, bean insect pests, and soil characteristics in Trans Nzoia district, Kenya. *Applied Soil Ecology* 35: 107-119.

Mehlich A., Pinkerton A., Robertson W. and Kepton R. (1962). Mass analysis methods for soil fertility evaluation. Cyclostyled paper, National Agricultural laboratories, Nairobi, Kenya.

Michaelsen K.F., Hoppe C., Roos N., Kaestel P., Stougaard M., Lauritzen L., Mølgaard C., Girma T. and Friis F. (2009). Choice of foods and ingredients for moderately malnourished children 6 months to 5 years of age. *Food and Nutrition Bulletin* 30: 343-403.

Mungai E.N., Agong S.G. and Matsumoto H. (2002). Aluminum tolerance of four bean (*Phaseolus vulgaris* L.) varieties. *Journal of Agriculture, Science and Technology* 4:52-65.

Mureithi J.G., Gachene C.K.K. and Ojiem J. (2003). The role of green manure in small holder farmers of Western Kenya; The Legume Research Network Project. *Tropical and Sub-Tropical Agrosystems* 1: 57-70

Muthamia, J. G. N. and Kanampiu, F. K. (1996). On-farm cowpea evaluation in the marginal areas of eastern Kenya. Pp. 677-685. In: Fungoh, P.O. and G.C.O. Mbadi (Eds. 1997). Proceedings of the 5th KARI Scientific Conference. KARI, Nairobi, Kenya.

Muthomi, J.W, Otieno P.E, Chemining'wa G.W and Wagacha J.M. (2007). Effect of legume root rot pathogens and fungicide treatments on nodulation and biomass accumulation. *Journal of Biological Sciences* 7: 1163-1170.

Mwang'ombe A.W., Thiong'o G., Olubayo F.M and Kiprop E.K. (2007). Occurrence of root rot disease of common bean (*Phaseolus vulgaris* L.) in association with bean stem maggot (*Ophyiomia* sp.) in Embu district, Kenya. *Plant Pathology Journal* 6: 141–146.

Naseri B. and Marefat A. (2011). Large-scale assessment of agricultural practices affecting *Fusarium* root rot and common bean yield. *European Journal of Plant Pathology* 131: 179-195.

National Academy of Science (1994). Biological Nitrogen Fixation. National Academy Press, Washington, DC. http://www.nap.edu/openbook.php?record_id=9288&page=R8, Accessed 23rd December 2014.

National Environmental Management Authority (NEMA) (2013). Busia District environment action plan (2009-2013). Ministry of Environment and Mineral Resources. https://www.google.com/?gws_rd=ssl#q=National+Environmental+Management+Authority+%282013%29.+Busia+District+environment+action+plan+%282009-2013%29.+Ministry+of+Environment+and+Mineral+Resources. Accessed 12th February,2016.

Nelson P.E., Tousson T.A., and Marasas W.F.O. (1983). *Fusarium* species -an illustrated manual for identification. The Pennsylvania State University Press, University Park, USA.

Nirenberg H. (1981). A simplified method for identifying *Fusarium* species occurring in wheat. *Canadian Journal of Botany* 59: 1599-1609.

Njeru C.M., Okalebo R.O., Ojiem J.O., Othieno C.O., Lauren L. and Medvecky B. (2009). Maize bean intercrop response to sole and combined organic and inorganic fertilizer application in low and high fertility areas of Nandi South District. http://www.kari.org/biennialconference/conference12/docs/maize-bean%20intercrop%20response%20to%20sole%20and%20combined%20organic%20and%20inorganic%20fertilizer.pdf, Accessed 30th January 2015.

Nyiraneza J. and Snapp S. (2007). Integrated management of inorganic and organic nitrogen and efficiency in potato systems. *Soil Science System of America* 71: 1508-1515.

Nzungize J., Gepts P. and Buruchara R. (2011). Pathogenic and molecular characterization of *Pythium* species inducing root rot symptoms of common bean in Rwanda. *Africa Journal of Microbiology Research* 5: 1169–1181.

Odhiambo G.D. and Ariga E.S. (2001). Effect of intercropping maize and beans on Striga incidence on grain yield. Seventh Eastern and Southern Africa Regional maize conference. pp183-186. https://www.uonbi.ac.ke/emmanuelariga/files/striga_intercropping_with_maize.pdf, Accessed 7th January 2016.

Odundo S.N., Okalebo R.O., Ojiem J.O., Othieno C.O., Lauren L. and Medvecky B.A. (2009). Effect of Phosphorus survival, Phosphorus accumulation and yield of cowpea (*Vigna unguiculata*) varieties across a soil fertility gradient in Western Kenya. World cowpea 2010 conference. 27th September to 1st October 2010, Saly, Senegal.

Ofori F. and Stern W. R. (1987). Cereal-legumes intercropping. *Advanced Agronomy* 41: 41-87.

Ogendo O.M.A.A and Joshua O. (2001). Response of common bean to *Rhizobium* inoculation and fertilizers. *Journal of Food Technology in Africa* 6: 121-125

Ogutu M.O., Owuoche J.O., Muasya R. and Ouma G. (2012). Effects of inter-specific interaction of nitrogen fertilizer and bean-maize cropping systems on quality of bean seed in Western Kenya, *Agriculturre and Biology Journal of North America* 3: 154-168.

Ojiem J.O., Ridder N., Vanlauwe B. and Giller K.E. (2006). Socio-ecological niche: A conceptual framework for integration of legumes in smallholder farming systems. *International Journal of Agricultural Sustainability* 4: 79-93.

Okalebo J.R., Woomer, P.L., Mukhwana, E.J., Musyoka, M.W., Ndungu, K.W., Kifuko, M N. and Kiraithe, C.K. (2003). Evaluation of soil fertility management technologies (best bets)

on yield and uptake of nitrogen and phosphorus by maize and legumes in Western Kenya: a six NGO study. *African Crop Science Conference Proceedings* 6: 480-488.

Okalebo J.R., Othieno C.O., Woomer P.L., Karanja N.K., Semoka J.R.M., Bekunda M.A., Mugendi D.N., Muasya R.M., Bationo A. and Mukhwana E.J. (2006). Available technologies to replenish soil fertility in East Africa, Nutrient. *Cycling in Agroecosystems* 76: 153-170.

Okoth S. and Siameto E. (2010). Suppression of *Fusarium* spp. in a maize and beans intercrop by soil fertility management. *Yeast and Fungal Research* 1: 035-043.

Okumu M.A., Mwonga S.M., Tabu I.M, Ojiem J. and Lauren (Unpublished). Effects of P-fortified compost manure on P-uptake and maize yield in smallholder mixed farming system in Western Kenya.

http://www.ccrp.org/sites/default/files/legumes__year_1___multipurpose_legumes_for_health_and_productivity_of_smallholder_farming_systems.pdf, Accessed 17th January 2016.

Olupot G., Etiang J., Ssali H. and Nahasirye M. (2004). Sorghum yield response to Kraal manure combined with mineral fertilizers in Eastern Uganda. MUARIK Bulletin 7: 30-37.

Opole R.A., Mathenge P.W., Auma E.O., Van Rheenen H.A. and Almekinder C.J. (2003). On-farm seed production practices of common beans (*Phaseolus vulgaris* L.). *African Crop Science Conference proceedings* 6: 722-725.

Opole R.A., Mathenge P.W., Auma E.O., Van Rneenen H.A. and Wambugu P.W. (2006). On-farm seed storage of common bean in western Kenya. *African Crop Science Conference Proceedings* 7: 1173–1178.

Oshone K., Gebeyehu S. and Tesfaye K. (2014). Assessment of common beans (*Phaseolus vulgaris* L) seed production under different cropping system by small holder farmers in

Eastern Ethiopia. *African Journal of Food, Agriculture, Nutrition and Development* 14: 8566-8584.

Otsyula R.M., Ajanga S.I., Buruchara R.A. and Wortmann C.S. (1998). Development of an integrated bean root rot control strategy for western Kenya. *Africa Crop Science Journal* 6: 61-67.

Page A.L., Miller R.H. and Keeney D.R. (1982). Methods of soil analysis. Part 2. Second edition. American Society of Agronomy, Madison, Winconsin, USA. pp 595-622.

Ramert B., Lennartson M. and Gareth D. (2002). The use of mixed cropping to manage pests and diseases-theory and practice. In Powell *et al* (eds). Proceedings of UK Organic Research conference, Institute of Rural Studies, University of Wales Aberystwyth, pp 207-210.

Rao I.M., Friesen D.K and Osaki M. (1999). Plant adaptation to phosphorus-limited tropical soils. pp. 61-96. In M. Pessarakli (ed.), Handbook of Plant and Crop Stress. Marcel Dekker, New York, U.S.A.

Riddell R.W. (1950). Permanent stained mycological preparations obtained by slide culture. *Mycologia* 42: 265-270.

Rheneen H.A., Hasselbach O.E. and Muigai S.G.N. (1981). Effect of growing beans together with maize on the incidence of bean diseases and pests. *Plant Pathology* 87:193-199.

Remeeus P. M. and J. W. Sheppard. 2006. Proposal for a new method for detecting Xanthomonas axonopodis pv. phaseoli on beans seeds. *ISTA method validation reports supplementary* 3: 1-11.

Rubyogo J.C., Sperling L. and Assefa T. (2007). A new Approach for facilitating farmers "access to bean seed." *Leisa Magazine* 23: 27-29.

Rusike J., van den Brand G., Boahen S., Dashiell K., Kantengwa S., Ongoma J., Mongane D.M., Kasongo G., Jamagani Z.B. and Abaidoo R. (2013). Value chain analyses of grain legumes in N2Africa: Kenya, Rwanda, eastern DRC, Ghana, Nigeria, Mozambique, Malawi and Zimbabwe, www.N2Africa.org,96Pp, Accessed on 3rd October 2015.

Rusuku G., Buruchara R., Gatabazi M., and Pastor-Corrales M., (1997). Occurrence and distribution in Rwanda of soil borne fungi pathogenic to the common bean. *Plant Disease* 81: 445-449.

Sacred Africa (2002). MBILI is Number 1: A Handbook of innovative maize-legume Intercropping. pp 20.

Saettler A.W. and Hart L.P. (1983). Bean Anthracnose. Extension bulletin E-1671. Michigan State University. Michigan State, USA. http://archive.lib.msu.edu/DMC/Ag.%20Ext.%202007-Chelsie/PDF/e1671-1983.pdf, Accessed on 25th January 2015.

Saettler A.W., Hart L.P. and Correa F. (1984). Angular leaf spot of dry beans. Extension bulletin E-1753. Michigan State University. http://fieldcrop.msu.edu/uploads/documents/E1753.pdf, Accessed on18th January 2015.

Saettler A.W. (1989). Common bacterial blight in Schwartz and Pastor-Corales M.P. (eds). Bean production problems in the tropics. International Center for Tropical Agriculture (CIAT), Cali, Colombia. pp 29-32.

Saremi H. and Burgess L. (2000). Effect of soil temperature on distribution and population dynamics of *Fusarium* species. *Journal of Agricultural Science and Technology* 2: 119-125.

Saremi H., Amir M. and Ashrafi J. (2001). Epidemiological aspects of bean decline disease caused by *Fusarium* species and evaluation of the bean resistant cultivars to disease in Northwest Iran. *African Journal of Biotechnology* 10: 14954-14961.

Schwartz H. and Pastor-Coralles M. (1980). Bean Production Problems in the Tropics. International Centre for Tropical Agriculture (CIAT), Cali, Colombia.

Scott J., Kambewa P., Chirwa R., Vas Aggarwall (2003). Local seed systems for beans in Malawi. International Centre for Tropical Agriculture (CIAT) Africa occasional publication series, No.40.

Shiferaw W., Silim S., Muricho G., Audi P., Mligo J., Lyimo S., You L. and Christiansen J.L. (2007). Assessment of the adoption and impact of improved Pigeon pea varieties in Tanzania. *Journal of Agricultural Research* 3: 1-27.

Skelsey P., Rossing W. A. H., Kessel G. J. T., Powell J. and Van der Werf W. (2005). Influence of host diversity on development of epidemics: An evaluation and elaboration of mixture theory. *Phytopathology* 95:328-338.

Smithson J.B. and Lenne J.M. (1996). Varietal mixtures: a viable strategy for sustainable productivity in subsistence agriculture. *Annual Applied Biology* 128: 127-158.

Thuita M.N., Okalebo J.R., Othieno C.O., Kipsat M.J. and Nekesa A.O. (2011). Economic Returns of the "MBILI" intercropping compared to conventional systems in Western Kenya.In: A. Bationo et al. (eds.), *Innovations as Key to the Green Revolution in Africa*. https://www.google.co.ke/search?tbm=bks&hl=en&q=thuita+m.n.%2c+okalebo+j.r.%2c+othieno+c.o.%2c+kipsat+m.j.+and+nekesa+a.o.+%282011%29.+economic+returns+of+the+%e2%80%9cmbili%e2%80%9d+intercropping+compared+to+conventional+systems+in

+western+kenya.in%3a+a.+bationo+et+al.+%28eds.%29%2c+innovations+as+key+to+the+green+revolution+in+africa.pdf, Accessed on 7th April 2016.

Tisdale S.L, Nelson W.L, Beaton J.D. (1985). Soil fertility and fertilizers, 5th edition, Macmillan Publishing Company, New York, USA.

Trutmann P., Voss J. and Fairhead J. (1993). Management of common bean diseases by farmers in Central African Highlands. *International Journal of Pest Management* 39: 334-342.

Wanjekechee, Mwangi T.J., Kamidi M., Powon P., and Khaemba J. (1997). Farmer participation in evaluation of grain legumes in north Western Kenya. http://www.kainet.or.ke/documents/farmer-participation-evaluation-grain-legumes-north-western-kenya, Accessed 16th January 2015.

Welch R. and Graham R. (2000). A new paradigm for world agriculture: productive, sustainable, nutritious, healthful food systems. *Food and Nutrition Bulletin* 21: 361-366.

Wortmann, C.S., Sengooba,T. and Kyamanywa (1991). Banana and Bean Intercropping: Factors Affecting bean yield and Land Use Efficience. *Journal of Experimental Agriculture* 28: 283-291.

Wortmann, C.S., R.A. Kirkby, C.A. Eledu, and D.J. Allen. (1998). Atlas of common bean (*Phaseolus vulgaris* L.) production in Africa. International Center for Tropical Agriculture (CIAT) Cali, Colombia. pp 445–449.

APPENDIX

Appendix I: Monthly precipitation (mm), temperature (°C) and relative humidity (%) data recorded at Kakamega Meteorological Weather Station for the year 2015.

Month	Total precipitation (mm)	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity 06Z (%)	Relative humidity 12Z (%)
January	3.4	31.0	13.8	60.0	31.0
February	52.2	32.6	14.1	60.6	31.2
March	210.6	32.4	15.4	55.2	33.0
April	368.3	28.0	15.8	83.2	65.4
May	302.5	27.6	15.9	84.0	66.0
June	230.7	26.9	15.1	87.9	64.4
July	146.0	28.1	14.6	82.0	54.0
August	198.8	28.8	14.8	77.0	52.0
September	110.5	28.8	15.0	77.0	57.0
October	195.6	28.2	16.0	*	*
November	NIL	NIL	NIL	*	*
December	132	27.6	15.3	*	*

Relative humidity 06Z - relative humidity taken at 9.00am; relative humidity 12z - relative humidity taken at 3.00pm

*Missing weather data.

Source: Ministry of Environment, Water and Natural Resources, State Department of Environment, Meteorological Service, Kenya (2015).