EFFECT OF SOIL NUTRIENTS AND INTERCROPPING ON SOIL BORNE DISEASES AND SEED QUALITY OF COMMON BEAN IN BUSIA COUNTY

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DECLARATION

This Thesis is my original work and has not been presented for award of a degree in any other University

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DEDICATION

I dedicate my Thesis to my son Enoch K. Jarry, mother, Emma F. Morris, late father Emmanuel K. Morris and A Alexander Dunbar. They have been my greatest inspiration.

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ABBREVIATIONS AND ACRONYMS

AE	Agronomic Efficiency
AEZ	Agro-ecological Zones
ALS	Angular Leaf Spot
BNF	Biological Nitrogen Fixation
C	Carbon
CBB	Common Bacterial Blight
CEC	Cation Exchange Capacity
CFU	Colony Forming Units
CGIAR	Consultative Group for International Agricultural Research
FAO	Food and Agriculture Organization of the United Nations
GLP2	Global Legume Program Two
ISTA	International Seed Testing Association
KARLO	Kenya Agricultural and Livestock Research Organisation
KK8	Kakamega Eight
NARL	National Agricultural Research Laboratories
Ppm	Parts Per Million
RCBD	Randomized Complete Block Design
ISFM	Integrated Soil Fertility Management
K	Potassium
KCL	Potassium Chloride
LM	Lower Midland
LER	Land Equivalent Ratios
N	Nitrogen
N2	Nitrogen Gas
OMA	Organic Matter Amendment
P	Phosphorus

PDA	Potato Dextrose Agar
SAPEC	Smallholder Agricultural Productivity Enhancement and Commercilization
SOM	Soil Organic Matter
SSA	Sub Saharan Africa
SSP	Single Super Phosphate
SOC	Soil Organic Carbon
$ZnNO_3$	Zinc Nitrate

GENERAL ABSTRACT

High occurrence of bean root rots is attributed to continuous and inappropriate cropping systems, low soil fertility, use of low quality seed and use of susceptible varieties. Intercropping system is important in a sustainable agricultural production, thereby contributing to improved soil fertility and disease management. This study evaluated the effect of soil nutrients and intercropping on soil borne diseases and seed quality of severed common bean varieties. The field experiments were set up in Alupe, Busire and Butula of Busia County with two farmer saved bean varieties KK8 and GLP2 in pure stand, intercropped with maize and applied with and without fertilizer. Soil samples were collected to determine the soil nutrients status and population of soil borne fungal pathogens. The pathogens population was determined as the number of colony forming units after isolation on Potato dextrose agar medium by dilution plate method. Data on crop emergence stand count, bean fly incidence, disease distribution, incidence and severity was also collected. Root rot and bean fly damage incidences were assessed at second and fourth week after emergence while foliar diseases were assessed at the fourth and sixth week after planting. Fungal infections on bean stem bases were determined by isolation on agar medium while plant biomass, numbers of pods per plant and grain yield were determined at harvest. Quality of the bean seed was assessed based on physical purity, seed discoloration, seed shrivelling and germination. Bacterial contamination of seeds was determined as the number of bacterial colony forming units in seed washings plated on nutrient agar medium. Soil nutrient levels varied significantly ($P \leq 0.05$) between sites, where soil from Alupe was sufficient in most elements than soils from

Butula and Busire. The fungal soil borne pathogens isolated from soil and stem bases were *Fusarium oxysporum, F. solani, Pythium* spp., *Macrophomina* spp. and *Rhizoctonia* spp. The highest population was observed in soil sample from Butula (Mean = 8000 CFU/g), with *Fusarium* spp. being the most predominant with a mean population of 3000 CFU/g and incidence of 40%. There was a significant variation ($P \leq 0.05$) on the incidence of root rot pathogens isolated from stem bases between sites and treatments. The stem bases from Butula had the highest incidence of root rot (Mean = 50%). Beans intercropped with maize and applied with fertilizer had significantly lower ($P \leq 0.05$) intensity of root rot of about 20% compared to pure stand. Foliar diseases observed in the field were common bacterial blight, angular leaf spot, bean anthracnose, web blight, bean rust and *Aschochyta* leaf spot. Disease intensity varied significantly ($P \leq 0.05$) among the different treatments. Bean seed yield was below the potential yield of 1400 to 2000Kg/Ha. However, the KK8 variety intercropped with maize and applied with fertilizer had a higher yield of 1040 Kg/Ha. The bean seed samples did not meet the 95% recommended purity level; however samples from the intercrop plots had higher purity levels and recommended germination level of 85%. Bean seeds from sole crop plots had higher levels of *Xanthomonas axonopodis* pv. *phaseoli* at 1091 CFU/seed and *Pseudomonas savastanoi* pv *phaseolicola* at 776 CFU/seed. Results from this study indicated that low soil fertility, use of low quality seed and high inoculum levels of soil borne pathogens in the soil contribute to the high incidences of bean diseases. The study concluded that Low soil fertility increase the severity of soil borne diseases. Intercropping system prevents buildup of soil borne pathogens, thereby lowering insect pest incidences, diseases thus improving soil fertility, growth and yield of the crop. The

study recommended that there should be an incorporation of intercropping system, crop rotation and field sanitation as common bean disease management and soil fertility improvement measures. Price reduction of bean certified seed for affordability by small scale farmers and farmer training on improved post-harvest and storage practices.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Common bean is an important grain crop in the world and has been recognized as a crop that could ensure food security mostly in Sub – Saharan Africa (Mlyneková *et al*., 2014). The size of land under bean production in Africa is about 4 million hectares, with an annual production of approximately 2 million tons (CIAT, 2014). It is estimated that the crop can meet more than 50% of dietary protein requirements at household level (Lupwayi *et al*., 2011; Sinclair and Vadez, 2012). The crop increases soil carbon and nitrogen contents in cropping systems and plays an essential role in conserving farming systems by improving the soil nutrient levels, porosity and structure (Espinoza *et al.,* 2015). This reduces several environmental problems associated with artificial nitrogen use in agriculture and lowers the incidence of soil borne pathogens like *Fusarium* spp., *Pythium* spp. and *Rhizoctonia* spp. (Daryanto *et al.,* 2015). In Kenya, common bean is a cheap source of protein and is grown mainly by small scale farmers for consumption and sale (Sinclair and Vadez, 2012). The crop is adapted to varied climatic and agronomic conditions, and exhibits considerable variation in growth habit and seed type (Zerihun *et al.,* 2013).

In Sub Saharan Africa, the crop is grown primarily by small scale farmers who have limited resources and usually produce the crop under adverse conditions such as low input use which include informal seeds, marginal lands, and intercropping with competitive crops (Namugwanya *et al.,* 2014). The annual per capita consumption of common bean is higher among low-income people and it is a major source of iron for populations in Eastern Africa and Latin America (Sinclair and Vadez, 2012). In Eastern Africa, the per capita consumption of 50 to 60 kg per year in Rwanda, Kenya and Uganda is considerably higher than in Latin America where per capita consumption is 4 and 17 kg per year in Colombia and Brazil, respectively (Namugwanya *et al.*, 2014). In addition to its subsistence value, common bean is an important source of income and revenue to the majority of rural peasants in Sub Saharan Africa (Broughton *et al*., 2003).

Common bean production is affected by biotic and abiotic stresses which seriously compromise their yields (Zerihun *et al.,* 2013), and these are constraints or factors that limit the production of legumes in Sub-Saharan Africa. The principal constraints include diseases, pests, market constraints, low seed quality, drought and low soil fertility (De Luque, José, and Creamer, 2014). The crop productivity is severely constrained by biotic factors such as diseases which include ascochyta leaf blight, angular leaf spot, anthracnose, root rot and common bacterial blight. Root diseases that are caused by soil-borne pathogens are often the main constraints in legume crop production (Erper *et al*., 2008). The disease depresses seedling germination and cause post emergence damping off that result in poor crop stand and low yield (Erper *et al*., 2008; Muthomi *et al*., 2007). This study was carried out to contribute to improved legume productivity through nutrient management, cropping systems and reduced impact of soil borne diseases.

1.2 Problem statement

Common bean is constrained by several biotic and abiotic factors including diseases, insect pests, poor seeds quality, drought, low soil fertility and poor crop management (Birachi *et al*., 2011). The seed yields in most African countries have been declining due to low soil fertility (Khalid *et al*., 2012). Common bean requires essential nutrients and organic matter in the soil for proper growth (Espinoza *et al.,* 2015). Phosphorus, nitrogen and potassium are the essential nutrients required for proper growth and production of the common bean (Puri *et al.,* 2016). The amount of organic matter in the soil influences soil structure, water holding capacity and cation exchange capacity (Espinoza *et al.,* 2015). However, the plant vigor of common bean is poor in soils with low extractable soil phosphorus (Namugwanya *et al.,* 2014).

Angular leaf spot, anthracnose, common bacterial blight, bean rust, bean Common mosaic virus, *Fusarium* wilt and root rots are the most common diseases of beans causing yield losses. Soil and seed borne diseases have a significant and devastating effects in common bean growing areas since they negatively affect the quality and quantity of the crop (Scotti *et al*., 2015). Bean root rot is caused by a complex of soil borne fungal pathogens which include *Fusarium* spp., *Rhizoctonia solani*, *Pythium* spp. and *Macrophomina* spp. which are often the main constraints in common bean production (Erper *et al*., 2008). Seed yield in most African countries has been declining due to bean root rot. In western Kenya, root rot is a major constraint affecting the crop's productivity, and high population density of the pathogens results from the intensification in land use (Erper *et al*., 2008) causing a buildup of inoculum in the soil. The bean fly (*Ophiomyia phaseoli)* is an important pest of common bean. The insect pest interferes with nutrient transport and creates passage for root rot pathogens thus threatening common bean production (Naseri, 2008). The incidence and severity of seed borne infection by major fungal and bacterial pathogens remain a limiting factor to common bean production (Naseri, 2014).

Seedborne diseases often strike early in the growth of the crop causing poor crop establishment and reduced plant vigor, leading to yield loss and poor seed quality (Mohammed, 2013). Economically important seed borne diseases of common bean include anthracnose (*Colletotrichum lindemuthianum*), common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*) and angular leaf spot (*Phaeoisariopsis griseola* (Sacc.) (Danish *et al.,* 2013). The reliance on farm saved seeds by farmers cause a decline in common bean production due to reduced germination capacity, vigor and seedling damage resulting in development of disease at later stages of plant growth (Mohammed, 2013). Moreover, yield gap has been associated with low quality seed and poor soil fertility (Naseri, 2014). Therefore, this study aimed at contributing to improved legume productivity through nutrient management, cropping systems and reduced impact of soil borne diseases.

1.3 Justification

Common bean (*Phaseolus vulgaris* L.) is an important herbaceous annual grain legume in the world chiefly grown as a cheap source of protein among majority of Sub-Saharan African people The crop plays a big dietary role in supplying proteins, carbohydrates, essential elements and vitamins to both rural and urban households (Oshone *et al.,* 2014). The production of common bean in Eastern and Southern Africa is 40 percent of the total production of the crop in Africa. However, the crop is marketed at a market value of USD 452 million (Katungi *et al.,* 2009). Regular consumption of common bean is promoted by health organizations because the crop reduces the risk of diseases such as cancer, diabetes and coronary heart diseases (Mlyneková *et al*., 2014). Globally, about 12 million metric tons of common beans are produced annually (Daryanto *et al.,* 2015; Zerihun *et al.,* 2013). Latin America is the largest producer, while Africa is the second most important region, producing about 2.5 million metric tons (Zerihun *et al.,* 2013).

The crop serves as low cost nutrient management technology for rapidly improving the fertility levels by adding carbon and nitrogen to the soil (Mutegi *et al*., 2014). Common bean based cropping systems generally enhance yield, and fix nitrogen thereby reducing reliance on nitrogen fertilization that has been linked to environmental problems (Maraseni, 2014). Studies have reported that intercropping common bean with different crops increases yield and are a better management approach in enhancing seed quality and soil fertility levels (Latati *et al.*, 2013). The crop also has positive impacts on yield when grown in rotation or as cover crop with cereals; it has also been found to increase soil carbon and nitrogen content, improve the resistance of soil to erosion, and reduce the incidence of certain soil pathogens (Daryanto *et al*., 2015). Common bean is the most important grain legume of human consumption and has a role in sustaining agricultural system (Sinclair and Vadez, 2012). This study was therefore carried out to contribute to improved legume productivity through nutrient management, cropping systems and reduced impact of soil borne diseases.

1.4 Objectives

The overall objective of this study was to contribute to improved legume productivity through nutrient management, cropping systems and reduced impact of soil borne diseases.

The specific objectives were:

i. To determine the effect of soil type and fertility on the incidence and severity of root rot disease of common bean.

ii. To determine the effect of fertilization and intercropping on foliage diseases and seed quality of common bean

1.5 Hypotheses

i. Soil type and fertility level influence the incidence and severity of root rot disease of common bean.

ii. Intercropping and fertilization affect foliage diseases and seed quality of common bean diseases and seed quality.

CHAPTER TWO: LITERATURE REVIEW

2.1 Soil fertility levels and common bean production

Common bean (*Phaseolus vulgaris* L.) is an important food grain legume crop that is widely grown as a subsistence crop by smallholder farmers to provide an important source of dietary protein (Sinclair and Vadez, 2012). Despite the relatively high importance and demand, the yields of common bean have remained low, especially under resource-poor farmer conditions and low soil fertility (Mutegi *et al*., 2014). Low levels of soil fertility affect the production of common bean which are related to the soil organic matters depletion (Tairo and Ndakidemi, 2013). Organic matter increases yield and reduce the production cost thereby improving crop growth, productivity and economy (Lehmann and Kleber, 2015). Soil organic matter is a complex mixture that contributes positively to soil fertility, soil tilth, crop production, and soil sustainability, thus improving soil quality (Liao *et al.*, 2015). Therefore, low levels or loss in soil organic matter affects soil fertility and cause a decline in the productivity of common beans (Lehmann and Kleber, 2015; Mutegi *et al*., 2014). Soil organic carbon is an essential indicator of the soil fertility thus regulating nitrogen application in farming systems. Low soil organic carbon levels can be an environmental threat since low fertility results in low biomass yield (Lehmann and Kleber, 2015).

Soils that have low levels of N and P have limited capacity to support growth of common bean, since these nutrients are vital in enhancing the crop growth and development (Tairo and Ndakidemi, 2013). Factors leading to soil nutrient depletion through physico- climatic processes are loss of N and P through wind, water and erosion as well as leaching away of N and P. In addition to improving plant growth, N is also highly needed for all enzymatic reactions in plants, and it plays a vital role in photosynthesis and is a major component of several vitamins

(Omotayo and Chukwuka, 2009). Phosphorus as an important nutrient of the soil influences the growth and nutrition of the crops, and its deficiency in tropical soils is one of the most yield-limiting factors for successful production of common beans (Fageria *et al.,* 2013).

2.2 Effect of soil nutrient and fertility levels on common bean production

Agriculture is marked by its low productivity due to several factors causing soil infertility. However, crop production is hindered due to the texture and chemical composition of soils (Vanlauwe *et al.,* 2015). Common bean (*Phaseolus vulgaris* L.) is a nutrient-demanding crop due to its sensitivity to environmental stresses. The yields of common bean have remained low, especially on small scale farms due to low fertility of soils, which limits plant nutrition (Liao *et al.,* 2015). Soil-related constraints particularly the deficiencies of nitrogen, phosphorus and soil acidity-related are the biggest causes of a persistent gap between potential and realized crop productivity (Kumar and Babel, 2010). The yields of common bean in most African countries are low due to low soil fertility (Muthomi *et al.,* 2007), and declining levels of soil fertility have limited capacity to support growth of the crop (Naseri, 2014).

The soil type and texture influence soil borne pathogens which have negative impact on the crop (Naseri, 2008). Epidemic of the root diseases caused by group of different fungi is a result of the heterogeneity of the soil environment (Liao *et al.,* 2015). The epidemics of soil-borne diseases depend on interactions between the disease development and soil environment (Naseri, 2008). Naseri (2014) working on bean production and *Fusarium* root rot in diverse soil environments, indicated that the soil pH, organic materials and soil texture influenced *Fusarium* root rot. Organic matter amendments can be an effective practice in controlling diseases caused by soil borne pathogens due to the soil type and nutrient depletion. Improved soil structure has the ability to hold water and nutrients thereby enhancing soil fertility (Scotti *et al.,* 2015).

Common bean *(Phaseolus vulgaris* L.*)* yields in Western Kenya are low and this has been attributed to low soil fertility (Keino *et al.,* 2015). Low soil fertility is a major constraint in common bean production (Liao *et al.,* 2015) and is related to soil organic matter depletion. Declining soil nutrients are due to the continuous cultivation without the use of fertilizer (Kajumula and Muhamba, 2012). Therefore, the deficiencies of nitrogen (N), phosphorous (P), potassium (K), magnesium (Mg), zinc (Zn), and calcium (Ca) and manganese (Mn), aluminium (Al) and salt (NaCl) toxicities (Allen *et al.,* 1996; Wortmann *et al.,* 1998) have all negatively affected beans production (Bot, 2016).

2.3 Management of soil fertility

In improving the soil fertility levels and nutrient supply, integrated soil fertility management that enhances crop production in an environmental friendly manner is required (Agegnehua *et al.,* 2016). Integrated soil fertility management consists of different practices, preferably used in combination, including resistant varieties, the appropriate use of fertilizer, organic resources amendment and good agronomic practices that conserve the soil (Vanlauwe *et al.,* 2015). Integrated soil fertility management also uses common bean in small scale farming system which play a complementary or alternative role as a source of organic fertilizer thus enhancing soil fertility. Common bean serves as soil fertility improvement crop and has the potential of sustaining the farming system (Adjei-Nsiah, 2012). Intercropping common bean with other crops serves as one of the ISFM practices and is beneficial to smallholder farmers due to the ability of the common bean to contribute to addressing the problem of the declining levels of soil fertility (Matusso, 2014).

Common bean increases the levels of N and P in the soil and also has the ability to fix N through symbiotic fixation (Namugwanya *et al.,* 2014). The crop serves as low cost nutrient management technologies facilitating nutrient uptake, improving soil fertility and crop yield (Mutegi *et al.,* 2014). Common bean as rotational crop serves as a management strategy for soil fertility. This process builds soil nutrients, improves the fertility levels and preserves the environment. Common bean based rotation can serve as an improvement strategy for soil fertility (Kurwakumire *et al.,* 2015).

2.4 Importance of common bean

Common bean (*Phaseolus vulgaris* L.) is the most important grain legume in human diets, and serves as an important source of dietary protein, vitamins and essential minerals for more than 300 million people in the tropics and the second most important crop after maize (Petry *et al.*, 2015). Over 200 million people in sub-Saharan Africa depend on the crop as a primary staple, which is cultivated by small scale farmers mainly by women (Mlyneková *et al*., 2014). The annual per capita consumption of common bean is higher among low-income people, and millions of small-scale farmers in Latin America and Africa rely on the production mainly for consumption and house hold income (Katungi *et al.,* 2010). According to the Food and Agricultural Organization of the United Nations, the world demand for protein is estimated at 40% (Lewin and FAO, 2016), therefore common bean provide some of the protein because they are excellent sources of protein. The crop also acts as a source of other nutrients, such as iron and zinc, similar to seafood, meat, and poultry (Sinclair and Vadez, 2012).

In addition as a food-secure and nutritious crop, especially in Sub-Saharan Africa (SSA), common bean has the capacity for symbiotic nitrogen fixation, underscoring their importance as a source of nitrogen in both natural and agricultural ecosystems (Mlyneková *et al.,* 2014). The agricultural system can use the nitrogen from common bean which has the potential to sustain the agricultural productivity (Liao *et al.,* 2015). Common bean in cropping systems adds and recycles biologically fixed nitrogen gas (N_2) by enhancing nutrients uptake, and ensured long-term sustainability of the soil system (Maraseni, 2014). Globally, the prize of N fertilizer is escalating; therefore rotating common bean offers a cheaper alternative for increasing soil carbon levels, improving the productivity, profitability and sustainability of the soil systems (Mlyneková *et al.,* 2014; Mutegi *et al.,* 2014).

2.5 Production and economic importance of common bean

Common bean is estimated to be one of the most important legumes worldwide and is an important source of nutrients for more than 300 million people in parts of Eastern Africa and Latin America (Petry *et al.,* 2015). Common bean represents 65% of the total protein consumed and is an important component of the production systems for smallholder farmers in Eastern and Southern Africa (Sinclair and Vadez, 2012). The annual global bean production is approximately 12 million metric tons, with 5.5 and 2.5 million metric tons alone in Latin America Caribbean and Africa, respectively (Petry *et al.,* 2015). In Africa, the highest apparent per capita consumption is found in Burundi, Kenya and Rwanda, ranging from 31 kg to 66 kg per year (Katungi *et al.,* 2009). Common bean is a major source of micronutrients such as iron, zinc, thiamin and folic acid. However, the crop has the potential to alleviate micronutrient malnutrition and hunger as it is rich in quality protein (Katungi *et al.,* 2009).

In Latin America and other parts of Africa, small-scale farmers rely on the production and sales of common beans as an important source of household income (CGIAR, 2012; Zerihun *et al.,* 2015). Given the importance of common bean as a source of protein and nutrition, they also have the potential to serve a useful role in reducing poverty thereby improving food security (De Luque José and Creamer, 2014). In Kenya, common bean is an important source of protein for many households, but the production has reduced due to many constraints (Leitch *et al.,* 2016).

Bean production has not kept pace with the consumption rate and productivity is less than 25 percentage of the potential yield, and this reduction is due to biotic and abiotic stresses such as insect pest, diseases and poor soil fertility (Tryphone *et al.,* 2012). Study shows that in 2007, the production was 417000 metric tonnes while the demand was estimated at 500000 metric tonnes (FAOSTAT, 2010).

Common bean is one of the most ancient crops of the new world. It is a stable food for more than 100 million people in Africa (Tryphone *et al.,* 2012), that is adapted to many niches, both in agronomic and consumer preference terms (Daryanto *et al.,* 2015). The crop can be obtained in as little as two (2) months, and rotations are possible with other crops during short growing seasons (Broughton *et al.,* 2003). Common bean is ranked among humanity's most important agricultural food crops (Zerihun *et al.,* 2015; Daryanto *et al.,* 2015). Common bean (*Phaseolus vulgaris* L.) has the ability to form a symbiotic relationship with soil bacteria capable of trapping nitrogen gas from the atmosphere and converting it into ammonia, which can be used by the plant for growth, development and seed production (Mlyneková *et al.,* 2014). The capacity of common bean to fix atmospheric nitrogen gives it an advantage over non-leguminous crops when grown on soils low in nitrogen (Namugwanya *et al.,* 2014). The agricultural system can use the nitrogen from common bean which has the potential to sustain the agricultural system (Maraseni, 2014).

2.6 Production of common bean in Western Kenya

Common bean is a major food staple in Western Kenya, grown by small scale farmers. The grain provides proteins, income and acts as a feed for livestock as well as improving soil fertility (KARI, 2014). The productivity of common bean in Western Kenya has declined and yields are low due to biotic stresses including diseases and pests (Mutegi *et al.,* 2014). Soil borne diseases cause yield loss in the crop's production, and this is due to the continuous cultivation of a single crop (Naseri, 2008). Root rot is a major soil borne disease that reduces the germination, plant stand and yield in the county. There are two varieties that are most popular to farmers in Western Kenya which include Rose coco and KK8 (CIAT, 2014; Mutegi *et al.*, 2014). Studies have shown that rose coco is susceptible to root rot while KK8 is the resistant variety (CIAT, 2014).

The bean crop in Western Kenya is affected by foliar diseases of which many are seed borne (Mutuma *et al.,* 2014). Seed borne diseases remain a major constraint due to the reliance on farm saved seeds by small scale farmers (CIAT, 2014). In Western Kenya, poor soil fertility continues to challenge small scale farmers in crop production (Mutuma *et al.*, 2014). Yield losses in the Busia County have been associated with low quality seed and poor soil fertility (Mutegi *et al.*, 2014). However, the farmers rely on common bean as a nutrient management strategy for rapidly improving the nutrient status fertility levels of the soil (Mutuma *et al.*, 2014; Mutegi *et al.*, 2014).

2.7 Different cropping systems of common bean

In agriculture, cropping systems such as intercropping, cover cropping and crop rotation play a critical role by influencing optimal yield (Wang *et al.,* 2014). Crop rotation is the primary aspect of cropping systems and has great production potential with less element of risk (Pokhrel, 2013). Common bean crop rotation is a best alternative for plant nutrient management which is environmentally safe and can efficiently reduce fertilizer consumption (Namugwanya *et al.*, 2014; Pokhrel, 2013). Monocropping has a negative impact on crop production which has raised the need for studying intercropping approaches (Gebru, 2015).

Common bean can be grown as a monocrop which is usually higher in forage quality (Abera *et al.,* 2017), however, intercropping improves crop production and nutrients level in the soil. Unlike monocropping, intercropping changes the dynamics of the crop diseases and pest and thereby positively influencing seed health (Oshone *et al.,* 2014). Intercropping common bean with different crops produces a greater yield and is a better management approach in enhancing seed quality and soil fertility levels (Sinclair and Vadez, 2012). Intercropping system provides higher cash returns to smallholder farmers than growing monocrops (Matusso, 2014). Common bean, a major legume in Western Kenya is mostly intercropped with maize and sorghum (CIAT, 2014).

2.8 Effect of the different cropping systems on common bean diseases

Agronomic practices are designed to manage biodiversity in the agro ecosystem by enhancing diversity and repressing pests and diseases outbreaks, and practices such as intercropping and crop rotation have positive changes in the soil structure and root rot disease dynamics leading to increase in yield (Ellouze *et al.,* 2014). Soil borne diseases damage plants upon penetration and have the potential to seriously harm the agro ecosystem significantly affecting global food production (Gao *et al.,* 2014). Root rots are caused by a complex of soil-borne fungal pathogens which include *Fusarium solani*, *Fusarium oxsporum*, *Pythium* spp., *Macrophomina phaseolina*, and *Rhizoctonia* spp. (Naseri, 2014).

Occurrences of the different pathogens result in higher disease incidences and severity, therefore crop rotation and intercropping are the simple and economic alternatives of disease management which prevent crop losses (Belel *et al.,* 2014). Intercropping systems of common bean reduces weed, insect and disease incidence. Crop rotation interrupts pathogens cycle and is the primary aspect of cropping systems, therefore disease reduction is variable in combining common bean and cow pea in rotation (Lupwayi *et al.*, 2011).

2.9 Effect of common bean cropping systems on soil fertility

Common bean cropping systems have soil quality benefits which include increasing soil organic matter, improving soil porosity, recycling nutrients, improving soil structure and water holding capacity, decreasing soil pH, in the soil (Nwaogu and Muogbo, 2015). Common bean has greater roles in cropping systems, especially in regions where accessibility and affordability of fertilizer is an issue (Lupwayi *et al.*, 2011). In common bean cropping systems, there is an increase in soil fertility as a result of nutrient rich residues provided by common bean (Sinclair and Vadez, 2012). Intercropping as a major cropping system is advanced as one of the integrated soil fertility management practices (Lupwayi *et al.*, 2011; Sinclair and Vadez, 2012).

The productivity of small holder farming system is under threat due to soil fertility decline, and grain legumes such as common bean in cropping systems can play a complementary or alternative role as a source of organic fertilizer due to its ability to enhance soil fertility (Adjei – Nsiah, 2012). Legume cropping systems are popular across the world and contribute to reduced nitrogen and carbon losses in the soil (Sinclair and Vadez, 2012). Nitrogen is quantitatively the most essential nutrient for plant growth and its absence serves as a major constraint in crop production which leads to low productivity and widespread food insecurity (Belel *et al.*, 2014). Therefore, common bean in cropping systems adds and recycles biologically fixed Nitrogen gas (N_2) by enhancing nutrients uptake, and ensure long-term sustainability of the soil system (Maraseni, 2014). Crop rotation offers a cheaper alternative for increasing soil carbon levels, improving the productivity, profitability and sustainability of the soil systems (Sainju *et al.*, 2012).

2.10 Diseases of common bean

Yield stability of common bean is constrained by a number of pest and diseases (Abebe *et al.*, 2013). Major fungal foliar diseases are rusts , powdery and downy mildews, ascochyta blights, botrytis gray molds, anthracnose, angular leaf spot, vascular wilts and white molds (Singh and Schwartz, 2010). Moreover, fungal infestation of seed coat decreases viability of seeds, or may cause abnormal seedlings (Embaby *et al.*, 2013). Common bean is often attacked by the pathogenic rust fungi, *Uromyces appendiculatus* (Pers.), of which the development of pathogen is highly influenced by environmental factors such as temperature and humidity, and host factors such as leaf age (Singh and Schwartz 2010).

Bean anthracnose caused by *Colletotrichum lindemuthianum* is one of the most important seed borne disease of common bean (*Phaseolus vulgaris* L.) in the world. The disease causes up to 100% yield loss and symptoms appear on leaves, stems, pods and seeds (Mohammed, 2013). Seed infection is the primary means by which the pathogen spreads (Mohammed, 2013; NAFIS, 2015). Under favorable environmental conditions the disease can cause a 100% yield loss. A study by Amin (2014) stated that yield loss up to 62.8% due to anthracnose was recorded in Ethiopia on susceptible cultivars of common bean. The disease causes blackening along the veins, particularly on the undersurface of the leaves (Infonet biovision, 2015). Angular leaf spot caused by *Pseudocercospora griseola* (Sacc.) is one of the most important and widely distributed diseases of common bean in producing regions. However, seeds, plant debri and volunteer crops can serve as important sources of the disease (Leitch *et al.,* 2016). The disease causes premature defoliation, shrivelled pods, and shrunken seeds.

The major bacterial diseases found in common bean are bacterial brown spot, caused by *Pseudomonas syringae* pv. *Syringae*, common bacterial blight (CBB), caused by *Xanthomonas*

Xanthomonas axonopodis pv. *phaseoli* and halo blight, caused by *Pseudomonas syingae* pv. *phaseolicola* (Infonet biovision, 2015). These diseases are known to reduce growth vigor, yield and quality (Akhavan *et al.,* 2013). Common bacterial blight is considered mainly a foliar disease in which symptoms initially appear as small water-soaked spots that then enlarge and become necrotic and usually bordered by a chlorotic zone (Akhavan *et al.,* 2013). Among all means, contaminated seed is probably the major source of bacteria introduced into new bean field (Mokhtar *et al.,* 2014). Halo blight of bean causes considerable problem in beans field, attacking both foliage and pods. The symptom of the disease appear as small water soaked lesions on leaves which later turn to a greenish yellow halo that results into the death of the crop (Arnold *et al.,* 2011).

2.11 Effect of root rots in common bean production

Soil borne fungal pathogens are widespread throughout common bean production areas, and are a major threat to its production (Naseri, 2014). Root rot is one of the most prevalent soil borne bean diseases, caused by a complex of fungal pathogens including *Fusarium* spp., *Rhizoctonia solani*, *Macrophomina* spp. and *Pythium* spp. (Embaby *et al.*, 2013). These pathogens are among the limiting factors in common bean production all over the world, affecting quality and yield (Erper *et al.*, 2008). Root rot pathogens are the most frequently soil borne pathogens that cause high economic damages in various common bean growing locations in Western Kenya (Saremi *et al.,* 2011).

Common bean is of great importance to human diet mainly based on their grains (Sinclair and Vadez, 2012). However this culture is subjected to biotic and abiotic stresses which seriously compromise their yields (Abebe *et al.,* 2013). The soil borne pathogens causing root rots are among the limiting factors in legumes production worldwide causing wilting and heavy yield losses (Muthomi *et al.,* 2007). The disease depresses seedling germination and cause post emergence damping off that result in a poor crop stand and low yield (Naseri, 2014). Root rot is very common in common bean growing areas and the disease incidence and severity are at the highest worldwide causing economic yield loses (Erper *et al.*, 2008).

2.12 Management of diseases of common bean

Common bean is constrained by biotic stresses like bacterial and fungal diseases which reduce the yield in farmer's field (Naseri, 2014). Management strategies used to minimize seed and soil borne disease infections in the field include preventive, cultural, chemical and biological control methods (Karavina *et al.*, 2011).

Preventive management strategies involve pathogen free seeds, site selection, field sanitation, different cropping systems and crop rotation to avoid pathogen build up in the soil (Dey *et al.*, 2015; NAFIS, 2015). Major bacterial diseases are seed borne and the selection of pathogen free seeds is very important in preventing the spread of pathogens (Mohammed *et al.*, 2013). Seed infection is the primary means by which the pathogens spread, and the use of certified seeds would help in managing seed borne diseases (Mohammed, 2013; NAFIS, 2015). In addition to these, the implementation of integrated crop production strategies such as crop rotation, sanitation, seed treatment, tolerant/resistant cultivar selection and proper bactericide application are also effective (Karavina *et al.,* 2011). Fungal diseases are the largest and most important group affecting all parts of the plants at all stages of growth, and are controlled by the application of several disease management strategies like cultural practices, resistant varieties and the use of both protectant and systemic fungicides (NAFIS, 2014).

Integrated disease management is used to combat common bean diseases, and it is primarily based on host plant resistance or genetic resistance, which is essential to the exploitation of this crop's potential (Dey *et al.*, 2015). The use of resistant varieties provides a practical and less costly method of disease management for farmers (Mohammed *et al.*, 2013). Disease management in forage common bean relies heavily on using disease-resistant varieties and chemical control (Sanya *et al.*, 2015). It is important to integrate both of these strategies into a comprehensive disease management program (Dey *et al.*, 2015). The appropriate use of chemicals sometimes plays a significant role in managing certain diseases, but it is secondary to sound cultural practices and proper variety selection (Mohammed, 2013).

CHAPTER THREE

EFFECT OF SOIL TYPE AND FERTILITY ON THE INCIDENCE AND SEVERITY OF ROOT ROT DISEASE OF COMMON BEAN

3.1 Abstract

High occurrence of root rots is attributed to continuous and inappropriate cropping systems, low soil fertility levels, use of farm saved seeds and use of root rot susceptible bean varieties. This study evaluated the effect of soil fertility on the incidence and severity of root rot diseases of common bean. Soil samples were collected at the start of the 2016 short rain cropping season to determine the soil nutrients status, and the incidence and population of soil borne fungal pathogens. Soil samples were analyzed for total nutrient status and pH levels. Soil borne pathogens were isolated from the soil and stem bases by pour plate technique. Farm saved seeds were planted in field experiments at three sites in pure stand, intercropped with maize, applied with and without fertilizer. Data collected included emergence, stand count, bean fly incidence, root rot distribution, incidence and severity and yield. The pathogens isolated from soil and stem bases included *F. oxysporum, F. solani, Pythium* spp, *Macrophomina* and *Rhizoctonia* spp, with *Fusarium* spp. being the most predominant at 3000 CFU/g and 40% Incidence. Bean intercropped with maize had 22% lower intensity of root rot compared to the sole crop. The study concluded that low soil fertility, use of farm saved seeds and high inoculum levels of soil borne pathogens can lead to high incidence of root rots in the field. The study recommended that there should be farmer training on improved post-harvest and storage practices. Also, intercropping, crop rotation and field sanitation should be incorporated in common bean disease management and soil fertility improvement measures.

Key words: Common bean, root rots, soil fertility, soil borne pathogens

3.2 Introduction

Common bean (*Phaseolus vulgaris* L.) is an important grain legume in Eastern Africa, which is grown primarily as a food crop and to generate income by smallholder (Namugwanya *et al.*, 2014). Common bean is a short season crop in Kenya, growing in both the long rain season (April to June) and the short rain season (July to October). The crop has a role in sustaining the agricultural system by improving soil fertility and crop yield thereby reducing reliance on inorganic fertilization by small scale farmers (Sinclair and Vadez, 2012). However, common bean production has been declining due to various biotic and abiotic constraints such as insect pests, diseases and poor soil fertility (Tryphone *et al.,* 2012).

The crop is mainly grown by small scale farmers who carry out continuous bean cultivation due to decreased land size. This has led to a decline in soil fertility and build-up of pathogens in the soil, hence contributing to high disease pressure (Omotayo and Chukwuka, 2009). In Western Kenya, the crop is produced by smallholder farmers with limited resources to allocate to soil improvement. However the crop is grown as pure stand or intercropped with maize, bananas, tuber crops and other crops (Keino *et al.,* 2015). Common bean based cropping systems generally enhance yield, increasing soil carbon content, improving the resistance of soil to erosion, and thus reducing the incidence of soil borne pathogens (Mutegi *et al*., 2014). The grain yield of common bean varies across countries and regions, from 200 kgha^{-1} in unfavourable environments to 700 kg ha-^{1} in favourable environments when grown in pure stands, and about half of this when intercropped (Maraseni, 2014). In 2007, production of common bean in Kenya was estimated at 417000 metric tons while demand was estimated at 500000 metric ton (FAOSTAT, 2010), thus the productivity was less than 25% of the potential yield. In Western

Kenya, the per capita consumption is over 66 kg, but productivity has declined and yields are low typically less than 1 ton per hectare, which is 30% less than the genetic potential of the crop (Mutegi *et al*., 2014).

One of the major constraints of common bean production is low soil fertility. A global perspective of fertility decline is as a result of continuous and inappropriate cropping systems with very little or no external nutrient input to replenish soil fertility (Vanlauwe *et al.,* 2015). Phosphorus is a major nutrient required for bean production, and unlike nitrogen, phosphorus requires application of external nutrients (Yen *et al.,* 2013). A study by Namugwanya *et al.* (2014, indicated that low productivity of common bean is a result of poor soil fertility, nutrient depletion, low quality seed, high incidences of soil borne pathogens and insect pests.

According to Fernandez and Zentner (2005), high intensity of root rot was found in areas with low fertility especially low nitrogen and phosphorus. Declining soil fertility decreases the ability of common bean to fix atmospheric nitrogen. It is estimated that the losses due to low soil fertility in Eastern, Central and Southern Africa are 1,128 million tons per year (Vanlauwe *et al.*, 2015). Common bean is attacked by certain soil borne fungi causing root rot infections, however the disease is caused by individual pathogens or as a complex of the root rot pathogens (El-Mougy *et al.*, 2007). *Fusarium* spp. *Pythium* spp, *Rhizoctonia* spp and *Macrophomina* spp are known to be the main pathogens responsible for root rot of common bean. Root rots are the major limiting factor to common bean production, reducing seedling emergence, causing crop failure, limiting crop establishment and thereby lowering the crop's yield (Naseri, 2014). Root rot infections occur at all plant growth stages, and higher incidence and severity of the disease is caused by high inoculum of the pathogens in the soil (El-Mougy *et al.*, 2007). Therefore, this study aimed at determining the effect of soil fertility on the incidence and severity of root rot diseases of common bean.

3.3 Material and Methods

3.3.1 Description of the study area

The experiment was conducted in farmers' fields at three sites during the long rain cropping season of 2016 in Alupe, Busire and Butula of Lower Midland zone one (LM1) in Busia County. Busia County is located in the Western part of Kenya between longitude 33º 55' and 34º 25' East and latitudes 0º 30' and 0º 45' North (ARDAP, 2011) (Appendix II). The County is in the Lower Midland (LM) zone and it is divided into four agro-ecological zones (AEZ) namely Lower Midland I,II,III and IV (Jaetzold *et al.,* 1983). Busia County has varying climatic conditions with annual rainfall ranging between 800 mm to 2000 mm with 50% of the rains in the long season which starts in April and continues into June, while 25% of the rain falls in the short rain season which starts in late August and continues into October. The County has an average temperature of 22°C and the altitude range between 1,216 M and 1,520 M above sea level (ARDAP, 2011; Jaetzold *et al.,* 1983) (Appendix 1).

3.3.2 Collection of soil samples and determination of levels of soil nutrients

Soil samples were collected before planting from each experimental plot to determine soil nutrient status and population of soil borne pathogens. Top soils were taken from 0-10 cm depth at four equidistant positions in each plot and samples were collected at a depth 10-15 cm. One kilogram sample was collected using a sterile spatula. The soils were mixed thoroughly to obtain a composite sample of one kg per plot for analysis (Azevedo *et al.,* 2013). The soil samples were put in khaki bags and stored in a refrigerator at 4 ºC before microbial analysis. Analysis of the soil samples for soil nutrients and other characteristics such as the pH level was done at the National Agricultural Research Laboratories (NARL) in Kenya.

The analysis was carried out for total N by Kjekdahl digestion method (Hinga *et al*. 1980), organic carbon in soil samples by calorimetric method (Anderson and Ingram, 1993), and the available phosphorous by Olsen method (Olsen *et al.*, 1954). Soil pH was determined in a 1:1 soil water suspension with a pH meter. Available elements such as iron, zinc, copper, potassium, calcium manganese and magnesium were extracted in a 1: 10 ratio using Mehlich double acid method (Page *et al.*, 1982; Hinga *et al.*, 1980).

3.3.3 Determination of the population and diversity of soil borne fungal pathogens

Soil sub-samples were obtained from the composite samples described in Section 3.3.2. One gram was placed in 10millileter of sterilize distilled water and mixed on a mechanical shaker for 40 minutes. The suspension was serially diluted up to 10^3 and one milliliter aliquots of 10^2 and 10^3 dilutions was plated in each Petri dish in which approximately 20 millilitres of molten Potato Dextrose Agar amended with 50 part per million(ppm) streptomycin and 40ppm tetracycline was added (Naseri and Mousavi 2015). The content was gently swirled, allowed to solidify and incubated at room temperature for 5 to 7 days (Akhani *et al.*, 2012). Fungal colonies showing different cultural characteristics were observed and recorded and the total number of colony forming units (CFU) per gram of soil was calculated using the formula by Naseri and Mousavi (2015).

CFU ⁄ gram soil = Total number of colonies × dilution factor

Each fungal colony type was subcultured separately on fresh PDA media. *Fusarium* species were also sub cultured on Synthetic Nutrient agar (SNA) media containing 1g KH_2PO_4, 1g KNO_3, 0.5g $MgSO_4 \cdot 7H2O$, 0.5g KCl, 0.2g Glucose, 0.2g Sucrose and 20g Agar in 1000ml water (H_2O) (Moya- Elizondo *et al.*, 2014). The plates were incubated for 7 to 14 days in a dark room to allow sporulation. The fungal were identified by morphological and cultural features such as colony color and type of growth supplemented with microscopic identification using identification keys (Watanabe, 2010).

To allow for undisturbed fungal structures, riddle slides were prepared by placing a sterilized cover slip over a block of sterile agar on microscopic slides and placed over V- shaped glass rod on moist filter paper (Moya- Elizondo *et al.*, 2014). Seven day old cultures were used to rapidly prepare fungal colonies for identification. The agar was inoculated with fungal mycelia and incubated at room temperature for seven (7) days. The growth of each pathogen extended over onto the coverslips and the microscopic slide. The cover slip was removed and mounted directly on to a microscope slide with appropriate stain (Nugent *et al.*, 2006). The observed features of microconidia, macroconidia and chlamydiospores, conidia, sporangiophores and oospores were used to identify the fungal pathogens. The morphological identification of *Fusarium* spp was made as described by Leslie and Summerell (2006), while the identity of other soil borne pathogens was confirmed using fungal identification keys described by Watanabe *et al.* (2002).

3.3.4 Isolation of root rot pathogens from stem bases

Ten (10) symptomatic and ten non-symptomatic bean plants were randomly sampled from each plot. The stem bases were cut off after washing in running tap water. Each stem base was surface sterilized in 1.3% solution sodium hypochlorite for 30 seconds and then rinsed in three changes of sterilize distilled water and blot dried. The cut tissues were plated on PDA amended with 50ppm streptomycin and incubated for 7 - 14 days at 23 ± 2 °C. Fungal colonies of different cultural characteristics were recorded. Root rot pathogens were identified based on their morphological and cultural characteristics as described in Section 3.3.3.

3.3.5 Field assessment of root rot infection on bean plants

Field assessment of root rot infection was carried out at the second and fourth weeks after crop emergence by observing and counting infected plants showing root rot symptoms such as stunted growth, yellowing of leaves, wilting, brown dark- colored roots and root rotting. Assessment of disease distribution was scored using a scale of 0-2 where 0 = no disease, 1 = disease occurs in localized spots and 2 = disease distributed in whole field (Arabi and Jawhar, 2013). The incidence of root rots was determined by counting the number of infected plants within each plot, and the percentage incidence calculated as follows:

$$\text{Percentage incidence} = \frac{\text{Total number of infected plants}}{\text{Total number of plant per plot}} \times 100$$

Severity of the disease was assessed by observing symptoms on the leaves and the pods using a rating scale of 0 – 3, where: 0 = No disease; 1 = Mild infection; 2 = Moderate infection 3 = Severe infection (Reynolds *et al.*, 2012; Pande *et al.*, 2009). The total percentage disease index of 0 – 100 was calculated using the following formulae (Mc Kinney, 1923):

$$\text{Percent disease index} = \frac{\text{Distribution scored} + \text{incidence scored} + \text{severity scored}}{\text{maximizing total disease index}} \text{X } 100$$

3.3.6 Assessment of bean fly incidence

Data on the incidence of bean fly was taken on the 4^{th} and 6^{th} weeks after emergence. Bean plants in each plot were examined for bean fly infestation symptoms such as swollen cracked tunneling through stem tissues and discolored rotten stem. Bean fly distribution was scored using a scale of 0-2 where 0 = no disease, 1 = disease occurs in localized spots and 2 = disease distributed in whole field (Arabi and Jawhar, 2013), while the incidence was expressed as the number of infested plants per plot (Pande *et al.*, 2009).

3.3.7 Data analysis

Data on soil nutrients status, incidence and population of soil borne pathogens, percentage plant emergence and stand count, bean fly incidence and root rot disease index were subjected to analysis of variance (ANOVA) using GENSTAT software version 14. The means were separated using Fisher's protected least significant different (LSD) at 5% level of significance.

3.4 Results

3.4.1 Soil nutrient levels

There was significant variation ($P \leq 0.05$) in soil pH, level of copper and available nutrients which included nitrogen, carbon, potassium, magnesium, calcium, sodium, and manganese in the three study sites in Busia (Table 3.1). Soils from Butula had the lowest levels of soil nutrients compared to Alupe and Busire. Soils in Butula and Busire had an acidic pH of 4.8 while those in Alupe had a near neutral pH of 5.5. Both soils from Alupe and Busire had a 0.2% higher level of nitrogen, while soil from Butula had the lowest level of nitrogen. The level of manganese was

0.6% higher in soil from Busire compared to levels in soils from Alupe and Butula while there was no significant variation ($P \geq 0.05$) in levels of phosphorus, iron and zinc across the three study sites. Levels of potassium, calcium, magnesium, carbon and sodium were significantly higher in Alupe compared to the other sites while iron was 5.9 ppm higher in soil from Butula.

Table 3. 1: Nutrients levels (ppm and %) in soils sampled from three study sites in Busia County

Site	pH	N	C	P	K	Ca	Mg	Mn	Cu	Fe	Zn	Na
Alupe	5.5 a	0.2 a	1.8 a	6.7 a	0.5 a	4.2 a	2.9 a	0.4 b	6.5 b	57.1 a	12.1 a	0.4 a
Busire	4.8 b	0.2 a	1.7 a	6.7 a	0.1 b	2.3 ab	2.4 a	0.6 a	13.0 a	46.0 a	9.7 a	0.1 b
Butula	4.6 b	0.1 b	0.7 b	5.0 a	0.1 b	1.8 b	0.8 b	0.5 ab	2.0 c	65.9 a	9.5 a	0.1 b
Mean	5.0	0.1	1.4	6.1	0.3	2.8	2.0	0.5	7.2	56.3	10.4	0.2
LSD ($P \leq 0.05$)	0.2	0.1	0.9	6.0	0.1	2.1	0.9	0.21	1.1	22.7	9.7	0.1
CV (%)	1.9	20.3	29.4	43.1	10.2	34.0	19.1	18.6	7.0	17.8	40.9	13.6

Means accompanied by the same letter(s) in each column are not significantly different at $p \leq 0.05$; LSD - Least significant difference at $P \leq 0.05$; CV - coefficient of variation.

3.4.2 Incidence and population of fungal pathogens from the soil

The fungal pathogens isolated from soils sampled from the three study sites in Busia County were *Fusarium, Pythium, Macrophomina, Rhizoctonia*, *Penicillium* and *Sclerotinia* (Figure 3.1). There were significant differences ($P \leq 0.05$) in the incidence of soil borne pathogens in soils from the three study sites (Table 3.2). The root rot pathogens isolated from soil were *Fusarium solani, F. oxysporum, Rhizoctonia solani, Pythium ultimum* and *Macrophomina phaseolina*. There was no significant difference ($P \geq 0.05$) in the incidence of *F. solani, Rhizoctonia, Macrophomina* across the study sites; while the incidence of *Pythium* and *F. oxysporum* varied significantly($P \leq 0.05$) across the three study sites. Soil samples from Butula had significantly ($P \leq 0.05$) higher incidence of *F. solani, F. oxysporum* and *R. solani*.

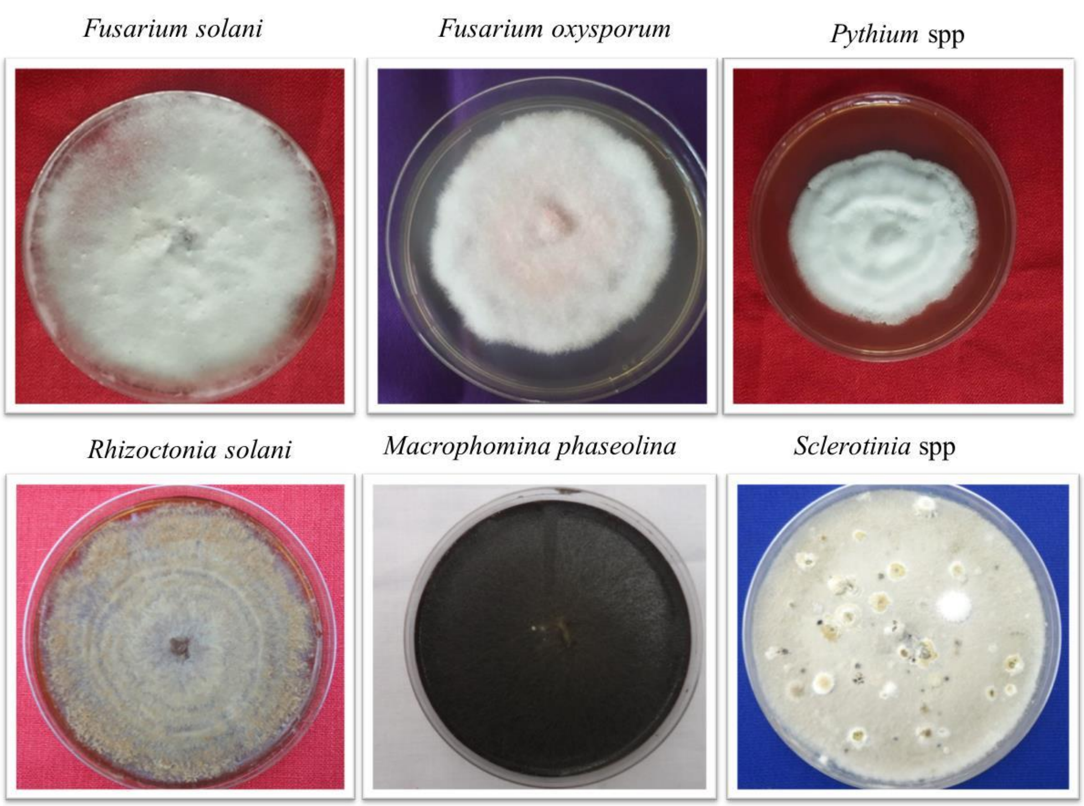

Figure 3.1: Cultures of major soil borne pathogens of common bean isolated from soil sampled from three sites in Busia County

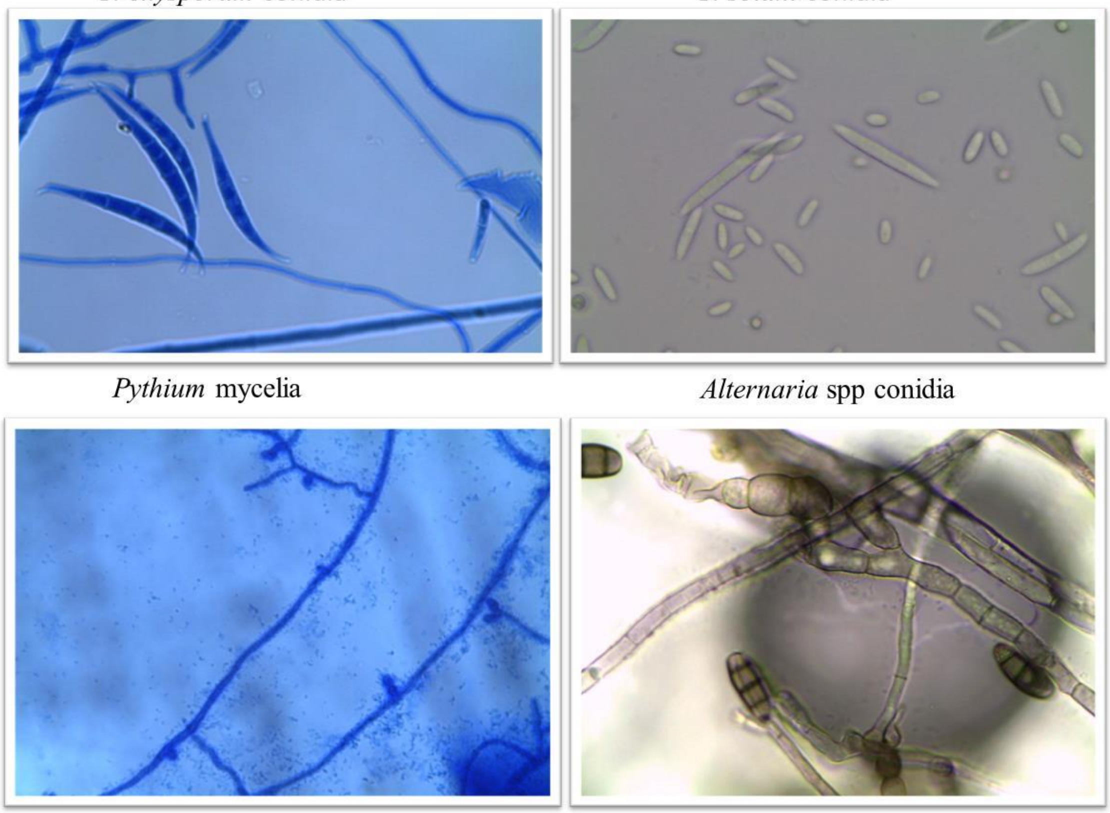

Figure 3.2: Asexual structures of root rot pathogens isolated from soil and bean stem bases collected in three study sites in Busia County

There was significant difference in the population of soil borne pathogens across sites (Table 3.3). Soil from Butula had a 45% higher population of soil borne pathogens compared to soil samples from Alupe which had the lowest population.

Table 3.2: Incidence (%) of soil borne pathogens in soils sampled from three sites in Busia County

Site	*F. solani*	*F. oxysporum*	*Macrophomina*	*Pythium*	*Rhizoctonia*	Others
Alupe	22.6 a	19.2 b	11.8 a	15.3 a	11.5 a	19.6 a
Busire	20.7 a	23.0 ab	9.9 a	15.4 a	10.4 a	20.6 a
Butula	23.7 a	25.0 a	11.7 a	10.9 b	11.8 a	17.04 a
LSD ($P \leq 0.05$)	10.7	11.1	10.3	11.4	10.8	14.0
CV (%)	29.2	30.1	56.4	50.1	58.5	44.8

Means accompanied by the same letter(s) in each column are not significantly different at $P \leq 0.05$; LSD - Least significant difference at $p \leq 0.05$; CV- coefficient of variation.

Table 3. 3: Population (CFU/g) of fungal pathogens in soils sampled from three sites in Busia County

Site	*F. solani*	*F. oxysporum*	*Macrophomina*	*Pythium*	*Rhizoctonia*	Others
Alupe	1917 c	2083 b	917 b	917 c	1000 b	1458 b
Busire	2375 b	2625 a	1125 b	1750 b	1208 b	2417 a
Butula	3458 a	2917 a	1792 a	2333 a	1750 a	2958 a
LSD ($P \leq 0.05$)	1269	1383	1081	1320	1223	1675
CV (%)	30	33	52	48	56	45

Means accompanied by the same letter(s) in each column are not significantly different at $P \leq 0.05$; LSD - Least significant difference at $p \leq 0.05$; CV- coefficient of variation.

3.4.3 Root rot infection and effect on emergence and plant stand

There was no significant variation ($P \geq 0.05$) in the plant stand of bean seedlings across sites and among the treatments (Table 3.4; Figure 3.3). However, the plant stand of bean varieties intercropped with maize was higher than the sole crops. The highest stand count at sixth week was in Alupe compared to other sites.

Percent root rot disease index at second and fourth week after planting varied significantly ($P \leq 0.05$) between sites and among the treatments (Table 3.5, Figure 3.4). Root rot disease index in Butula was 17% higher than in the other study sites. Alupe had the lowest root rot disease index of about 48%, while the bean varieties intercropped with maize had significantly lower ($P \leq 0.05$) root rot disease index compared to the sole crops in the three study sites. The bean variety KK8 had significantly lower disease index of root rot than the bean variety GLP2 across the three study sites.

Table 3. 4: Plant stand (%) of two common bean varieties planted in pure stand or intercropped with maize and with or without fertilizer at fourth and sixth week post emergence in three sites in Busia County

	Fourth week			Sixth week		
Treatment	Alupe	Busia	Butula	Alupe	Busia	Butula
GLP2 pure	33.7 d	47.2 bc	42.0 c	80.5 ab	73.0 b	71.7 c
KK8 pure	43.8 cd	47.3 bc	43.2 c	72.8 ab	69.8 b	69.7 c
KK8 + maize	69.6 a	70.4 a	67.5 ab	94.6 a	96.3 a	87.9 ab
GLP2 + maize	70.0 a	74.2 a	64.2 b	95.4 a	94.6 a	80.4 bc
GLP2 pure + fertilizer	43.8 bcd	39.5 c	48.0 c	85.0 ab	81.7 b	70.0 c
KK8 pure + fertilizer	37.7 cd	45.5 bc	38.2 c	74.5 ab	74.8 b	76.3 c
KK8 +maize + fertilizer	67.1 ab	58.3 ab	70.0 ab	71.2 b	78.7 b	87.5 ab
GLP2+maize+ fertilizer	60.8abc	60.0 ab	77.9 a	82.1 ab	78.8 b	94.2 a
LSD ($P \leq 0.05$)	21.8	15.7	10.6	20.5	11.3	10.2
LSD ($P \leq 0.05$)	Site; 5.39	Treat; 8.8	Site * Treat; 15.25	Site; 4.95	Treat;8.09	Site * Treatment; 14.01
CV (%)	23.3	16.2	10.7	14.3	8.0	7.3

GLP2 – Rose coco, KK8- Kakamega 8: Bean varieties. Means accompanied by the same letter(s) in each column are not significantly different at $P \leq 0.05$; LSD- Least significant difference at $P \leq 0.05$; CV- coefficient

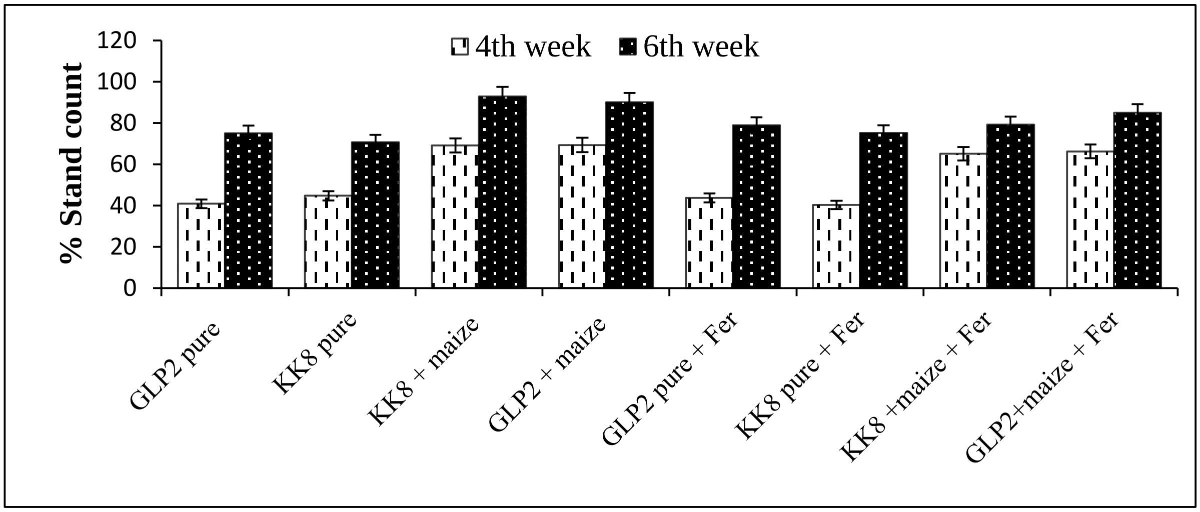

Figure 3.3: Percent stand count of two bean varieties at fourth and sixth week after emergence in plots planted as pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

Table 3. 5: Percent root rot index of two common bean varieties planted in pure stand or intercropped with maize and with or without fertilizer at second and fourth week post emergence in three sites in Busia County

	Second week			Fourth week		
Treatments	Alupe	Busire	Butula	Alupe	Busire	Butula
GLP2 pure	35.3 a	51.7 a	77.0 a	62.9 ab	62.7 ab	85.7 a
KK8 pure	46.1 a	56.9 a	79.7 a	68.8 a	69.6 ab	70.5 ab
KK8 + maize	40.7 a	39.8 a	57.7 bc	35.6 c	46.9 b	59.4 b
GLP2+ maize	52.7 a	41.3 a	66.0 abc	41.2 bc	52.2 ab	64.5 ab
GLP2 pure + fertilizer	46.7 a	58.2 a	59.1 bc	58.0 abc	74.5 a	70.1 ab
KK8 pure +fertilizer	45.7 a	57.0 a	69.3 ab	46.3 bc	74.3 a	74.8 ab
KK8 + maize +fertilizer	58.3 a	52.2 a	52.6 c	35.8 c	57.3 abc	64.1 ab
GLP2+maize+fertilizer	53.4 a	47.4 a	53.3 c	36.3 c	55.7 abc	75.6 ab
LSD (P ≤ 0.05)	23.6	16.9	13.7	23.4	23.4	22.1
LSD (P ≤ 0.05)	Site; 6.88	Treat 11.2	Site *Treat;19.5	Site; 7.29	Treat; 11.9	Site * Treat; 20.6
CV (%)	28.5	19	12.1	24.2	21.7	17.9

GLP2 – Rose coco, KK8- Kakamega 8: Bean varieties. Means accompanied by the same letter(s) in each column are not significantly different at P ≤ 0.05; LSD- Least significant difference at P ≤ 0.05; CV- coefficient of variation

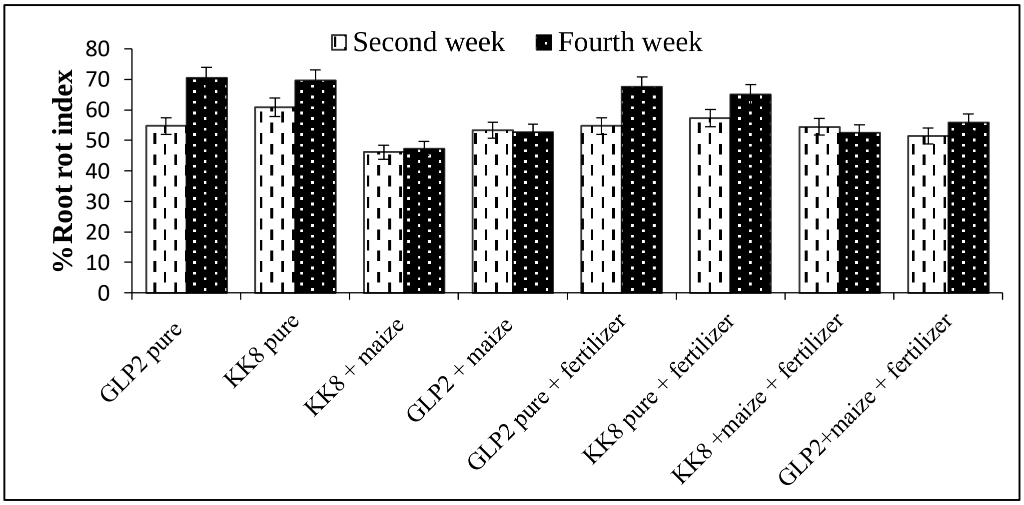

Figure 3. 4: Root rot index of two bean varieties at fourth and sixth week after emergence in plots planted as pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

3.4.4 Incidence of bean fly infestation

The incidence of bean fly at the fourth and sixth week after planting varied significantly ($P \leq 0.05$) across sites and various treatments (Table 3.6; Figure 3.5). During the fourth week the incidence of bean fly in Butula was 7% higher than the overall mean of bean fly, while the incidence of bean fly in Busire was 5% lower than the overall mean. The bean varieties KK8 and GLP2 intercropped with maize had lower bean fly incidence compared to the sole crops, while the variety KK8 had significantly lower ($P \leq 0.05$) bean fly incidence across the sites than the variety GLP2. During the sixth week, Butula had the highest bean fly incidence of about 70% compared to the other sites.

Table 3. 6: Percent incidence of bean fly infestation of two common bean varieties planted in pure stand or intercropped with maize and with or without fertilizer at fourth and sixth week post emergence in three sites in Busia County

	Fourth week			Sixth week		
Treatment	Alupe	Busia	Butula	Alupe	Busia	Butula
GLP2 pure	69.0 a	68.7 a	69.6 a	74.1 a	68.6 ab	80.4 a
KK8 pure	64.3 a	68.3 a	69.9 a	68.9 a	68.6 ab	80.8 a
KK8 + maize	33.9 b	28.3 b	51.5 c	51.3 b	51.1 d	57.5 c
GLP2 + maize	34.0 b	28.1 b	58.2 b	50.9 b	51.0 d	69.5 abc
GLP2 pure + fertilizer	69.7 a	68.9 a	70.2 a	68.4 a	68.5 ab	75.1 ab
KK8 pure + fertilizer	63.8 a	63.4 a	69.6 a	68.8 a	74.0 a	80.2 a
KK8+Maize+fertilizer	45.8 b	34.2 b	51.4 c	51.4 b	57.5 cd	57.8 c
GLP2+maize+fertilizer	46.4 b	34.2 b	51.4 c	57.7 b	62.9 bc	62.7 bc
LSD (P ≤ 0.05)	12.8	10.3	5.9	9.3	9.7	14.6
LSD (P ≤ 0.05)	Site; 3.34	Treat; 5.46	Site * Treat; 9.45	Site; 4.05	Treat; 6.61	Site * Treat; 11.45
CV (%)	13.7	12	5.4	8.6	8.8	11.8

GLP2 -Rose coco, KK8- Kakamega 8: Bean varieties. Means accompanied by the same letter(s) in each column are not significantly different at P ≤ 0.05; LSD- Least significant difference at P ≤ 0.05; CV- coefficient of variation

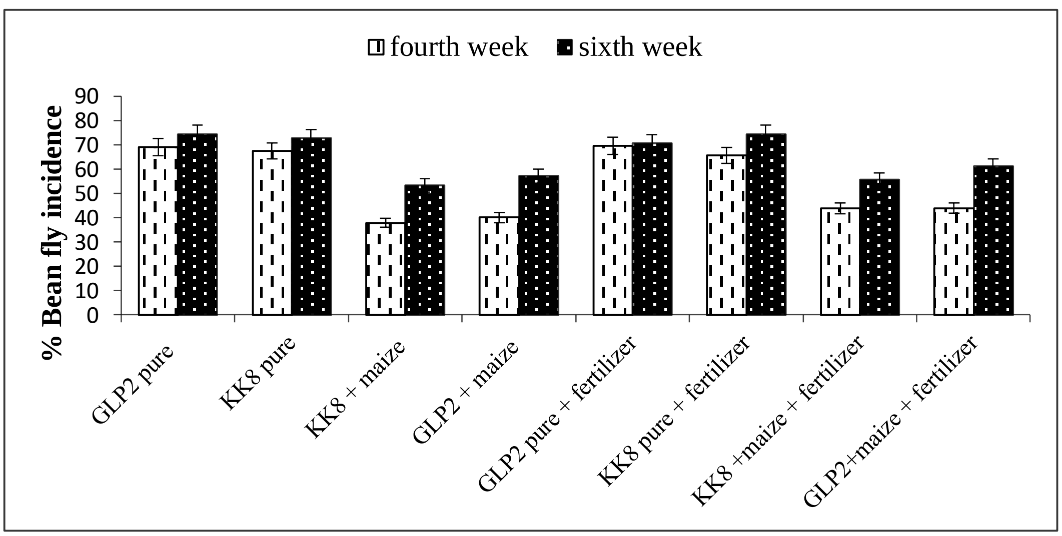

Figure 3. 5: Bean fly incidence mean of two bean varieties at fourth and sixth week after emergence in plots planted as pure stand or intercropped with maize and with or without fertilizer at three sites in Busia County

3.4.5 Root rot incidence and infection of bean on stem bases

The five root rot complex pathogens were isolated from symptomatic and asymptomatic stem bases of the various treatments in the study sites. The five pathogens were generally isolated in higher incidence in symptomatic and asymptomatic stem bases (Tables 3.7; Table 3.8; Table 3.9). There was no significant variation ($P \leq 0.05$) in incidence of the root rot pathogens from symptomatic stem bases across sites. However, general variations were observed with incidence of *F. solani, F. oxysporum* and *Pythium* being high on bean stem bases from Butula. The incidence of *Macrophomina phaseolina* was high in stem bases from Alupe, while the incidence of *Rhizoctonia* was high in stem bases from Busire.

There was a significant variation ($p \leq 0.05$) in the incidence of the root rot pathogens across sites in the asymptomatic stem bases isolated (Table 3.7, Table 3.8, Table 3.9). Asymptomatic stem bases from Busire had a 23% higher incidence of *Fusarium solani* and 19% of *F. oxysporum*. Asymptomatic stem bases from Butula had higher incidence of *Macrophomina phaseolina* and *Rhizoctonia solani*; while the stem bases from Alupe had a 38% higher incidence of *Pythium*.

Table 3.7: Incidence (%) of root rot pathogens isolated from symptomatic and non- symptomatic stem bases of two common bean varieties planted in pure stand or intercropped with maize and with or without fertilizer in Alupe

	F. solani	*F. oxysp*	*Macroph*	*Pythium*	*Rhizoctonia*
Symptomatic					
GLP2 pure	28.9 a	32.8 a	5.6 a	17.8 a	15.0 a
KK8 pure	28.3 a	21.7 a	21.7 a	13.3 a	15.0 a
KK8 + maize	33.3 a	26.7 a	13.3 a	26.7 a	0.0 a
GLP2 + maize	31.1 a	17.8 a	25.6 a	18.9 a	6.7 a
GLP2 pure + fertilizer	40.0 a	20.0 a	13.3 a	6.7 a	20.0 a
KK8 pure + fertilizer	35.0 a	20.0 a	8.3 a	21.7 a	15.0 a
KK8 + maize + fertilizer	26.1 a	24.4 a	15.0 a	15.0 a	19.4 a
GLP2 + maize + fertilizer	27.8 a	27.8 a	16.7 a	22.2 a	5.6 a
LSD ($P \leq 0.05$)	18.9	32.1	21.5	19.4	21.4
CV (%)	34.5	76.8	82.1	62.2	101.2
Non- symptomatic					
GLP2 pure	22.2 a	0.0 a	25.0 a	47.2 a	5.6 a
KK8 pure	20.0 a	13.3 a	8.3 a	50.0 a	8.3 a
KK8 + maize	15.1 a	10.3 a	18.7 a	45.6 a	10.3 a
GLP2 + maize	22.2 a	17.8 a	12.2 a	41.1 a	6.7 a
GLP2 pure + fertilizer	18.1 a	18.1 a	6.7 a	52.4 a	4.8 a
KK8 pure + fertilizer	15.0 a	6.7 a	15.0 a	52.2 a	11.1 a
KK8 + maize + fertilizer	13.3 a	20.0 a	6.7 a	46.7 a	13.3 a
GLP2 + maize + fertilizer	8.3 a	20.6 a	12.2 a	46.7 a	12.2 a
LSD ($P \leq 0.05$)	28.6	22.5	9.6	32.1	21.7
CV (%)	97.4	96.1	20.7	38.4	137.2

Root rot pathogens, *Fusarium solani*, *Fusarium oxysporum*, *Macrophomina* spp., *Pythium* spp.and *Rhizoctonia* spp. Means accompanied by the same letter(s) in each column are not significantly different at $P \leq 0.05$; LSD – Least significant difference at $p \leq 0.05$; CV- coefficient of variation.

Table 3.8: Incidence (%) of root rot pathogens isolated from symptomatic and non- symptomatic stem bases of two common bean varieties planted in pure stand or intercropped with maize and with or without fertilizer in Busire

	F. solani	*F. oxysp*	*Macroph*	*Pythium*	*Rhizoctonia*
Symptomatic					
GLP2 pure	25.1 a	22.7 a	12.0 a	15.3 a	24.8 a
KK8 pure	38.4 a	23.2 a	9.1 a	14.6 a	14.6 a
KK8 + maize	28.3 a	25.6 a	11.1 a	12.7 a	22.3 a
GLP2 + maize	27.5 a	27.6 a	11.4 a	19.5 a	14.0 a
GLP2 pure + fertilizer	28.3 a	36.0 a	8.6 a	11.9 a	15.2 a
KK8 pure + fertilizer	30.3 a	25.7 a	7.0 a	22.4 a	14.5 a
KK8 + maize + fertilizer	28.5 a	26.0 a	10.4 a	18.1 a	17.0 a
GLP2 + maize + fertilizer	33.4 a	26.4 a	12.5 a	15.3 a	12.3 a
LSD ($P \leq 0.05$)	18.6	18	13.5	10.8	11.7
CV (%)	35.4	38.6	75	37.8	39.5
Non- symptomatic					
GLP2 pure	36.5 a	35.4 a	9.3 a	14.0 ab	4.8 a
KK8 pure	37.3 a	42.9 a	4.8 a	10.3 ab	4.8 a
KK8 + maize	30.6 a	41.7 a	11.1 a	5.6 ab	11.1 a
GLP2 + maize	47.2 a	44.4 a	0.0 a	0.0 b	8.3 a
GLP2 pure + fertilizer	33.3 a	27.8 a	11.1 a	11.1 ab	16.7 a
KK8 pure + fertilizer	38.9 a	40.3 a	4.2 a	4.2 ab	12.5 a
KK8 + maize + fertilizer	38.9 a	25.0 a	11.1 a	19.4 a	5.6 a
GLP2 + maize + fertilizer	28.4 a	45.1 a	4.8 a	11.4 ab	10.3 a
LSD ($P \leq 0.05$)	25	26.1	15.3	14.1	18
CV (%)	39.3	39.3	123.8	84.7	111.3

Root rot pathogens, *Fusarium solani*, *Fusarium oxysporum, Macrophomina* spp., *Pythium* spp.and *Rhizoctonia* spp. Means accompanied by the same letter(s) in each column are not significantly different at $P \leq 0.05$; LSD - Least significant difference at $p \leq 0.05$; CV- coefficient of variation

Table 3.9: Incidence (%) of root rot pathogens isolated from symptomatic and non- symptomatic stem bases of two common bean varieties planted in pure stand or intercropped with maize and with or without fertilizer in Butula

	F. solani	*F. oxysp*	*Macroph*	*Pythium*	*Rhizoctonia*
Symptomatic					
GLP2 pure	36.1 abc	27.8 a	15.1 a	26.4 a	7.0 a
KK8 pure	40.2 ab	19.6 a	14.3 a	25.7 a	5.6 a
KK8 + maize	30.0 abc	24.4 a	7.9 a	18.9 a	6.7 a
GLP2 + maize	24.2 bc	16.7 a	15.0 a	27.3 a	12.2 a
GLP2 pure +fertilizer	40.3 ab	25.7 a	22.4 a	18.8 a	18.6 a
KK8 pure +fertilizer	46.3 a	30.0 a	13.1 a	15.7 a	10.0 a
KK8 + maize+fertilizer	17.0 c	21.7 a	10.4 a	26.1 a	12.2 a
GLP2+maize+fertilizer	30.6 abc	13.9 a	10.4 a	27.8 a	8.3 a
LSD ($P \leq 0.05$)	19.6	15.5	18.6	19.1	18.8
CV (%)	33.8	39.4	78.3	46.7	95
Non- symptomatic					
GLP2 pure	35.6 abc	22.2 a	6.7 a	6.7 a	28.9 a
KK8 pure	23.3 abc	23.3 a	23.3 a	15.0 a	15.0 a
KK8 + maize	44.4 a	19.4 a	13.9 a	16.7 a	5.6 a
GLP2 + maize	38.9 ab	16.7 a	22.2 a	11.1 a	11.1 a
GLP2 pure + fertilizer	13.3 c	40.0 a	20.0 a	20.0 a	6.7 a
KK8 pure + fertilizer	38.3 ab	25.0 a	15.0 a	15.0 a	6.7 a
KK8 + maize + fertilizer	19.4 bc	44.4 a	11.1 a	0.0 a	25.0 a
GLP2 + maize + fertilizer	30.6 abc	22.2 a	19.4 a	8.3 a	19.4 a
LSD ($P \leq 0.05$)	21.2	27.4	25.4	21.2	25
CV (%)	39.7	58.7	88.3	104.6	96.5

Root rot pathogens, *Fusarium solani*, *Fusarium oxysporum*, *Macrophomina* spp., *Pythium* spp.and *Rhizoctonia* spp. Means accompanied by the same letter(s) in each column are not significantly different at $P \leq 0.05$; LSD - Least significant difference at $p \leq 0.05$; CV- coefficient of variation

3.4.6 Correlation among soil nutrients, population of soil borne pathogens, root rot infection

There was a negative correlation between the soil nutrients, soil borne inoculum, root rot intensity and root rot infection on stem bases. The soil nutrients positively correlated with the plant stand count, however soil borne inoculum positively correlated with the root rot intensity and the disease infection on the stem bases. In contrast the soil borne inoculum negatively correlated with the plant stand count. Root rot infection and intensity highly correlated with soil nutrients. This indicates that there is an increase in root rot when the soil fertility is low. Soil borne inoculum was high where there was reduction in the available soil nutrients. However, root rot intensity decreases with an increase in the soil nutrients, plant stand count decreased with increase root rot intensity. There was low high population of soil borne pathogens in low fertility areas. High plant stand counts were observed in area with high nutrients levels.

Table 3.10: Correlation among soil nutrients, population of soil borne pathogens, plant stand count, root rot intensity and infection on stem bases

	Soil Nitrogen	Soil Carbon	Soil Potassium	Soil Phosphorus	Soil PH	Soil borne inoculum	Root rot intensity	Root rot infection	Stand count
Soil Nitrogen	-								
Soil Carbon	0.5*	-							
Soil Potassium	0.5*	1.0**	-						
Soil Phosphorus	1.0**	0.5*	0.5*	-					
Soil PH	0.7*	1.0**	1.0**	0.7*	-				
Soil borne inoculum	0.8**	0.9**	0.9**	0.8**	1.0**	-			
Root rot intensity	-0.8**	-0.9**	-0.9**	-0.8**	-1.0**	-1.0**	-		
Root rot infection	-1.0**	-0.5*	-0.5*	-1.0**	-0.7*	-0.8**	0.8**	-	
Stand count	0.9**	0.8**	0.8**	0.9**	0.9**	1.0**	-1.0**	-0.9**	-

*- significant; ** - highly significant at 5% level of probability

3.5 Discussion

3.5.1 Soil nutrient and root rot pathogen inoculum levels

Significant levels of soil pH, and available nutrients as nitrogen, carbon, potassium magnesium, calcium, sodium, manganese and copper were observed in this study. The soils from Butula had the lowest levels of the nutrients compared to Alupe and Busire. However, the soil fertility status was not significantly different among the three experimental sites. Total nitrogen and carbon in soils from the study sites were below the recommended levels. The low soil nutrients status could be attributed to continuous cultivation, removal or burning of crop residues, loss of nutrients through soil erosion, and continuous application of acidic fertilizers. The findings of the current study concur with the results by Keino *et al.* (2015) who reported that low soil nutrient status was due to inadequate use of inorganic fertilizers and soil erosion that have led to inadequate food production per capita in smallholder farms in Western Kenya.

The pH of the soil samples from the three study sites was slightly acidic and in the range of 4.6 to 5.5. The soil pH range concurs with research by Kebeney *et al.,* (2015) who reported low soil pH values for soils in Western Kenya. The study also indicated that low soil pH values below pH < 5.5 are strongly acidic and have potential to cause toxicity problems and deficiency of some essential plant nutrients as well as affect soil microbial activities (Kebeney *et al.,* 2015). Stunting and yellowing of leaves are symptoms of acidic soils which result in limited plant growth and declining yields worldwide (Iqbal, 2012). Ilori *et al.* (2014) also reported that pH influences the availability of other nutrients, for example, acidity of the soil induces deficiency of macronutrients such as copper. Phosphorus content in the soil was low and ranged from 5.0 to 6.7. This finding concurs with the results by Ilori *et al.* (2014), who reported that phosphorus content in the soil ranged from 1.87 to 17.80 and was regarded as very low. The results by Ilori *et al.* (2014) further indicated that phosphorus is considered the most available nutrient in the soil near a pH of 6.5 with availability of the nutrient decreasing at lower pH values. The micronutrients were high in Butula and generally low in Busire and Alupe. This could be due to the different soil properties in different sites. A study by Kumar and Babel (2010) indicated that the availability of micronutrients positively correlated with silt, clay, organic carbon, pH and CEC of soils.

There were variations in the incidence of root rot pathogens inoculum in soils from the study sites. This could be attributed to the poor nutrients status of the soils. Higher incidences of root rot pathogens were observed in Butula where the soil pH and fertility levels were the lowest among the study sites. The results agree with the findings of Naseri (2014), who reported higher incidence of root rot pathogens in low soil fertility areas. Ahanger *et al.* (2013) indicated that conventional and intensive farming practices with time have led to a decline in soil structure, fertility, microbial diversity and given rise to many soil and root pathogens. The same author also reported that root diseases are more devastating in poor soil fertility. Another study by Narisawa *et al.* (2005) indicated that soil moisture and soil pH influence root rot pathogen densities in soil. The current study also reported that there was significant reductions in root rot pathogens in soil with high fertility and moisture content of 80%.

Bhattara *et al.* (2015) indicated that the microbial population in soil is determined by various factors such as soil depth, organic matter, and soil pH. Microorganisms recycle secondary and micro nutrients decompose organic matter, detoxifying toxic substances, fixing nitrogen, transformation of nitrogen, phosphorous and potassium. These major biochemical activities are performed by microbes in soil and low population of microorganisms is found in soils with low organic matter percentage (Bhattara *et al.,* 2015).

3.5.2 Root rot infection, intensity and effect on emergence and plant stand.

Root rot infection on stem bases varied significantly among sites and treatments, and the major root rot pathogens isolated from the stem bases were *F. oxysporum, F. solani, Pythium* spp, *Macrophomina* and *Rhizoctonia* spp. The disease had higher incidence in the study sites in both the second and fourth week post emergence with Butula having the highest infection. This can be attributed to low soil nutrient status where Butula had the lowest soil pH and fertility levels among the study sites. Naseri (2014), reported that higher incidence of root rot pathogens is prevalent in areas of low fertility soils. The incidence of root rot isolated from symptomatic and non-symptomatic stem bases of the beans was similar and high across sites. This could be attributed to the reliance on farm saved seeds. However, recycling of farm saved seeds leads to build-up of inoculum and loss of resistance of the seed against fungal and bacterial infections. The study findings agree with Binagwa *et al.* (2016) who reported that farm saved seed serve as a source of inoculum that is detrimental to crop production. In addition, the study indicated that the survival structures of the pathogens are stored within the seed and the pathogens may cause failure of the seed to germinate, infect the germinated seedlings and the mature plants. There were differences in the intensity of root rot between the different bean varieties with KK8 intercropped with maize having a lower disease index compared to GLP2 intercropped with maize. This could be attributed to the resistance and susceptibility of bean varieties. The results concur with findings by Muthomi *et al.* (2014)

who reported low incidence of root rot in variety KK8 is due to its tolerance compared to the susceptible variety GLP2.

There was variation in the rate of emergence and plant stand among the treatments of the experiment in the study sites. The difference in the rate of emergence between the intercrops and the sole crop could be due to high emergence, higher yield and reduction in damages caused by insect pests, diseases and weed associated with intercropping. The study findings concur with results by Latati *et al.* (2013) who reported that intercropping maize and beans increased percent emergence, reduced diseases and increased yields of both bean and maize compared to the monocrop system. The plant stand varied among the various treatments in the study sites, with higher percentage recorded in the intercrops compared to the sole crops. The variation could be explained by the ability of intercropping system in reducing pests and diseases. Findings by Mousavi and Eskandari (2011) indicated that intercropping system has the ability to reduce damage caused by pests and diseases.

3.5.3 Incidence of bean fly on beans

Bean fly (*Ophiomyia* spp.) is one of the insect pests that most seriously affect production of common bean (*Phaseolus vulgaris* L.) and losses up to 40% have been reported (Mwang`ombe *et al.,* 2007). Due to scarcity of land, majority of the farmers cannot practice rotation with non-host crops which are known to reduce bean fly infestation (Peter *et al.,* 2009). Low soil fertility aggravated by not applying inorganic fertilizers by the farmers leads to weakly growing bean plants which are vulnerable to bean fly attack (Mwanauta *et al.,* 2015).

Severe bean fly infestation may result into total yield losses, especially under low soil fertility and drought conditions (Mwang`ombe *et al.*, 2007). There was significant variation in the incidence of bean fly in both bean varieties and treatments across the three study sites. The varieties KK8 and GLP2 intercropped with maize had lower incidences of bean fly (*Ophiomyia* spp.) compared to the sole crops. This could be attributed to the advantages of intercropping that include reduction in damages caused by insect pests, diseases and weeds. However, the study findings are in agreement with Peter *et al.* (2009) who reported that the incidence of *Ophiomyia* spp. decreased with increasing plant populations. The author further indicated that low counts of insect pest were recorded in intercrops and stem damage was higher in pure bean plots, compared to the intercrops. Bandaraet *et al*. (2009) also reported that intercropping beans with maize reduced infestation of *Ophiomyia phaseoli* in beans and the bean fly count was significantly lower in mixed stands than in pure stands. In addition, Mwanauta *et al.* (2015) indicated that bean fly is often considered as the most important field pest of beans in Africa, and cultural practices that include site selection, intercropping, crop rotation, and cultivar and seed selection, may to a certain degree reduce the infestation of the insect pest. A contrary observation was made by Ssekandi *et al.*(2016) who reported that bean fly incidence in the maize bean intercrops was not significantly different from the sole crops.

Bean fly incidence was significantly higher in Butula compared to Alupe and Busire, hence the high root rot infection in the respective site. This could be attributed to bean fly being a predisposing factor of root rot disease and the damage by bean stem maggot creates avenues for the entry of the root rot pathogens. This agrees with findings by Mwang`ombe *et al.* (2007) who reported that bean root rot diseases and bean fly occur in a complex and there is a positive correlation especially where the soil fertility is low. Bean fly is a serious constraint to bean production creating entry for root rot pathogens, thus causing high root rot intensity, lowering plant stand count, and reducing yield. Therefore, cultural practices that include intercropping, crop rotation and resistant varieties may to a certain degree reduce the infestation of bean fly in the field (Mwanauta *et al.*, 2015).

CHAPTER FOUR:

EFFECT OF FERTILIZATION AND INTERCROPPING ON FOLIAGE DISEASES AND SEED QUALITY OF COMMON BEAN

4.1 Abstract

Intercropping systems of common bean are important in sustaining an agricultural system due to ability of the beans contributing to improved soil fertility, increased yields, better seed quality and reduction of diseases, pests and weeds in the field. This study evaluated the role of different cropping systems on common bean diseases. Farm saved seeds were planted in field experiments at three sites as a pure stand, or intercropped with maize, and applied with and without fertilizer. Seeds of two farms saved bean varieties KK8 and GLP2 were assessed for quality before planting and at harvest to determine physical purity, germination capacity and bacterial contamination. Assessment of foliar fungal and bacterial diseases was done at the fourth and sixth week after planting. The physical purity, germination and bacterial contamination of the bean seeds varied significantly ($P \leq 0.05$) before planting and at harvest. All the treatment seed samples did not meet the 95% recommended purity level however; bean varieties KK8 and GLP2 intercropped with maize had 11% higher purity than the bean varieties in sole cropping system. Germination percentage of seeds from the intercropped bean varieties after harvest met the 85% recommended standard with lower proportions of infected seedlings and mouldy seeds. The seed samples from the bean varieties produced under sole cropping had significantly ($P \leq 0.05$) higher levels of *Xanthomonas axonopodis* pv. *Phaseoli* (1091 CFU/seed) and *Pseudomonas savastanoi* pv *phaseolicola* (776 CFU/seed) compared to the seed samples from bean varieties intercropped with maize which had significantly ($P \leq 0.05$) lower population of the pathogens (235 CFU/seed and 143 CFU/seed). The overall disease intensity for foliar fungal and bacterial diseases was variable and significantly ($P \leq$

0.05) lower on KK8 intercropped with maize and GLP2 intercropped with maize. The seed yield ranged from 600Kg/Ha to 1040Kg/Ha which was below the potential yield of 1400 to 2000Kg/Ha; however the bean variety KK8 intercropped with maize had an average grain yield of 1040 Kg/Ha. The study concluded that intercropping and fertilization reduce foliage diseases and increase the seed quality. The study recommended that intercropping system should be incorporated in common bean disease management.

Key words: *Phaseolus vulgaris* L., intercropping, seed quality and seed infection

4.2 Introduction

Intercropping systems of common bean are important in sustaining agricultural systems due to the contribution of beans to improved soil fertility, increased yields, better seed quality and reduction of diseases, pests and weeds in the field (Oshone *et al.*, 2014). Fungal and bacterial diseases remain major constraints in common bean production, and cause severe losses to yield and quality (Lupwayi *et al.*, 2011). Common bacterial blight, halo blight, and bacterial brown spots are severe bacterial diseases, while angular leaf spot, anthracnose, root rot and white molds are the severe fungal diseases (Singh and Schwartz, 2010). Intercropping common beans with maize, sorghum and ground nut has effects on soil borne fungal and bacterial pathogens, thereby lowering diseases and improving the growth and yield of the crop (Sinclair and Vadez, 2012). Rotating common bean with other crops such as cassava and maize reduces pathogen build up within the soil compared to continuous production of common bean in the same field (Sainju *et al.*, 2012).

Majority of small scale farmers in Africa get their seeds mainly from informal channels which include farm saved, local seed market and seed exchanges among farmers (Wekesa *et al.*, 2015). These seeds are regarded as the primary source of inoculum of plant pathogens, and there over reliance by farmers can lead to a decline in common bean production (Mohammed, 2013). Physical characteristics and quality of seeds is affected by use of informal seeds which have poor germination potential in the field (Oshone *et al.*, 2014). The use of farmer saved seeds causes reduction in germination capacity and early development of diseases in stages of the plant growth (Mohammed, 2013). In the laboratory, the International Seed Testing Association (ISTA) has set the following laboratory standards for certification of bean seed: 99% varietal purity, 0.95% maximum inert matter, 0.05% maximum other seeds, 85% minimum germination and 14% maximum moisture content (ISTA, 1999).

The incidence and severity of seed borne infection by major fungal and bacterial pathogens remain a limiting factor to common bean production (Ghangaokar and Kshirsagar, 2013). Seed borne diseases often strike early in the growth of the plant causing poor crop establishment and reduced plant vigor, leading to yield loss and poor seed quality (Mohammed, 2013). Economically important seed borne diseases of common bean include anthracnose (*Colletotrichum lindemuthianum*), common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli* and angular leaf spot (*Phaeoisariopsis griseola* (Sacc.) (Danish *et al.*, 2013). Seed borne diseases remain a major concern, because seed serves as the primary source of the disease inoculum when planted (Mohammed, 2013).This study therefore determined the effect of fertilization and intercropping on foliage diseases and seed quality of common bean.

4.3 Materials and Methods

4.3.1 Field experimental design and layout

Field experiment was conducted at three different sites in Busia County in fields with history of planting common beans and maize. The three sites were Butula, Busire and Alupe. The treatments included two farm saved varieties of Rose coco and KK8. Rose coco is susceptible to root rot and is the most commonly grown bean variety by the farmers in Busia County, while KK8 has resistance to root rot and foliage diseases (Muthomi *et al.,* 2007). The bean varieties KK8 and rose coco (GLP2) were sourced from farmers own saved seed in Butula. The eight treatments evaluated were:

i. Rose coco farm saved pure stand
ii. Rose coco farm saved intercropped with maize
iii. KK8 farm saved pure stand
iv. KK8 farm saved intercropped with maize
v. Rose coco farm saved pure stand applied with fertilizer
vi. Rose coco farm saved intercropped with maize applied with fertilizer
vii. KK8 farm saved pure stand and applied with fertilizer
viii. KK8 farm saved intercropped with maize and applied with fertilizer

Planting was done at the start of the short rain season of 2015. The planting was done at a spacing of 15M by 38M, while the mixed crop plots and the bean pure stand plots were 3M x 3M with guard rows of 1.5 M between plots (Amos *et al.,* 2001). Maize was planted at a spacing of 75 x 30 cm per plot of 3x3 M while the bean was planted at a spacing of 30 x 15 cm – 2 rows of bean between every two rows of maize. The experimental design was Randomized Complete Block Design (RCBD) replicated three times. Diammonium Phosphate

(DAP) (18% nitrogen and 46% phosphorus) fertilizer was used at the recommended rate of application on beans of 36 kg N/ha and 40 kg $P_2 O_5$/ha (Musandu *et al.*, 2001). Weeding was carried out as required and data on soil nutrient status at planting, soil borne disease inoculum levels in soil at planting, disease development, incidence and severity of root rots and foliar fungal and bacteria diseases, incidence of bean fly, number of pods per plant, plant biomass at harvest and seed yield was collected.

4.3.2 Field assessment of foliar fungal and bacterial diseases on bean plants

Foliar fungal and bacterial diseases were assessed at fourth and sixth weeks after emergence. The number of plants showing symptoms of a particular disease in each plot were counted and recorded. Major foliar fungal and bacterial diseases assessed included anthracnose, rust, angular leaf spot, Ascochyta leaf spot, web blight and common bacterial blight. The diseases were assessed based on symptoms in each plot, and the assessment of disease distribution, incidence and severity of foliar fungal and bacterial diseases was done using the same disease scales used in assessing root rots in Section 3.3.5.

4.3.3 Assessment of agronomic parameters

The parameters assessed in the study were emergence and plant stand count at second, fourth and sixth week after planting. Plant emergence was determined by counting the number of emerged seedlings in each plot at the second week, while the plant stand count was determined by counting the number of plants in each plot at the fourth and sixth week.

4.3.4Assessment of yield components

The parameters determined at harvest were number of pods, biomass and seed yield. Ten (10) plants were randomly selected in each plot and the number of pods recorded and expressed as the average number of pods per plant. The pods per plot were shelled separately, dried and weighed for determination of grain yield. The biomass per plot was sun dried, weighed and data were taken per plot, while the grain yield and biomass were converted to per hectare in each plot (Ikeogu and Nwofia, 2013).

4.3.5 Determination of physical quality of bean seeds

The common bean seed samples collected at planting and harvest were examined to determine the physical characteristics and varietal quality of the seeds. For a given seed lot, a working sample of 50g was used to carry out purity tests following the International Seed Testing Association procedure (ISTA, 2013). The 50g seed sample from each site was subjected to physical purity analysis to determine varietal quality. The seeds were separated into pure seed, discolored seed, inert matter (chaff, stones, soil particles), other bean varieties, shivered seed and insect damaged seed (ISTA, 1999). White paper was used for separation and the component parts were weighed individually and the percentage of each part calculated as follows:

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

4.3.6 Determination of germination and seedling infection of common bean seeds

Germination test was determined following the procedure by the International Seed Testing Association procedures (ISTA, 2013). At planting and harvesting, fifty (50) seeds were randomly selected from each treatment sample and replicated three times. The seeds were surface sterilized using 1.3% of sodium hypochlorite for 2 minutes and rinsed in three exchanges of sterile distilled water (ISTA, 2013).

The sterilized seeds were randomly placed evenly on three layers of blotting paper, to make five rows of ten (10) bean seeds each. The paper were wetted with sterile distilled water and covered with three layers of wet sterile paper towels and rolled carefully. This was placed in sterile polythene and incubated at room temperature (23 ± 2 ^{o}C) for 7 days and monitored for seed germination (Botelho *et al.*, 2013). The seedlings were categorized as normal seedling, abnormal seedling, diseased seedling, dead or hard seed and moldy seed and data taken on each component. Each component was expressed as percentage of the total number of seeds planted and the germination percentage was calculated in accordance with ISTA (2010).

$$\text{Germination \%} = \frac{\text{Number of germinated seeds}}{\text{Total number of seeds evaluated}} \times 100$$

4.3.7 Determination of bacterial infection in common bean seeds

Bacterial infection in seeds was determined by dilution and pour plate technique on nutrient agar. Seed wash test was carried out for extracting of bacterial pathogens from the seeds. The process of extraction was done by taking a subsample of 50 grams of seeds per treatment and the seeds suspended separately in sterile saline solution with dissolved 8.5g sodium chloride ($NaCl_2$) in 1000ml of distilled water containing 0.2 mililiter Tween 20 in conical flasks (ISTA, 2013). The number of seeds in 50 grams of each sample was counted and the thousand seed weight (TSW) calculated as follows:

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

The seed sub samples were soaked overnight in sterile saline solution for 16–18 h at 5°C and the conical flasks were shaken vigorously for three (3) to five (5) minutes to obtain a homogenous extract and then allowed to settle for one minute before dilution. Serial dilution up to 10^{-3} from seed extracts was carried out and 1ml of each sample was taken and pipetted in 9ml of sterile distilled water. One milliliter of dilutions 10^2 and 10^3 of each sample were pipetted onto three separate Petri dishes containing approximately 20 mileleter of sterile molten nutrient agar and shaken gently to allow the molten agar mix with the suspension.

When the molten agar was solidified, the Petri dishes were sealed with cling film and incubated at 28 ^{o}C in a transposed position for a period of 48 to 72 hours (Denardin and Agostini, 2013). Observation, counting and identification of bacterial colonies were done for each dilution per sample and data was taken on the number of *Xanthomonas campestris* pv *phaseoli* and *Pseudomonas savastanoi* pv *phaseolicola*. Quantification of the seed infection levels in each sample was determined by calculating the colony forming units using the formula as described by Kebede *et al.* (2016).

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

4.3.8 Data analysis

The disease indices, physical purity, germination and yield data were subjected to analysis of variance (ANOVA) using GENSTAT software version 14. Data on bacterial population (CFU) was transformed before analysis using $\log_{10}$ (X+1). The means were separated using Fisher's protected least significant different (LSD) at 5% level of significance.

4.4 Results

4.4.1 Quality of the experimental bean seed samples

The quality parameters of the total seed samples determined for two farm saved common bean varieties KK8 and GLP2 before and after planting were pure seed, other bean varieties, discoloured and shrivelled seed, insect damaged seeds and inert matter (Figure 4.1). Germination was done before planting and after harvesting of beans to determine proportions of germinated seed, normal seedling, abnormal seedling, seedling with infection, dead seed and moldy seed (Figure 4.2).

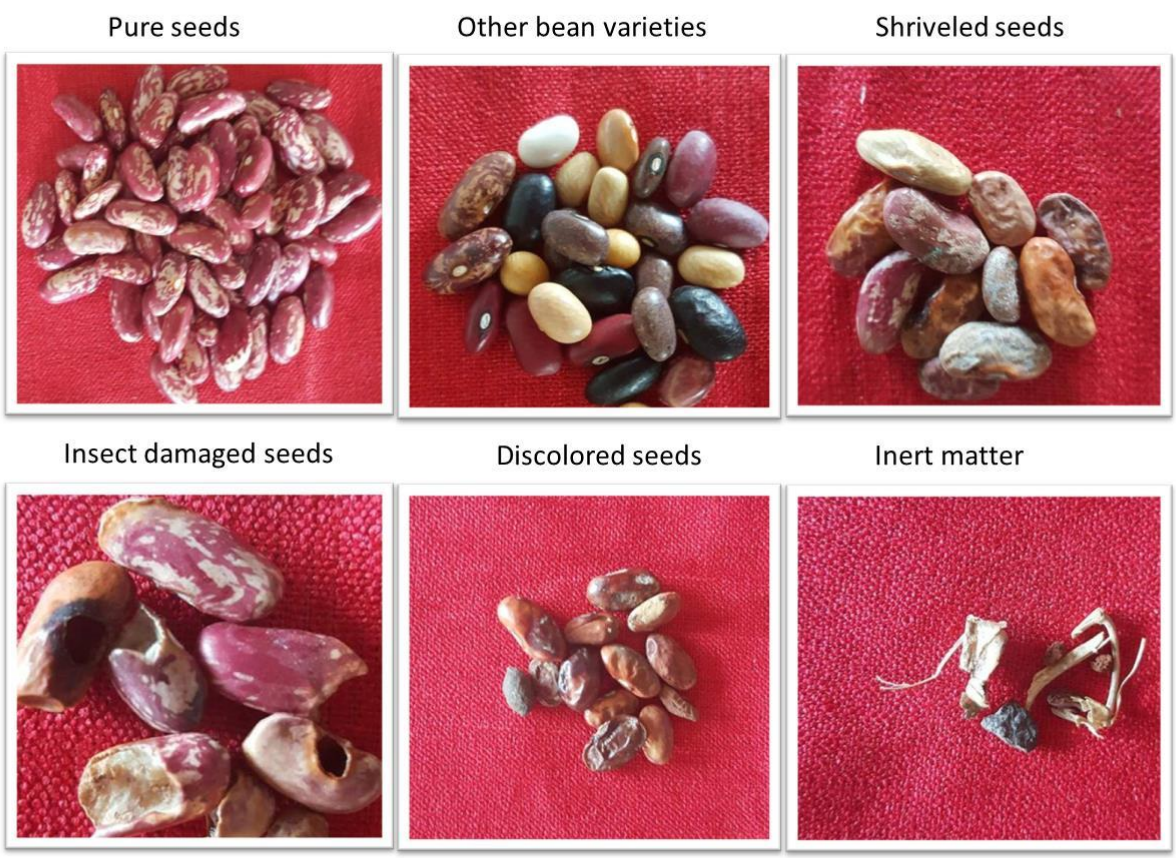

Figure 4. 1: Physical purity components for planted bean seed samples

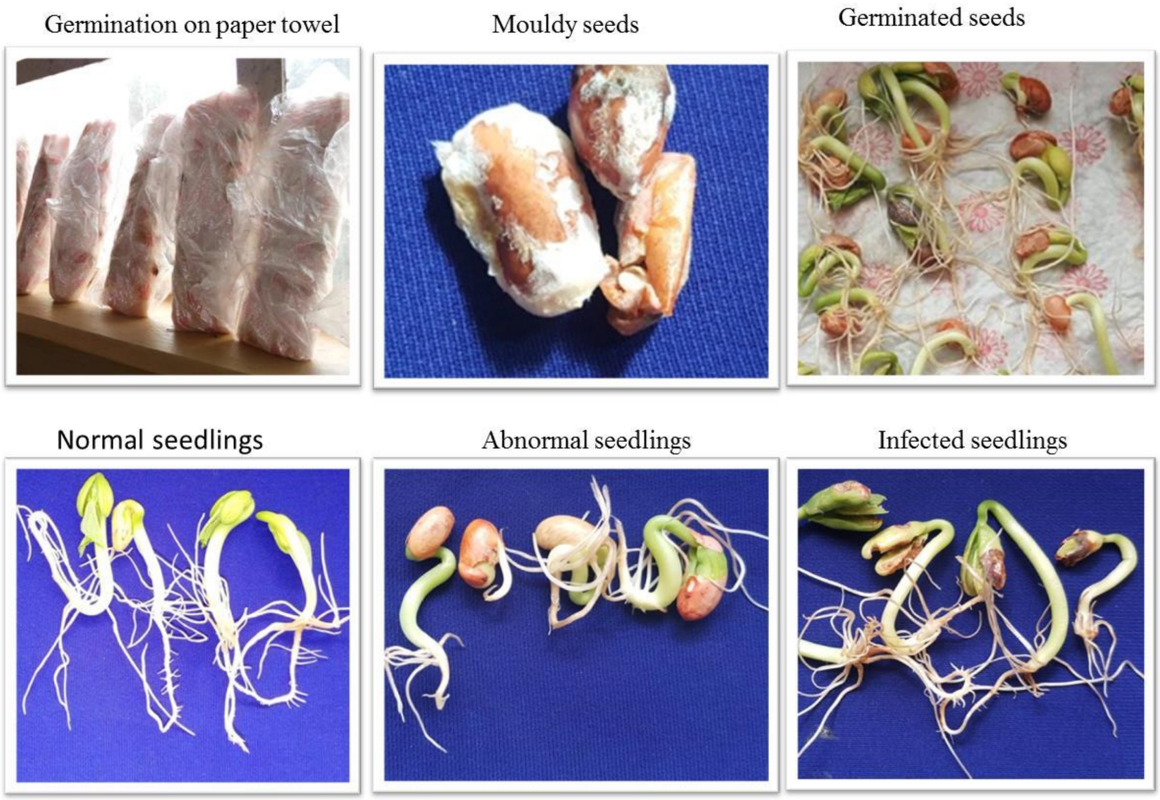

Figure 4. 2: Seed health parameters for bean varieties at planting and harvest of common bean seed samples

There was no significant variation (P ≥ 0.05) in the purity parameters among the two common bean varieties before planting (Figure 4.3). However, variety KK8 had higher percentages of pure seeds, other bean varieties and shriveled seed compared to variety GLP2. The proportion of discolored seeds was 15% higher in variety GLP2, while bean variety KK8 had a 20% proportion of insect damaged seed. There was no significant variation (P ≥ 0.05) in the mean germination and seed health parameters of the bean varieties KK8 and GLP2 before planting (Figure 4.4). The proportion of normal seedlings was 21% higher in variety KK8 compared to variety GLP2. Seedlings with infection and dead seeds were higher in variety KK8 compared to GLP2. The proportion of mouldy seeds was 23% higher in variety GLP2, compared to variety KK8. *Xanthomonas axonopodis* pv. *Phaseoli* (Xap) and *Pseudomonas savastanoi* pv. *phaseolicola* (Psp) were isolated in bean seeds before planting and at harvest. At planting, the population of Xap was significantly ($P \leq 0.05$) higher (Mean = 4362 CFU/seed) than Psp (3063 CFU/seed). Bean variety GLP2 had higher population of Xap (1300 CFU/seed) compared to the variety KK8 that had a population of 3522 CFU/seed (Figure 4.5).

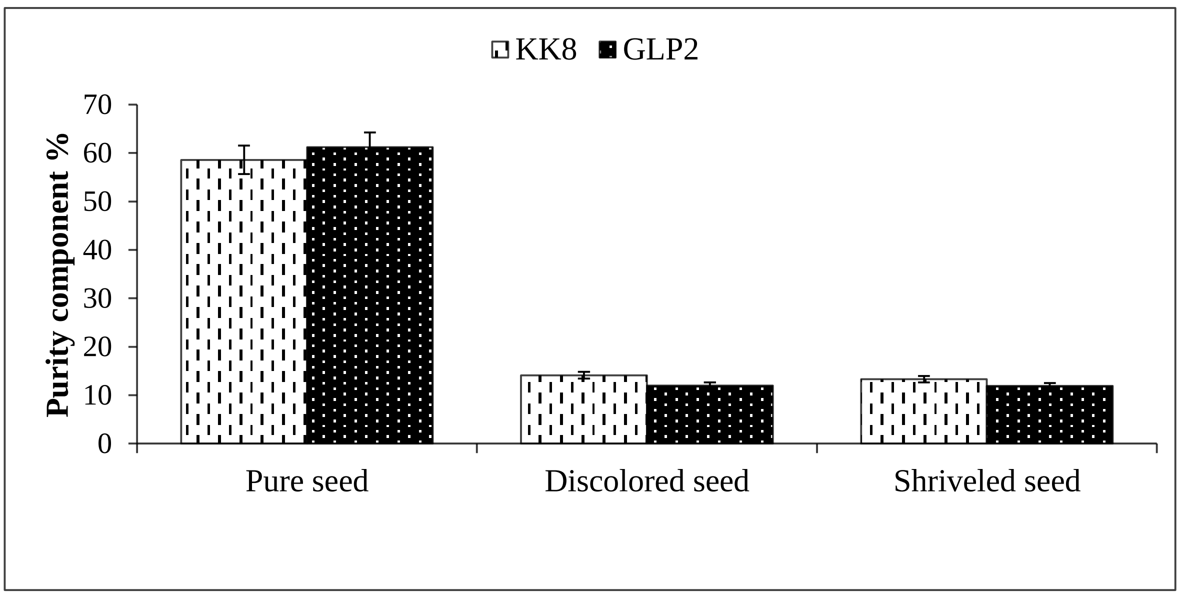

Figure 4. 3: Percent purity and seeds with symptoms of infection for two farm saved common bean varieties before planting

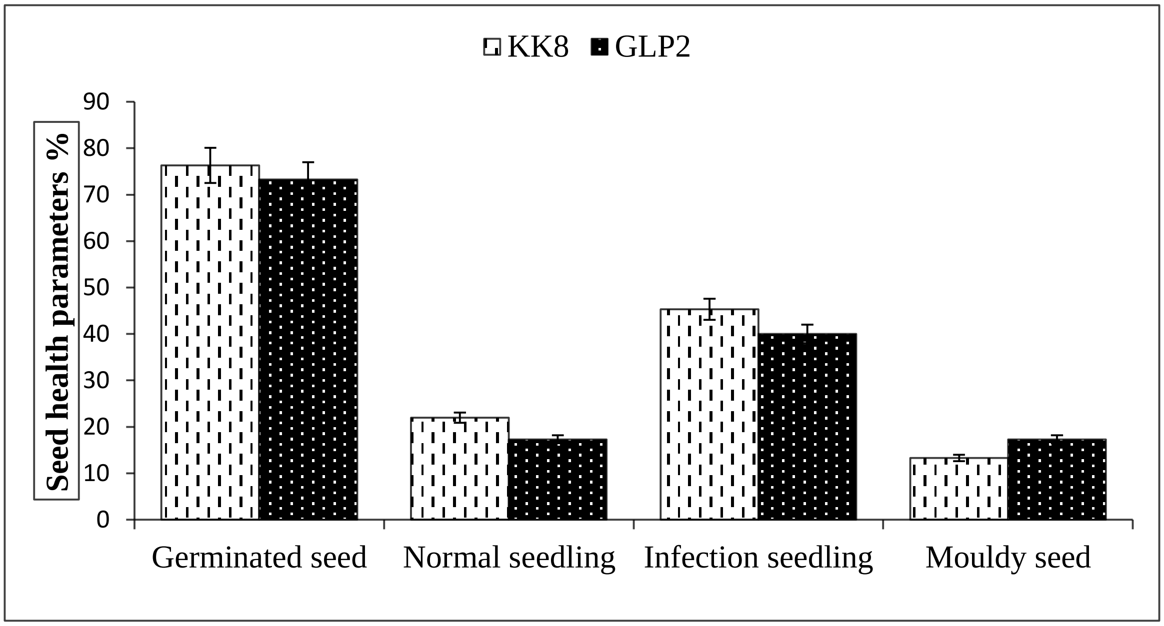

Figure 4. 4: Percentage germination and seedling infection for two farm saved common bean varieties before planting

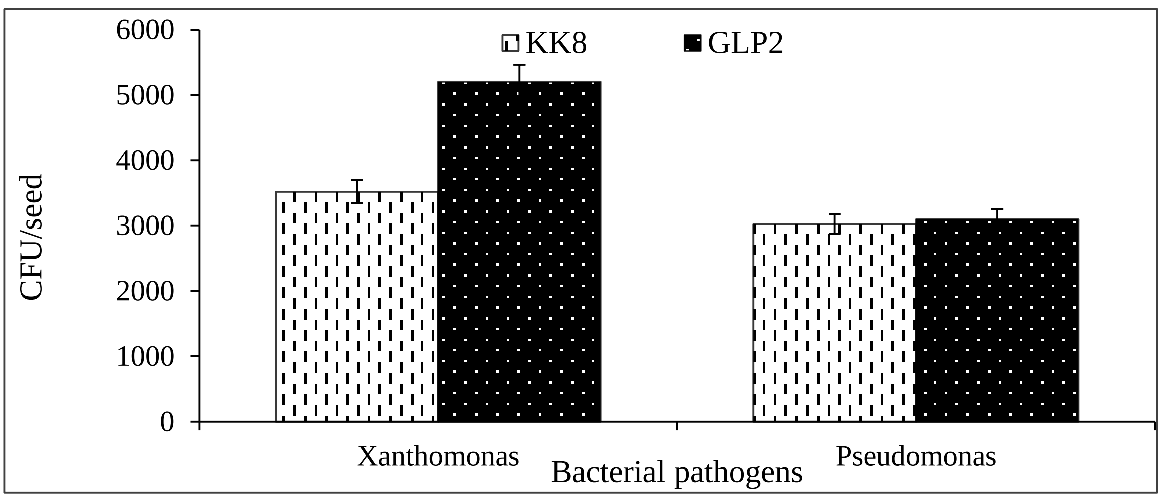

Figure 4. 5: Population (CFU/g seed) of *Xanthomonas axonopodis* pv. *Phaseoli* and *Pseudomonas savastanoi* pv *phaseolicola* in seed samples of two bean varieties sampled before planting

There was a significant variation ($P \leq 0.05$) in the proportion of pure seeds across the three study sites after harvest (Table 4.1; Figure 4.6). The proportion of pure seeds ranged from

63% to 72% however, common bean samples from Butula had significantly ($P \leq 0.05$) lower proportion of pure seed compared to Alupe and Busire. The bean variety GLP2 intercropped with maize had significantly ($P \leq 0.05$) higher proportion of pure seed. The proportion of pure seeds was significantly ($P \leq 0.05$) higher in bean varieties planted with fertilizer than the bean plots with no fertilizer application.

The proportion of discolored seeds and insect damaged seeds varied significantly ($P \leq 0.05$) across the study sites and various treatments (Table 4.1; Figure 4.6). Bean seeds from Butula had significantly ($P \leq 0.05$) higher fractions of discolored seeds than the other study sites. The proportion of discolored seeds was significantly ($P \leq 0.05$) lower in bean varieties intercropped with maize and with application of fertilizer than the sole crop of the bean varieties. .

The proportion of shriveled seed varied significantly (($P \leq 0.05$) across sites and the different treatments (Table 4.2; Figure 4.6). The proportion of shriveled seeds from Butula was 4.8% higher than seeds from the other sites. The bean varieties intercropped with maize with and without the application of fertilizer had 33% lower proportion of shriveled seeds compared to the pure bean varieties. The bean plots with fertilizer application had significantly ($P \leq 0.05$) lower shriveled seeds compared to bean plots planted without the application of fertilizer.

The proportion of germinated bean seeds, normal seedlings, dead seeds and mouldy seeds varied significantly ($P \leq 0.05$) across sites and various treatments after harvest (Table 4.2). The proportion of germinated seeds was higher in bean samples from Alupe and Busire and relatively lower in Butula (Table 4.3; Figure 4.7). However, there was no significant difference ($P \geq 0.05$) in germination rate of bean samples from different treatments across plots ranging from 82 to 87%.

The proportion of normal seedlings was 22% higher in bean samples from Alupe compared to samples from Butula and Busire (Table 4.2; Figure 4.7). Bean varieties which were intercropped had higher normal seedlings compared to the pure crops of the bean varieties. However, the pure crop of the bean varieties with the application of fertilizer had a higher proportion of normal seedlings.

There was significant variation ($P \leq 0.05$) in the percentage of normal seedlings, infected seedlings and mouldy seeds in the treatments across sites (Table 4.3; Table 4.4 Figure 4.7). Bean samples from the intercropped plots had significantly ($P \leq 0.05$) lower proportions of abnormal and infected seedlings; however, these two parameters were significantly ($P \leq 0.05$) higher in samples from pure stands compared samples taken from intercropped plots.

At harvest, significantly ($P \leq 0.05$) lower population of the pathogens was detected compared to population detected before planting of the seeds (4.5, Figure 4.8). The population of Xap (Mean = 251CFU/seed) was higher than Psp (Mean = 171CFU/seed) across sites and the various treatments. Beans harvested from Butula had the highest contamination of both pathogens, while samples from Busire had a 53% higher population of Xap. The bean varieties intercropped with maize had significantly ($P \leq 0.05$) lower population of the pathogens compared to the sole crop of the bean varieties. However, the variety KK8 intercropped with maize had the lowest population of both pathogens.

Table 4. 1: Percent purity of two common bean variety seeds harvested from plots in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

	Pure seeds			Other bean varieties		
Treatments	Alupe	Busire	Butula	Alupe	Busire	Butula
GLP2 pure	78.7 abc	61.9 b	75.0 ab	11.5 ab	15.5 a	5.2 d
KK8 pure	69.4 cd	77.1 a	52.9 d	7.3 bc	6.1 b	15.0 bc
KK8 + maize	73.4 bcd	81.4 a	60.4 bcd	15.0 a	4.3 b	7.8 cd
GLP2 + maize	81.9 ab	81.7 a	56.6 cd	7.7 bc	6.1 b	14.7 bc
GLP2 pure + fertilizer	74.5 bcd	78.9 a	70.3 abc	5.3 bc	8.1 b	10.8 bcd
KK8 pure + fertilizer	64.2 d	80.3 a	63.3 abcd	9.8 abc	8.6 b	16.2 ab
KK8 + maize + fertilizer	88.9 a	70.3 ab	52.8 d	3.3 c	13.7 a	23.1 a
GLP2 + maize + fertilizer	82.8 ab	80.9 a	79.1 a	6.4 bc	8.4 b	6.6 d
LSD (P≤ 0.05)	10.9	11.4	15.1	6.3	4.1	7.2
LSD (P≤ 0.05)	Site; 4.2	Treat; 6.8	Site*Treat;11.8	Site;2.0	Treat;3.2	Site*Treat; 5.6
CV (%)	8.1	8.5	13.5	43.3	26.2	33.2

GLP2 -Rose coco, KK8- Kakamega 8: Bean varieties. Means accompanied by the same letter(s) in each column are not significantly different at P ≤ 0.05; LSD- Least significant difference at P ≤ 0.05; CV- coefficient of variation

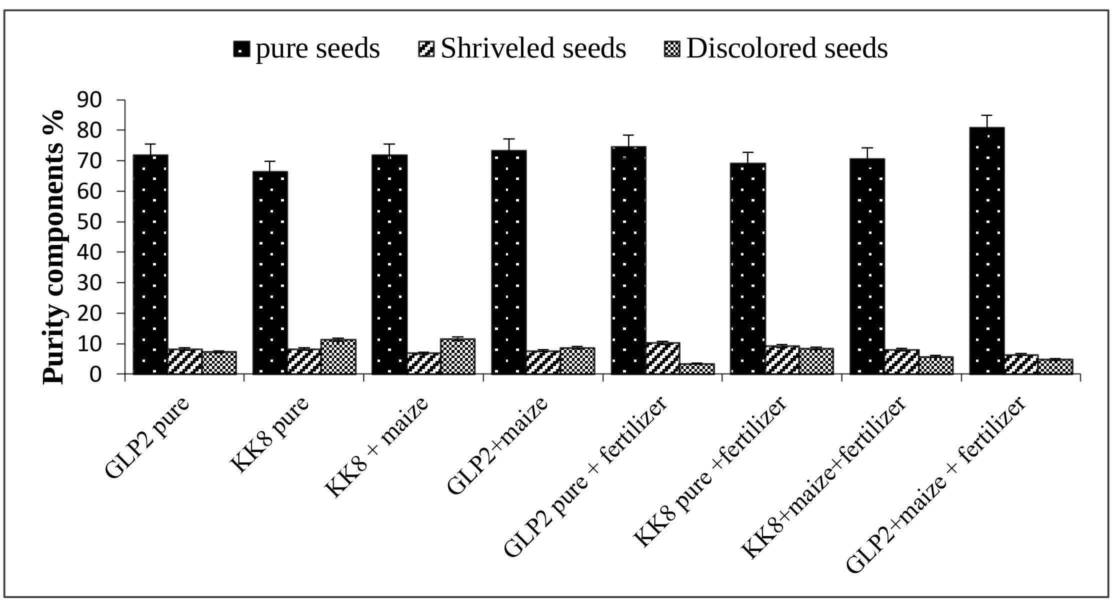

Figure 4. 6: Purity (%) of two common bean variety seeds harvested from plots in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

Table 4. 2: Percent shriveled and discolored seeds of two common bean variety seeds harvested from plots in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

	Shriveled seeds			Discolored seeds		
Treatments	Alupe	Busire	Butula	Alupe	Busire	Butula
GLP2 pure	6.0 bc	11.5 a	7.5 b	2.9 b	9.4 a	9.5 bc
KK8 pure	8.5 abc	8.7 ab	7.6 b	4.9 b	6.5 ab	22.6 a
KK8 + maize	6.7 bc	7.4 b	6.7 b	4.1 b	6.3 ab	24.3 a
GLP2 + maize	5.0 c	7.2 b	11.1 ab	4.6 b	4.8 ab	16.5 ab
GLP2 pure + fertilizer	10.9 ab	5.7 b	14.3 a	3.3 b	5.2 ab	1.8 c
KK8 pure + fertilizer	13.6 a	7.0 b	7.3 b	10.3 a	3.8 b	11.2 bc
KK8 + maize + fertilizer	4.4 c	8.8 ab	11.1 ab	1.9 b	5.1 ab	10.4 bc
GLP2 + maize + fertilizer	7.1 bc	6.1 b	6.0 b	3.1 b	3.9 b	7.3 bc
LSD (P≤ 0.05)	5.4	3.5	5.8	3.1	4.7	9.9
LSD (P≤ 0.05)	Site; 1.6	Treat ;2.7	Site * Treat; 4.7	Site; 2.2	Treat;3.6	Site*Treat; 6.2
CV (%)	39.4	25.7	36.9	40.9	47.7	43.7

GLP2 -Rose coco, KK8- Kakamega 8: Bean varieties. Means accompanied by the same letter(s) in each column are not significantly different at $P \leq 0.05$; LSD- Least significant difference at $P \leq 0.05$; CV- coefficient of variation

Table 4. 3: Percent germinated seeds and normal seedlings of two common bean variety seeds harvested from plots in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

	Germinated seeds			Normal seedlings		
Treatments	Alupe	Busire	Butula	Alupe	Busire	Butula
GLP2 pure	86.0 ab	87.3 abcd	80.7 abc	25.3 cd	24.0 b	20.7 bc
KK8 pure	80.7 b	88.7 ab	88.7 abc	24.7 d	24.7 b	17.3 c
KK8 + maize	88.7 a	91.3 a	76.0 c	32.7 abc	32.7 a	24.0 ab
GLP2 + maize	91.3 a	86.7 abcd	84.7 ab	35.3 a	28.7 ab	24.0 ab
GLP2 pure + fertilizer	84.0 ab	82.7 cd	80.0 bc	28.7 abcd	24.7 b	24.0 ab
KK8 pure + fertilizer	90.0 a	82.0 d	80.7 abc	26.7 bcd	24.0 b	21.3 bc
KK8 + maize + fertilizer	80.7 b	88.7 ab	80.7 abc	34.0 ab	32.0 a	25.3 ab
GLP2 + maize + fertilizer	90.7 a	85.3 bcd	85.3 a	32.7 abc	31.3 a	29.3 a
LSD ($P \leq 0.05$)	6.6	5.3	4.6	7.1	4.6	5.4
CV (%)	4.3	3.5	3.3	13.5	9.4	13.3

GLP2 -Rose coco, KK8- Kakamega 8: Bean varieties. Means accompanied by the same letter(s) in each column are not significantly different at $P \leq 0.05$; LSD- Least significant difference at $P \leq 0.05$; CV- coefficient of variation

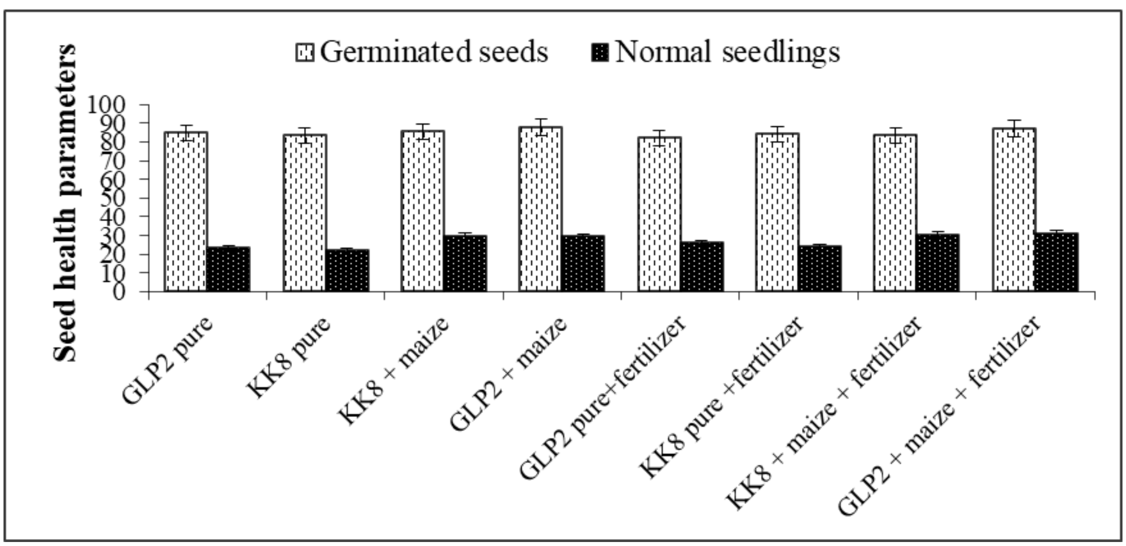

Figure 4.7: Geminated seeds and normal seedlings (%) mean of two common bean variety seeds harvested from plots in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

Table 4. 4: Percent infected seedlings and mouldy seeds of two common bean variety seeds harvested from plots in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

	Infected seedlings			Mouldy seeds		
Treatment	Alupe	Busire	Butula	Alupe	Busire	Butula
GLP2 pure	46.0 acd	47.3 a	48.0abc	10.7 bc	5.3 cd	15.3 a
KK8 pure	52.0 a	50.0 a	50.0 ab	12.7 ab	11.3 ab	14.0 ab
KK8 + maize	40.0 e	40.7 b	42.0 cd	11.3 bc	7.3 bcd	12.0 abc
GLP2 + maize	32.7 f	38.7 b	39.3 d	7.3 c	8.7 bc	9.3 bc
GLP2 pure+fertilizer	48.0 abc	46.0 a	44.7bcd	16.0 a	7.3 bcd	14.0 ab
KK8 pure +fertilizer	52.0ab	48.0 a	52.0 a	6.7 c	14.7 a	11.3 abc
KK8 + maize + fertilizer	37.3 ef	40.7 b	40.7 d	7.3 c	11.3 ab	11.3 abc
GLP2 + maize + fertilizer	40.7de	39.3 b	42.0 cd	7.3 c	3.3 d	8.0 c
LSD (P≤ 0.05)	5.6	4.8	5.9	4.5	4.7	5.1
LSD (P≤ 0.05)	Site;1.8	Treat; 3.0	Site*Treat; 5.2	Site;1.6	Treat; 2.6	Site * Treat; 4.6
CV (%)	7.3	6.3	7.5	25.6	30.8	24.2

GLP2 -Rose coco, KK8- Kakamega 8: Bean varieties. Means accompanied by the same letter(s) in each column are not significantly different at P ≤ 0.05; LSD- Least significant difference at P ≤ 0.05; CV- coefficient of variation

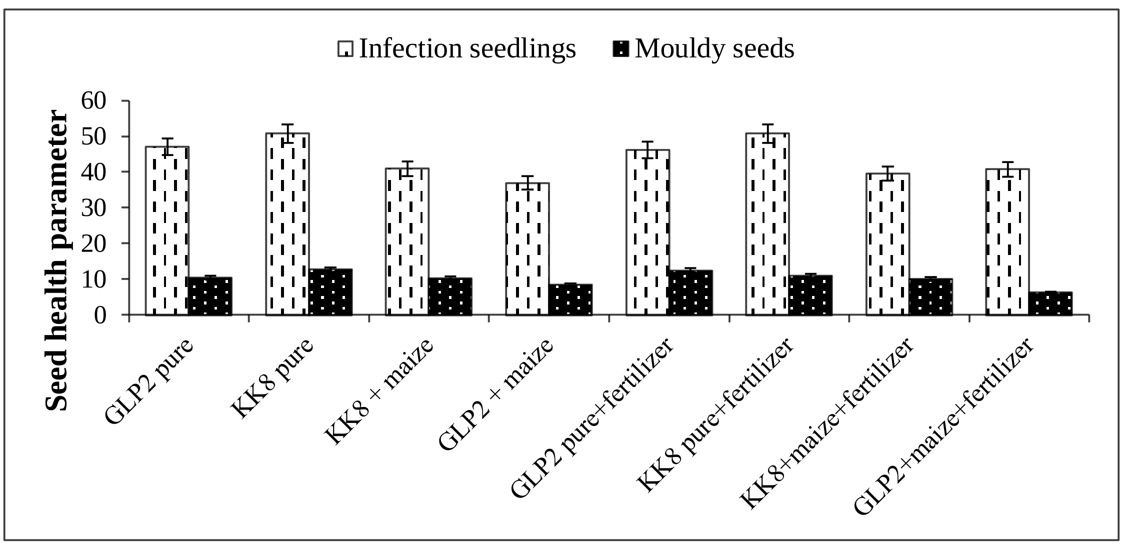

Figure 4. 8: Infected seedlings and mouldy seeds (%) mean of two common bean variety seeds harvested from plots in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

Table 4. 5: Population (CFU/seed) of common bacterial blight and halo blight bacterial pathogens in seeds of two common bean varieties harvested from plots in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

	Xanthomonas axonopodis pv. *Phaseoli*			*Pseudomonas savastanoi* pv. *Phaseolicola*		
Treatments	Alupe	Busire	Butula	Alupe	Busire	Butula
GLP2 pure	282 a	330 a	393 a	121 abc	198 a	206 ab
KK8 pure	284 a	294 ab	320 a	165 a	190 a	183 abc
KK8 + maize	203 a	224 cd	258 a	68 d	113 a	130 bc
GLP2 + maize	185 a	223 cd	298 a	100 bcd	201 a	129 c
GLP2 pure + fertilizer	270 a	266 abc	303 a	132 ab	160 a	163 abc
KK8 pure+ fertilizer	196 a	256 bc	301 a	128 abc	160 a	226 a
KK8+maize+ fertilizer	183 a	203 cd	272 a	77 cd	76 a	135 bc
GLP2+maize+fertilizer	232 a	181 d	310 a	59 d	178 a	127 c
LSD (P ≤ 0.05)	111	62.1	120.7	47.9	130.9	24.5
LSD (P ≤ 0.05) XAP	Site:34	Treat;55.8	Site*Treat ; 96.6	. Site:31.3	Treat :51.1	Site*Treat ;88.5
CV (%)	27.6	14.4	25.5	25.8	46.8	69.7

Means accompanied by the same letter(s) in each column are not significantly different at P ≤ 0.05; LSD- Least significant difference at P ≤ 0.05; CV- coefficient of variation

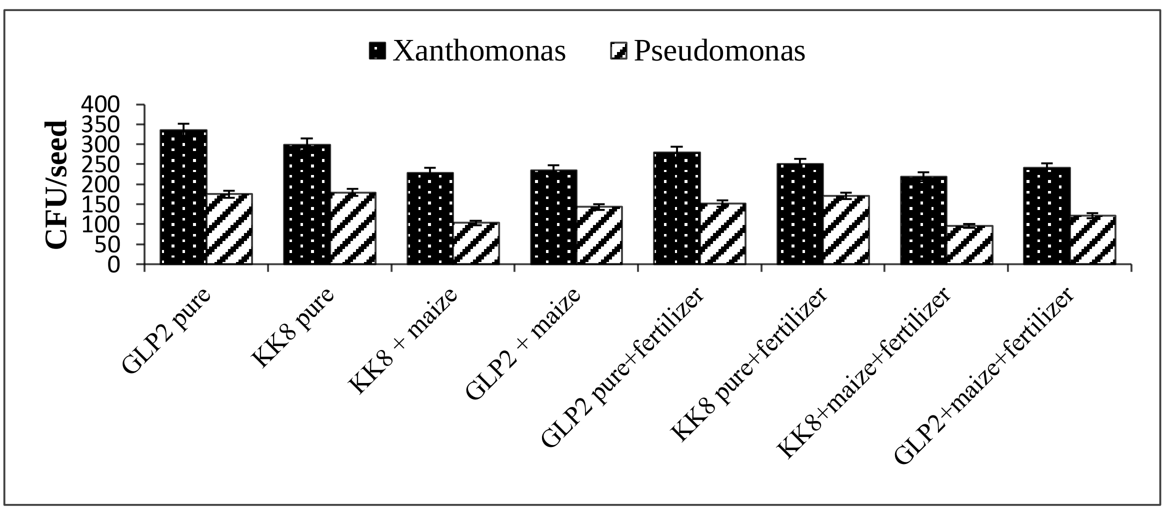

Figure 4. 9: Population (CFU/g seed) : Population (CFU/seed) of common bacterial blight and halo blight bacterial pathogens in seeds of two common bean varieties harvested from plots in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

4.4.2 Effect of seed quality and intercropping on foliage diseases

The foliar diseases assessed in the three study sites included common bacterial blight, angular leaf spot, bean anthracnose, bean rust, *Ascochyta* leaf spot and web blight (Figure 4.4). Common bacterial blight, angular leaf spot, web blight and bean anthracnose were the diseases with the highest intensity while rust and *Aschochyta* leaf spot had the lowest disease intensity rating.

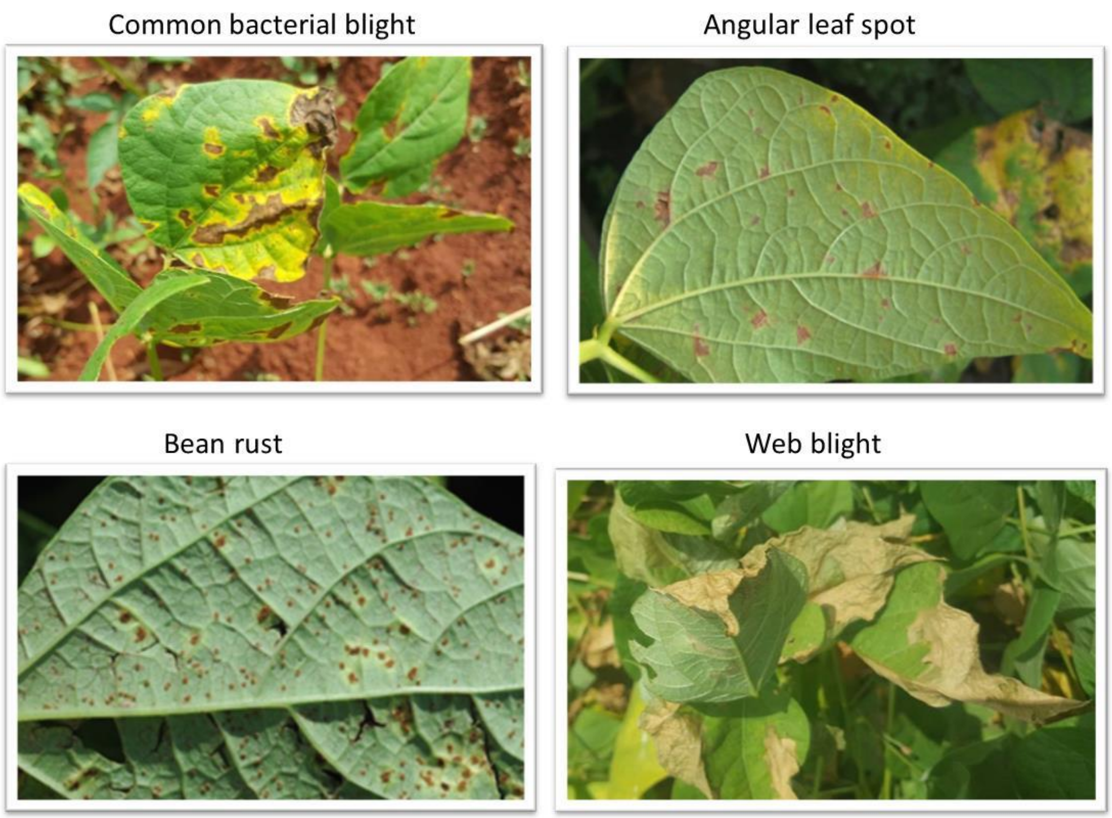

Figure 4. 10: Common symptoms of foliar diseases of common bean observed in the three study sites during the short rain cropping season of 2016

There was no significant variation ($P \geq 0.05$) in common bacterial blight across sites during the fourth week after planting (Table 4.6; Figure 4.11). The disease ranged from 70% to 86%, however the disease on common beans in Alupe had a 7% lower disease index compared to other sites. The pure crop of the bean varieties GLP2 and KK8 in Busire and Butula had a high disease index of about 80% compared to the bean varieties intercrops.

There was a significant variation ($p \leq 0.05$) in common bacterial blight across the study sites and among the various treatments in the sixth week after planting (Table 4.6; Figure 4.11). Common beans in Busire had a significantly ($P \leq 0.05$) higher disease index of about 92% than the other study sites. Varieties KK8 and GLP2 intercropped with maize in all the study sites had a significantly ($P \leq 0.05$) lower disease index compared to the sole crops of the bean varieties. The bean varieties planted with fertilizer had much lower disease index compared to beans planted without fertilizer.

Angular leaf spot varied significantly ($p \leq 0.05$) across sites and the various treatments in the fourth week after planting (Table 4.7; Figure 4.12). Common beans in Busire had a significantly ($P \leq 0.05$) higher index of angular leaf spot compared to beans in Alupe and Butula. The bean varieties intercropped with maize had significantly ($P \leq 0.05$) lower disease index in all the study sites, while the beans intercropped with maize and with fertilizer application had a much lower disease index of about 37%. During the sixth week after planting, angular leaf spot varied significantly ($P \leq 0.05$) across sites, while the overall disease index was 71.5% (Table 4.7). The disease index ranged from 60% to 73% with common beans in Butula having the highest disease index of 73%. KK8 intercropped with maize had a significantly ($P \leq 0.05$) lower disease index compared to the pure crops across the study sites.

Anthracnose varied significantly ($P \leq 0.05$) across sites and among the various treatments in both the fourth and sixth week after planting (Table 4.8 ; Figure 4.13). Common beans in Butula had the highest disease index of about 70% compared to other sites. Bean varieties intercropped with maize had 30% lower disease index compared to sole crops of the bean varieties across study sites.

There was no significant ($P \leq 0.05$) variation in bean rust across sites and treatments in the fourth and sixth week after planting (Table 4.9; Figure 4.14). Common beans planted in Butula had the highest disease index of about 44.8%. However, it was observed that the bean varieties intercropped with maize had about 11% lower disease index compared to the sole crop of the bean varieties.

Ascochyta leaf spot in the fourth week varied significantly ($P \leq 0.05$) across sites and treatments during the fourth and sixth week after planting (Table 4.10; Figure 4.15). Common beans in Busire had a high disease index of 51.4% in Busire. At the fourth week, common beans in Busire had the highest *Ascochyta* leaf spot index of 51% compared to the other sites. However, during the sixth week common beans in Butula had a disease index of 50%. There was no variation across sites, but the common beans in Butula had the highest disease index of 69%. There was no variation in web blight disease index across sites and treatment in the sixth week after planting (Table 4.16).

There was significant variation ($P \leq 0.05$) in total disease indices across study sites and the various treatments in the fourth and sixth week after planting (Table 4.12, Figure 4.17). The overall disease index was 52% during the fourth week; however, common beans in Busire had 15% higher disease compared to common beans in Alupe and Butula. The bean varieties intercropped with maize with and without fertilizer application had about 34% lower disease index than the pure crop of the varieties with and without fertilizer application. For the sixth week assessment, the total disease index was 71% and the bean varieties intercropped with maize had significantly lower overall disease intensities than the sole crops of the varieties.

Table 4. 6: Percent disease index for common bacterial blight at fourth and sixth week post emergence of two bean varieties planted in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

	Fourth week			Sixth week		
Treatments	Alupe	Busire	Butula	Alupe	Busire	Butula
GLP2 pure	75.6 a	86.9 a	86.7 a	97.8 a	98.5 a	97.1 a
KK8 pure	73.1 a	77.2 a	85.0 abc	98.2 a	97.4 a	92.6 a
KK8 + maize	71.2 a	75.3 a	74.6 bc	78.6 c	86.9 a	84.4 a
GLP2 + maize	77.2 a	75.7 a	75.7 abc	89.6 ab	87.4 a	86.9 a
GLP2 pure +fertilizer	73.3 a	82.4 a	77.7 abc	96.3 a	98.2 a	91.8 a
KK8 pure + fertilizer	73.9 a	76.2 a	86.4 ab	97.6 a	92.8 a	92.9 a
KK8+maize+fertilizer	72.2 a	77.5 a	73.8 c	78.3 c	88.0 a	86.2 a
GLP2+maize+fertilizer	73.2 a	82.2 a	73.0 c	80.8 bc	88.5 a	80.4 a
LSD ($P \leq 0.05$)	73.7 b	10.9	10.8	9.9	14.7	15.6
LSD ($P \leq 0.05$)	Site; 3.3	Treat; 5.2	Site * Treat; 9.2	Site; 4.4	Treat; 7.2	Site * Treat; 12.5
CV (%)	5.4	7.9	7.8	6.3	9.1	10

KK8- Kakamega 8; GLP2- Rose coco: Bean varieties. Means accompanied by the same letter(s) each column are not significantly different at $p \leq 0.05$; LSD-Least significant difference at $P \leq 0.05$; CV-coefficient of variation.

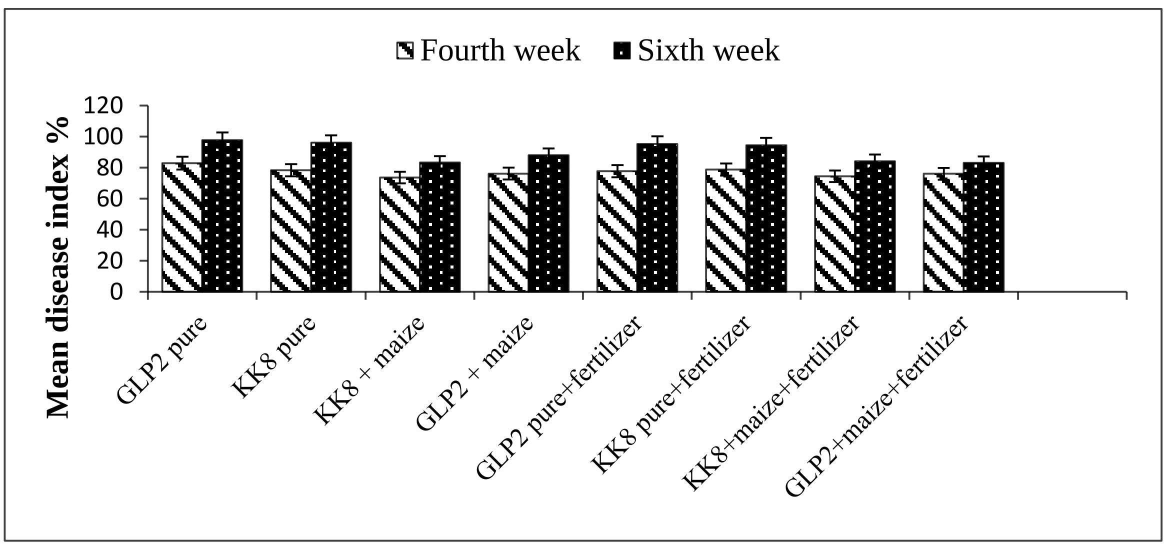

Figure 4. 11: Common bacterial blight index (%) mean of two bean varieties at fourth and sixth week after emergence in plots planted as pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

Table 4. 7: Percent index for angular leaf spot at fourth and sixth week post emergence of two common bean varieties planted in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

	Fourth week			Sixth week		
Treatment	Alupe	Busire	Butula	Alupe	Busire	Butula
GLP2 pure	69.6 a	69.2 a	69.2 a	80.1 a	80.5 a	81.1 a
KK8 pure	69.6 a	69.3 a	70.2 a	69.3 ab	75.4 ab	80.6 a
KK8 + maize	34.4 b	40.9 b	46.9 b	62.9 b	69.2 b	70.0 a
GLP2 + maize	40.1 b	51.7 b	41.1 b	63.2 b	69.3 b	69.9 a
GLP2 pure+fertilizer	69.4 a	69.8 a	69.8 a	74.6 ab	69.1 b	69.7 a
KK8 pure+fertilizer	69.7 a	69.5 a	70.1 a	69.5 ab	69.7 b	75.1 a
KK8+ maize+fertilizer	34.8 b	40.8 b	35.3 b	69.2 ab	69.5 b	69.7 a
GLP2+maize+fertilizer	40.4 b	46.3 b	40.8 b	70.0 ab	69.4 b	69.6 a
LSD ($P \leq 0.05$)	8.7	10.8	10.8	12.4	8.1	11
LSD ($P \leq 0.05$)	Site; 3.28	Treat; 5.35	Site * Treat; 9.27	Site; 3.49	Treat;5.69	Site * Treat; 9.86
CV (%)	9.3	10.8	11.1	10.2	6.5	8.6

KK8- Kakamega 8; GLP2- Rose coco: Bean varieties. Means accompanied by the same letter(s) each column are not significantly different at $p \leq 0.05$; LSD-Least significant difference at $P \leq 0.05$; CV-coefficient of variation.

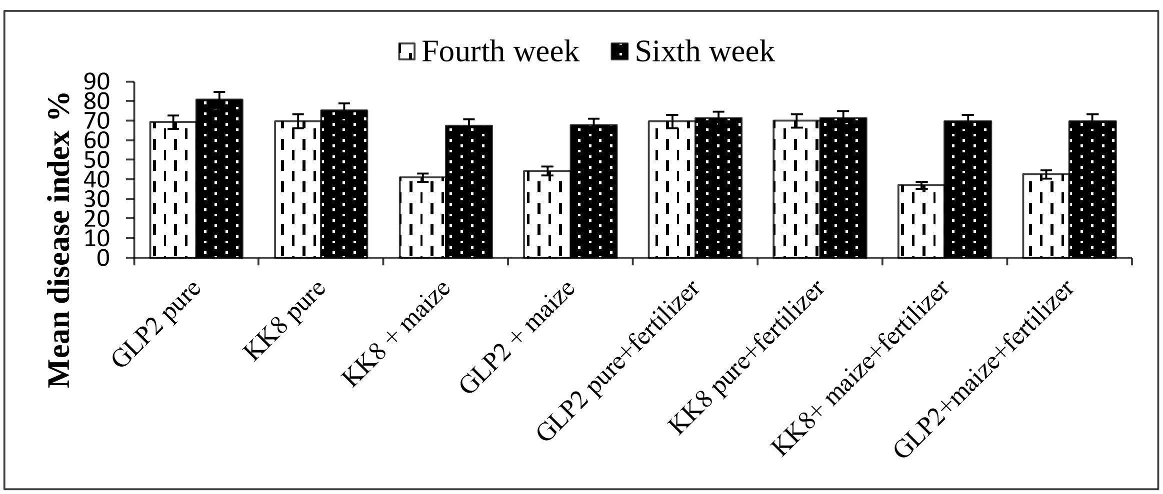

Figure 4. 12: Angular leaf spot index (%) mean of two bean varieties at fourth and sixth week after emergence in plots planted as pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

Table 4. 8: Percent index for bean anthracnose at fourth and sixth week post emergence on two common bean varieties planted in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

	Fourth week			Sixth week		
Treatment	Alupe	Busire	Butula	Alupe	Busire	Butula
GLP2 pure	46.4 ab	62.3 a	51.5 b	84.7 a	79.8 ab	68.7 a
KK8 pure	57.1 a	57.1 a	62.8 ab	79.3 a	85.4 a	68.6 a
KK8 + maize	22.5 c	33.7 bc	0.0 d	56.7 c	57.4 c	68.8 a
GLP2 + maize	0.0 d	22.5 c	22.4 c	51.2 c	57.4 c	69.4 a
GLP2 pure + fertilizer	51.7 ab	51.5 ab	68.0 a	73.6 ab	79.4 ab	74.2 a
KK8 pure + fertilizer	51.4 ab	56.8 a	62.6 ab	74.0 ab	68.6 bc	74.4 a
KK8 + maize + fertilizer	33.8 bc	33.9 c	33.8 c	62.5 bc	63.3 c	68.4 a
GLP2 + maize + fertilizer	22.6 c	33.8 bc	33.9 c	57.7 c	69.3 bc	68.9 a
LSD (P ≤ 0.05)	16.8	17.0	14.8	13.2	12.9	8.7
LSD (P ≤ 0.05)	Site; 6.03	Treatment; 9.85	Site * Treatment; 17.06	Site; 3.9	Treatment; 6.4	Site * Treatment; 11.09
CV (%)	26.9	22	19.8	11.2	10.5	7.1

KK8- Kakamega 8; GLP2- Rose coco: Bean varieties. Means accompanied by the same letter(s) each column are not significantly different at p ≤ 0.05; LSD-Least significant difference at P ≤ 0.05; CV-coefficient of variation

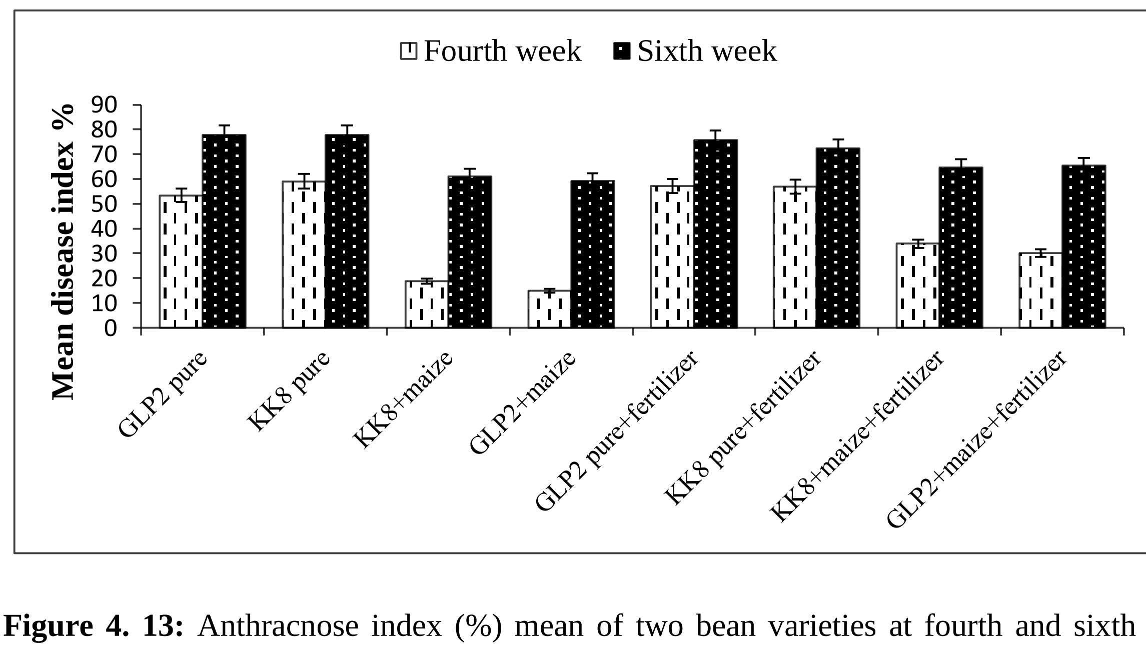

Figure 4. 13: Anthracnose index (%) mean of two bean varieties at fourth and sixth week after emergence in plots planted as pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

Table 4. 9: Percent index for bean rust at fourth and sixth week post emergence of two common bean varieties planted in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

	Fourth week			Sixth week		
Treatment	Alupe	Busire	Butula	Alupe	Busire	Butula
GLP2 pure	42.2 a	46.6 ab	41.9 ab	68.6 a	80.5 a	70.3 a
KK8 pure	47.0 a	41.1 ab	52.9 a	68.8 a	69.3 ab	70.4 a
KK8 + maize	39.6 a	40.4 ab	35.2 b	68.0 a	69.0 ab	63.7 a
GLP2+maize	34.0 a	45.8 ab	46.9 ab	73.7 a	74.9 ab	69.9 a
GLP2 pure + fertilizer	41.2 a	47.0 ab	41.6 ab	68.5 a	68.9 ab	75.6 a
KK8 pure +fertilizer	35.8 a	52.2 a	53.2 a	68.5 a	80.5 a	75.4 a
KK8+maize+fertilizer	33.9 a	34.7 b	35.1 b	62.2 a	63.4 b	69.6 a
GLP2+maize + fertilizer	34.8 a	40.4 ab	51.9 a	63.5 a	69.3 ab	63.8 a
LSD (P ≤ 0.05)	12.6	15.0	10.9	14.6	14.9	12.1
LSD (P ≤ 0.05)	Site; 4.15	Treatment; 6.78	Site * Treatment; 11.74	Site; 4.7	Treatment; 7.7	Site * Treatment; 13.4
CV (%)	18.6	19.7	13.9	12.3	11.8	9.9

KK8- Kakamega 8; GLP2- Rose coco: Bean varieties. Means accompanied by the same letter(s) each column are not significantly different at p ≤ 0.05; LSD-Least significant difference at P ≤ 0.05; CV-coefficient of variation

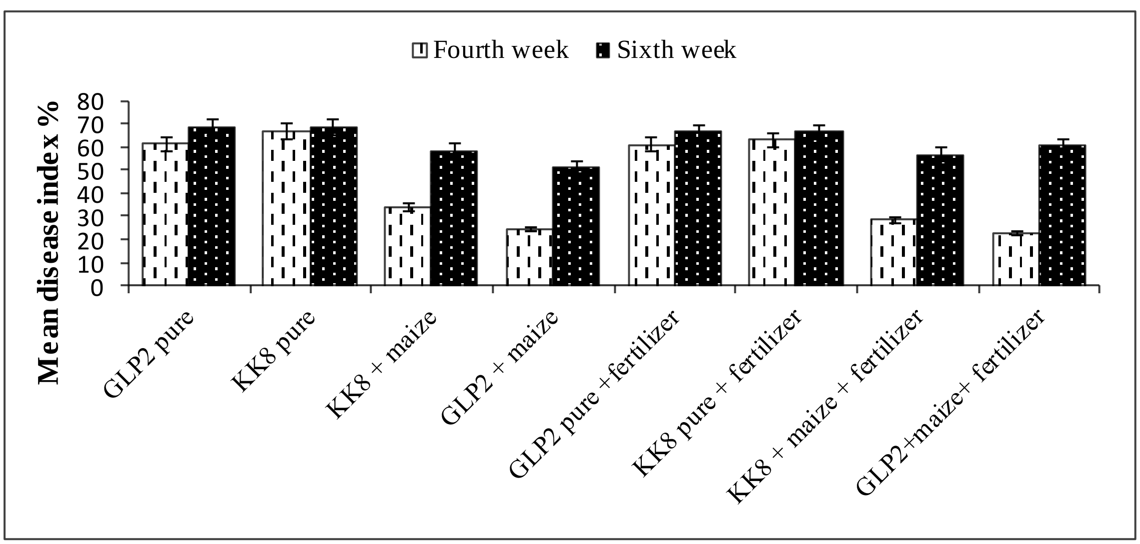

Figure 4. 14: Bean rust index (%) mean of two bean varieties at fourth and sixth week after emergence in plots planted as pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

Table 4. 10: Percent index for *Ascochyta* leaf spot at fourth and sixth week post emergence of two common bean varieties planted in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

	Fourth week			Sixth week		
Treatment	Alupe	Busire	Butula	Alupe	Busire	Butula
GLP2 pure	57.3 a	68.8 a	57.6 a	67.9 a	68.5 a	68.4 ab
KK8 pure	62.7 a	68.7 a	69.2 a	68.3 a	68.5 a	68.8 a
KK8 + maize	22.4 b	39.6 b	39.6 b	50.5 bc	62.0 a	62.5 abcd
GLP2 + maize	0.0 b	39.4 b	33.8 b	44.9 c	50.7 b	57.0 bde
GLP2 pure +fertilizer	50.9 a	63.0 a	68.5 a	67.7 a	68.0 a	63.0 abcd
KK8 pure + fertilizer	51.2 a	68.8 a	69.4 a	68.2 a	62.7 a	68.4 abc
KK8 + maize + fertilizer	11.3 b	40.3 b	33.7 b	50.7 bc	68.1 a	51.0 e
GLP2+maize+ fertilizer	11.2 b	22.7 c	34.0 b	56.5 b	56.8 ab	68.3 abc
LSD (P ≤ 0.05)	22.3	15	13.1	8.3	10.9	10.3
LSD (P ≤ 0.05)	Site; 5.76	Treatment ; 9.41	Site * Treatment; 16.3	Site; 3.35	Treatme nt; 5.46	Site * Treatment ; 9.46
CV (%)	38.2	16.7	14.8	8.0	9.9	9.3

KK8- Kakamega 8; GLP2- Rose coco: Bean varieties. Means accompanied by the same letter(s) each column are not significantly different at p ≤ 0.05; LSD-Least significant difference at P ≤ 0.05; CV-coefficient of variation

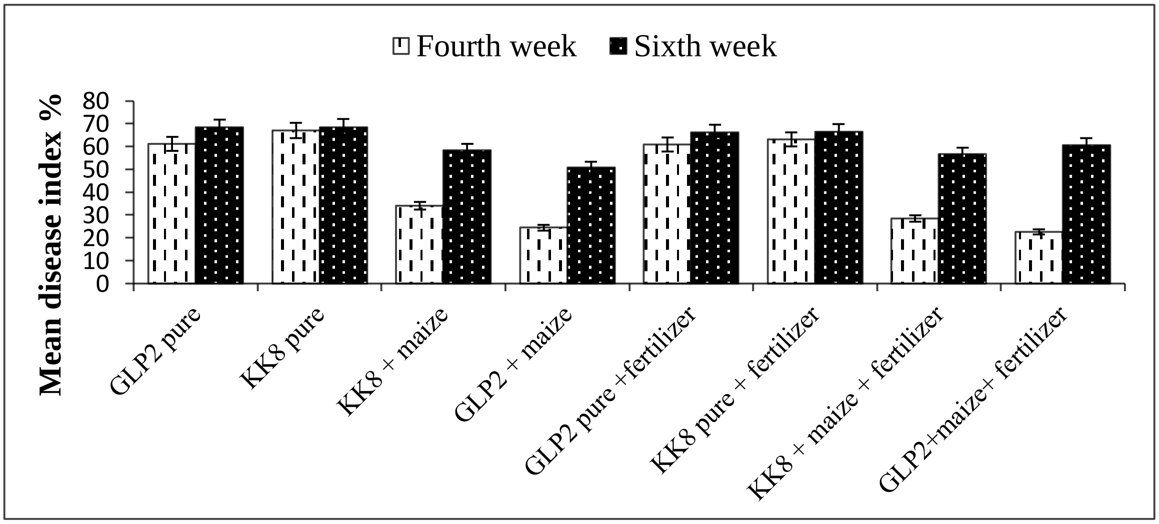

Figure 4. 15: Ascochyta index (%) mean of two bean varieties at fourth and sixth week after emergence in plots planted as pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

Table 4. 11: Percent disease index for web blight at sixth week post emergence of two bean varieties planted in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

Treatment	Alupe	Busire	Butula	Mean
GLP2 pure	73.8 a	68.4 ab	69.1 a	70.5 a
KK8 pure	68.3 ab	68.7 a	69.2 a	68.7 ab
KK8 + maize	61.9 ab	56.5 ab	68.4 a	62.3 bc
GLP2 + maize	56.4 b	56.2 b	68.7 a	60.4 c
GLP2pure +fertilizer	68.0 ab	68.2 ab	68.9 a	68.4 ab
KK8 pure +fertilizer	68.7 ab	68.0 ab	69.0 a	68.6 ab
KK8 +maize+fertilizer	62.1 ab	68.0 ab	68.2 a	66.1 abc
GLP2 + maize + fertilizer	56.5 b	62.2 ab	73.8 a	64.2 abc
LSD (P≤ 0.05)	14.2	11.0	5.9	66.1 abc
LSD (P≤ 0.05)	Site; 3.5	Treatment; 5.7	Site * Treatment; 9.9	
CV (%)	12.6	9.7	4.9	

KK8- Kakamega 8; GLP2- Rose coco: Bean varieties. Means accompanied by the same letter(s) in each column are not significantly different at P ≤ 0.05; LSD- Least significant difference at p ≤ 0.05; CV-coefficient of variation

Table 4. 12: Total disease index (%) at fourth and sixth week post emergence of two common bean varieties planted in pure stand or intercropped with maize and with or without fertilizer in the study sites in Busia County

Treatment	Fourth week			Sixth week		
	Alupe	Busire	Butula	Alupe	Busire	Butula
GLP2 pure	58.2 a	66.8 a	61.4 b	78.8 a	79.4 a	75.8 a
KK8 pure	61.9 a	62.7 a	68.0 a	75.4 a	77.5 ab	75.1 a
KK8 + maize	38.0 b	46.0 b	39.3 d	63.1 b	66.8 d	69.6 c
GLP2 + maize	30.3 c	47.0 b	44.0 cd	63.1 b	66.0 d	70.3 bc
GLP2 pure +fertilizer	57.3 a	62.8 a	65.1 ab	74.8 a	75.3 ab	73.9 ab
KK8 pure + fertilizer	56.4 b	64.7 a	68.3 a	74.5 a	73.7 bc	75.9 a
KK8 + maize + fertilizer	37.2 b	45.5 b	42.4 cd	64.2 b	70.1 cd	68.9 c
GLP2 + maize + fertilizer	36.4 b	45.1 b	46.7 c	64.2 b	69.2 cd	70.8 bc
LSD (P ≤ 0.05)	5.6	6.3	5.9	6.1	4.6	3.8
LSD (P ≤ 0.05)	Site; 2.1	Treat ment;3 .4	Site * Treatment; 5.9	Site; 1.6	Treatm ent;2.6	Site * Treatment; 4.5
CV (%)	6.8	6.5	6.2	5	3.7	3.0

KK8- Kakamega 8; GLP2- Rose coco: Bean varieties. Means accompanied by the same letter(s) in each column are not significantly different at P ≤ 0.05; LSD- Least significant difference at p ≤ 0.05; CV-coefficient of variation

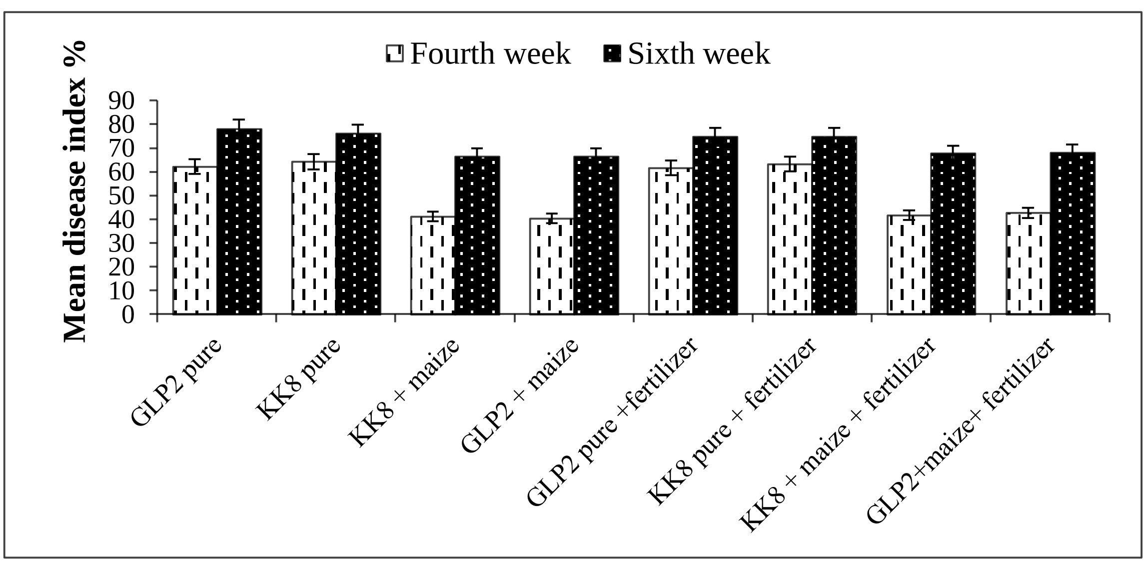

Figure 4. 16: Total disease index (%) mean of two bean varieties at fourth and sixth week after emergence in plots planted as pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

4.4.3 Effect of seed quality and intercropping on yield

There were significant differences ($p \leq 0.05$) in the seed yield and number of pods across sites and among the various treatments. The mean seed yield was 777 kg/Ha, but was as high as 957 and 944kg/Ha in Alupe and Busire compared to the seed yield in Butula which was 432 Kg/Ha (Table 4.13). Seed yield was higher for KK8 intercropped with maize and applied with fertilizer, compared to yield from KK8 pure without the application of fertilizer. Average yields ranging from 700Kg/Ha to 800 kg/Ha were obtained from varieties GLP2 and KK8 intercropped with maize and their pure crops with the application of fertilizer.

Bean crops in Alupe and Busire had an average of seven, compared to Butula which had an average of five pods (Table 4.14). The varieties GLP2 and KK8 intercrops with and without fertilizer application had higher average number of pods compared to the pure stands of the bean varieties. There was no significant difference ($P \geq 0.05$) in the biomass yield across sites and treatments; however, a general variation was observed (Table 4.15). Biomass yield was 30% higher in Alupe compared to Butula which had the lowest biomass yield. The sole crop of the bean varieties, KK8 and GLP2 with and without fertilizer had higher biomass yield across the sites. The varieties GLP2 and KK8 intercropped with maize with fertilizer application were higher in biomass yield compared to the varieties intercropped with maize with no application of fertilizer.

There were significant differences ($P \leq 0.05$) in maize yield and number of cobs per plant across sites and the treatments. The overall maize grain yield for the three sites was (Mean = 6709 kg/Ha), with Butula having the highest yield of 7490 ka/Ha, followed by Alupe (6602 kg/ Ha) then Busire (6037 kg/ Ha) (Table 4.13). Maize intercropped with KK8 and GLP2 with fertilizer application had significantly ($P \leq 0.05$) higher maize yield of 7345 and 7419 kg/Ha, respectively (Table 4.13).

Table 4. 13: Bean seed yield (kg/Ha) of two common bean varieties planted in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

Treatment	Alupe	Busire	Butula	Mean
GLP2 pure	1017 ab	1074 a	352 ab	727 b
KK8 pure	899 b	667 b	235 b	600 c
KK8 +maize	761 b	1217 a	485 ab	821 b
GLP2 + maize	1232 a	744 b	326 ab	759 bc
GLP2 pure + fertilizer	970 ab	1113 a	417 ab	782 b
KK8 pure+ fertilizer	817 b	733 b	402 ab	717 bc
KK8 +maize+fertilizer	754 b	1267 a	622 a	1040 a
GLP2 + maize + fertilizer	1207 a	736 b	620 a	776 b
LSD ($P \leq 0.05$)	249.5	254	290	
LSD ($P \leq 0.05$)	Site; 92.5	Treatment; 151.0	Site * Treatment; 261.5	
CV (%)	14.9	15.4	38.3	

KK8- Kakamega 8; GLP2- Rose coco: Bean varieties. Means accompanied by the same letter(s) each column are not significantly different at $p \leq 0.05$; LSD- Least significant difference at $p \leq 0.05$; CV-coefficient of variation

Table 4. 14: Average number of pods of two common bean varieties planted in pure stand or intercropped with maize and with or without fertilizer in three sites in Busia County

Treatment	Alupe	Busire	Butula	Mean
GLP2 pure	4.7 d	6.0 a	4.3 ab	5.0 c
KK8 pure	6.7 bcd	6.7 a	4.3 ab	5.9 abc
KK8 + maize	8.0 ab	7.3 a	5.0 ab	6.8 a
GLP2 + maize	6.3 bcd	6.7 a	5.7 a	6.2 ab
GLP2 pure + fertilizer	5.0 cd	6.7 a	4.7 ab	5.4 bc
KK8 pure + fertilizer	5.3 cd	6.3 a	3.7 b	5.1 bc
KK8 + maize + fertilizer	7.3 bc	7.0 a	4.3 ab	6.2 ab
GLP2 + maize + fertilizer	10.0 a	6.0 a	4.3 ab	6.8 a
LSD ($P \leq 0.05$)	2.3	2	1.7	5.9 abc
LSD ($P \leq 0.05$)	Site; 0.65	Treatment; 1.06	Site * Treatment; 1.83	
CV (%)	19.7	17.1	20.9	18.8

KK8- Kakamega 8; GLP2- Rose coco: Bean varieties. Means accompanied by the same letter(s) each column are not significantly different at $p \leq 0.05$; LSD- Least significant difference at $p \leq 0.05$; CV-coefficient of variation

Table 4. 15: Biomass (kg/Ha) of two bean varieties planted in pure stand or intercropped with or without maize and with or without fertilizer in three sites in Busia County

Treatment	Alupe	Busire	Butula	Mean
GLP2 pure	1074 a	1074 a	630 a	926 a
KK8 pure	963 a	778 a	778 a	840 a
KK8 + maize	852 a	778 a	519 a	716 a
GLP2 + maize	852 a	741 a	519 a	704 a
GLP2 pure + fertilizer	1000 a	1037 a	593 a	877 a
KK8 pure + fertilizer	889 a	889 a	815 a	864 a
KK8 + maize + fertilizer	889 a	852 a	630 a	790 a
GLP2 + maize + fertilizer	1037 a	852 a	778 a	889 a
LSD ($P \leq 0.05$)	361.5	257.8	179.5	826 a
LSD ($P \leq 0.05$)	Site; 99.5	Treatment; 162.5	Site * Treatment; 281.5	
CV (%)	21.9	16.8	15.6	

KK8- Kakamega 8; GLP2- Rose coco: Bean varieties. Means accompanied by the same letter(s) each column are not significantly different at $p \leq 0.05$; LSD- Least significant difference at $p \leq 0.05$; CV-coefficient of variation

Table 4. 16: Grain yield (kg/Ha) for maize intercropped with two bean varieties in three sites in Busia County

Treatment	Alupe	Busire	Butula	Mean
GLP2 +maize	6000 c	5185 b	7185 ab	6124 b
GLP2 +maize + fertilizer	7111 ab	6963 a	8185 a	7420 a
KK8 + maize	6074 bc	5037 b	6741 b	5951 b
KK8 + maize + fertilizer	7222 a	6963 a	7852 ab	7346 a
Mean	6602 b	6037 c	7491a	6710
LSD ($P\leq 0.05$)	1070	1478.1	1345.7	
LSD ($P\leq 0.05$)	Site; 553.6	Treatment; 639.2	Site * Treatment;1107.1	
CV (%)	8.1	12.3	9.0	9.7

KK8- Kakamega 8; GLP2- Rose coco: Bean varieties. Means followed by the same letter(s) each column are not significantly different at $p \leq 0.05$; LSD- Least significant difference at $p \leq 0.05$; CV-coefficient of variation

4.5: Discussion

4.5.1 Quality of the experimental bean seed samples

Seed is the most important agricultural input, and it is the basic unit for distribution and maintenance of plant population. The accessibility of quality seed by small scale farmers is a critical issue, and the planting of low quality seed leads to poor field emergence, infection with seed borne pathogens and lower yield (Njuki and Andersson, 2014). The farm saved bean varieties did not differ significantly in the number of pure seeds, shriveled seeds and discolored seeds before planting. However, the proportion of pure seeds was 60% which was below ISTA's minimum pure seed standard of 95%. This is consistent with the findings by Biemobd *et al.* (2012), who reported that farmer saved seeds were of poor quality and failed to meet the standard purity of 95%.

There was significant variation in seed quality parameters after harvest in the three study sites. All seeds sampled after harvest had physical purity ranging from 50% to 80%, and this proportion of pure seeds could be explained by farmers considering high quality seeds based on the physical quality and those that are free from insects attack (Odhiambo *et al.,* 2016). The sampled seed did not meet the standard pure seed of 95%, and disagrees with findings by Oshone *et al.* (2014) who reported that bean samples from small scale farmers in Ethiopia met the pure seed proportion of above 98%. In addition, Njingulula *et al.* (2014) reported that reduction of purity levels is as a result of genetic factors, ecological conditions and pre and post-harvest practices such as threshing, drying and storage of common bean seeds.

The sole crop of the bean varieties had high proportions of discolored, shriveled and insect damaged seed compared to the bean varieties intercropped with maize. This could be attributed to intercropping system serving as an important cultural practice that reduces pests and diseases on the crops in the field (Wekesa *et al.,* 2015). Intercropping systems of common bean acts as barriers which restrict the movement of insects and diseases (Oshone *et al.,* 2014). Similar findings were reported by Sebetha *et al*. (2014) who found out that low seed quality is due to the monocropping system, and that the disease inoculum in the seeds were reduced by intercropping system compared to monocropping system. The variation in the discolored seeds can be attributed to the higher prevalence of seed borne pathogens and favorable weather conditions for disease development (Icishahayo *et al.,* 2009), however intercropping system reduces the inoculum build up in soil and seeds in the field. In addition to reducing the inoculum in seeds, Dube *et al.* (2014) indicated that farmer saved seeds can be hand-sorted to remove discolored seed, thereby reducing the level of contamination by certain seed-borne fungi and improving seed germination.

Poor post-harvest handling practices and storage facilities contribute to low germination capacity and allow infection of seed borne pathogens of seeds (Kereth *et al.,* 2013). The farm saved bean varieties did not meet the minimum recommended standards of 85% (ISTA, 1999), before planting. The low germination rate in farm saved bean varieties can be explained by the poor post-harvest handling practices and storage facilities (Kereth *et al.,* 2013). This agrees with findings by Bishaw *et al.* (2012) who reported that the long storage periods in poor facilities of farmer saved seeds allow infection of seed borne pathogens causing seed discoloration and shriveling.

After harvest, the bean varieties intercropped with maize with and without fertilizer application met the minimum recommended germination standard of 85%, while the sole crop of the bean varieties had lower than the recommended standard. This could be due to intercropping system changing the dynamics of crop diseases and improving seedling growth rate, shoot length and seed sizes (Belstie and Bogale, 2014). Similar findings by Oshone *et al.* (2014) reported that the germination rates of farm saved seed samples collected from intercropping system were 93.5% and 87.1%. Findings obtained by Ogutu *et al.* (2012) reported that light interception by beans in intercropping system promotes photosynthesis and leads to increased germination and seedling vigor. The study further indicated that application of N fertilizer on beans when intercropped with other crops increases the germination rate, seedling growth and vigor and is due to the N fixed and the N applied.

High levels of mouldiness and infected seedlings were observed in sole crops of the bean varieties. This could be explained by high levels of pathogens inocula on the surface of the seed causing mouldiness and diseased seedlings showing infection (Icishahayo *et al.,* 2009). Similar findings by Oshone *et al.* (2014) stated that the proportion of seeds infected with diseases were less for those produced under intercropping system. The study further explained that intercropping system prevents high inoculum build up thereby reducing seedling infections.

Healthy seed is the most important agricultural input, and it is the basic unit for the distribution and maintenance of the plant population (Cram and Fraedrich, 2010). Seed borne fungal and bacterial diseases significantly reduce seed quality and grain yield, and seed serve as the primary source of inoculum for fungal and bacterial diseases (Denardin and Agostini, 2013). Seed borne bacterial pathogens were isolated from the farmer saved bean seeds before planting and after harvest. This concurs with findings by Oshone *et al.* (2014) who isolated bacterial pathogens in seeds collected from small scale farmers in Eastern Ethiopia. *Xanthomonas axonopodis* pv. *phaseoli* and *Pseudomonas savastanoi* pv. *phaseolicola* were the two main bacteria isolated from the common bean seed and *Xanthomonas* was isolated in high frequency from the study sites in Busia.

Xanthomonas axonopodis pv. *phaseoli* is the causative agent of common bacterial blight (CBB) and is a major constraint to common bean production. The pathogen is favored by high humidity and warm temperature (25-35˚C) and Western Kenya has such weather conditions (Horvath *et al.*, 2012; Jaetszord, 2009). A study by Fininsa and Tefera (2001) reported that bacterial contamination of bean seeds lowers seedling emergence, stand count and seed yield. Small scale farms are threatened by the introduction of bean seeds contaminated with bacterial pathogens. However, the bacterial pathogens survive in infected seed, infested debris and soil in the field (Cram and Fraedrich, 2010). This could be due to the recycling of seeds by farmers and the continuous cultivation of common bean. Bean varieties intercropped with maize had significantly lower population of the *Xanthomonas axonopodis* pv. *phaseoli*. This could be attributed to intercropping systems delaying pathogen build up in the soil and providing protection for beans from severe CBB (Akhavan *et al.,* 2013). These findings agree with those of Oshone *et al.* (2014) who reported that the proportion of seeds infected by *Xanthomonas axonopodis* pv. *phaseoli* were less for those produced under intercropped conditions.

4.5.2 Effect of seed quality and intercropping systems on bean foliar fungal and bacterial diseases

Major foliar diseases of common bean were common bacterial blight and angular leaf spot, while other diseases included bean anthracnose, *Ascochyta*, bean rust and web blight. The intensity of common bacterial blight and angular leaf spot was high in Butula and Busire with less intensity in and Alupe. This could be attributed to poor field sanitation, inoculum build up in the soil, continuous bean cropping and infected crop debris (Osdaghi *et al.,* 2010). A study by Fininsa and Tefera (2001) reported that the primary inoculum sources of *Xanthomonas campestris* pv. *phaseoli* are from infected seed, infested debris and infected soil due to continuous cultivation of the crop. Most foliar diseases are seed borne suggesting that farm saved seeds are of poor quality and had high seed-borne inoculum levels. This is consistent with findings by Bucheyeki and Mmbaga, 2013 who reported high transmission of bacterial and fungal diseases in farm saved seeds. In addition, Clayton *et al.,* 2009 reported that farm-saved seed resulted in a 20% yield loss compared to certified seed. This corresponds with Amodu and Aku, 2015 who reported that certified seeds had less inocula of *Xanthomonas axonopodis* p.v *phaseoli* than farm saved seed.

Foliar diseases were less severe on bean varieties intercropped with and without fertilizer application compared to the pure bean varieties planted. This can be attributed to intercropping system preventing the buildup of soil borne pathogens, thereby lowering diseases and improving the growth and yield of the crop (Wekesa *et al.,* 2015). Fininsa (2008) while investigating the effect of intercropping bean with maize on common bacterial blight and bean rust, reported that the intercropping system reduced common bacterial blight and bean rust incidence levels by 51% relative to sole cropping. In addition, Osdaghi *et al.* (2010) reported that farm saved seeds serve as a means for the survival of seed borne pathogens due to post harvest practices and storage, however intercropping system influenced the incidence of CBB, and reduced the disease under field conditions. Boudreau (2013) assessing foliar fungal diseases of common bean in different cropping systems, reported that intercropping system of common beans reduced the foliar diseases by 73%. In addition, the study concluded on developing a theoretical grounding that will allow improving the application of intercropping for tropical smallholders and industrial farmers alike.

4.5.3 Effect of seed quality and intercropping on yield

Declining crop yield in small holder farmers cropping systems is a crucial aspect in developing more sustainable production systems to improve the crops yield; however in Kenya the potential yield per hectare of common beans ranges between 1400 to 2000 Kg/Ha (Massawe *et al.,* 2016; FAOSTAT, 2015). The results of this study indicate that none of the treatments attained the potential bean yield. However, beans planted in Butula had the lowest yield performance unlike beans in Alupe which had the highest yield. The low yields in Butula could be attributed to several factors including depletion of essential plant nutrients from the soils due to continuous cropping and high incidences of fungal and bacterial diseases (Massawe *et al.,* 2016).

In addition, the poor fertility levels and the high prevalence of fungal and bacterial diseases led to reduced yield in Butula. These findings agree with Mulei and Woomer (2015) and Tan *et al.* (2005) who reported that nutrient depletion in soils adversely affects soil quality and reduces crop yield and consequently poses a potential threat to agricultural sustainability. The study further explained that low soil fertility increases soil borne pathogen inoculum in the soil and also increases the intensity of root rot on beans which reduced the germination capacity and plant stand in the field.

Both GLP2 and KK8 intercropped had high seed yield, biomass and number of pods unlike the sole crop of the varieties which yielded poorly. The good performance of the bean intercropped varieties could be explained by the intercropping system improving soil fertility, reducing weeds, pest and diseases (Massawe *et al.,* 2016). A study by Morgado and Willey (2008) indicated that cereal and common bean cropping systems also control insects and diseases by providing barrier that prevent the spread between the host and parasite. These findings concur with Massawe *et al.* (2016) who reported that bean intercropped with maize had higher yield compared to sole crop. The study further explained that intercropping decreases pest damages, inhibits growth of weeds compared to sole crops, and improves the fertility through nitrogen fixation in the soil and increases yield and quality.

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 General Discussion

The findings of this study indicated that soil samples from the study sites had low soil fertility status which influenced the population of soil borne pathogens and yield of beans. The low soil nutrients status and buildup of pathogens within the soils could be attributed to continuous bean production without fertilization, loss of nutrients through soil erosion and lack of crop rotation by most farmers. These findings concur with Keino *et al.* (2015) who reported that low soil fertility was due to continuous bean production, low use of organic and nitrogen fertilizer, and nutrient depletion in smallholder farms in Western Kenya.

Root rot pathogens were prevalent in all the study sites. *Fusarium* spp, *Macrophomina* spp, *Rhizotonia* spp and *Pythium* spp were isolated from soils and stem bases, however, their population varied among the study sites. Naseri (2014) and Ahanger *et al.* (2013) reported that root rot is more devastating in nutrient poor soils and that soil moisture and soil pH influence the incidence of root rot pathogens. The same authors further reported that conventional and intensive farming practices lead to destruction of soil structure, decline in fertility and microbial diversity hence the rise in the population of soil and root pathogens.The rate of root rot infection varied significantly among sites and treatments with Butula having the highest rate of infection. This can be attributed to low soil nutrient status where Butula had the lowest soil pH and fertility levels among the study sites. Naseri (2014) reported that higher incidence of root rot pathogens is found in areas of low fertility soils. The incidence and severity of root rot was low on the bean varieties intercropped with maize. This can be due to intercropping system creating a barrier to pests and diseases thus reducing their damages. The findings of the study are consistent with findings by Latati *et al.* (2013) who reported that intercropping beans and maize reduced the incidence of root rot.

Higher seed and biomass yields and high number of pods were recorded in beans intercropped with maize. Intercropping effectively enables a more efficient utilisation of available resources due to their difference in growth pattern, aboveground canopy, rooting system, and their water and nutrient demand, which can result in relatively higher yields than pure stands (Giller, 2001). Improved yields can also be due to better soil cover, which controls weeds, and leads to reduced erosion, nutrient leaching hence improved soil fertility in places associated with intercropping system (Latati *et al.,* 2013). The integration of beans in maize-based systems can partially counter N losses through atmospheric N fixation. The presence of a cereal, exploiting the soil mineral N, stimulate legumes to fix N for better soil nutrition and increased yields (Marschner, 1995; Jerenyama *et al.,* 2000). A similar study by Mousavi and Eskandari (2011) reported successful germination, seedlings emergence and lower seedlings mortality due to the positive effects of intercropping beans with maize compared to bean monocrop. Mucheru-Muna *et al*., 2010 reported increased bean yields in maize bean intercrop grown in poorly fertilized soil.

Due to unavailability and high cost of certified seeds, farm saved seed is the most preferred source by small scale farmers (Oshone *et al.,* 2014). From the study findings, the farm saved seeds collected did not meet the (ISTA 1999) recommended pure seed standard of 95% and germination percentage of 85%. This could be attributed to poor post-harvest handling practices and storage facilities of farm saved seeds which leads to infection by seed borne pathogens (Cram and Fraedrich, 2010). However, after harvest, the bean intercropped with maize planted with and without fertilizer met the minimum recommended germination standard of 85% compared to bean seeds from bean monocrop. These findings are in agreement with Oshone *et* *al.* (2014) who reported that the germination percentage of farm saved seed samples collected from intercropping system was 93.5% and therefore met the germination standard of 85%.

Xanthomonas axonopodis pv. *phaseoli* and *Pseudomonas savastanoi* pv. *phaseolicola* were the two main bacteria isolated from the common bean seeds with *Xanthomonas* being the most frequently isolated pathogen. This suggests that farm saved seed is the source of inocula for bacterial seed borne pathogens. This concurs with findings by Oshone *et al*. (2014) who reported that bacterial pathogens were isolated in high numbers from farm saved seeds collected from farmers in Eastern Ethiopia. Foliar diseases were less severe on varieties KK8 and GLP2 intercropped with maize and planted with and without fertilizer. This can be attributed to intercropping system preventing the spread of inoculum, thereby lowering foliar diseases and improving the growth and yield of the crop (Wekesa *et al.*, 2015). From the study findings, the population of bacterial pathogens in seed positively correlated with the proportion of infected seedlings and the intensity of foliar diseases. Cram and Fraedrich (2010) reported that bacterial pathogens in seed positively correlated with the intensity of foliar diseases due to the contamination of farm saved seed by bacterial pathogens. Cram and Fraedrich (2010) further indicated that this could be due to the recycling of seed by farmers and the continuous cultivation of common bean crop.

Root rot intensity negatively correlated with the seed yield which can be attributed to high disease pressure and reduced plant stand which led to reduced yields (Massawe *et al.*, 2016). A study by Naseri, 2014 reported that the incidence, severity and disease index of root rot were negatively correlated with the seed yield and number of pods per bean plant. Bean varieties intercropped with maize had high seed and biomass yield and number of pods unlike the sole crop which yielded poorly. The good performance of the bean intercrop could be attributed to the ability of intercropping system in improving soil fertility and yield and reduced weeds, pest and diseases (Massawe *et al.*, 2016; Mousavi and Eskandari 2011). Latati *et al.* (2013) reported that intercropping maize and beans increased emergence percentage, reduced diseases and increased yields of both bean and maize compared to the monocropping system. The findings of the current study showed that intercropping bean with maize is a soil fertility management practice which plays a major role in reducing diseases and insect infestation.

5.2 Conclusions

Due to reduced land size, small scale farmers do not practice crop rotation and therefore continuous cultivation of common beans has led to low soil nutrients status and high buildup of fungal and bacterial pathogens. From the study findings, the site with poor soil fertility had high populations of soil borne pathogens and high incidence of root rots infection. This shows that low fertility levels in the study sites played an important role in increasing the severity of soil borne pathogens.

Lower root rot intensity and bean fly incidence and higher seedling emergence and plant stand were recorded in bean varieties intercropped with maize. This emphasizes the importance of intercropping as an efficient ecological strategy to manage soil-borne diseases and insect pests and therefore should be incorporated in sustainable agricultural management practices. The variety KK8 had lower intensity of root rot than the variety GLP2. This shows that use of resistant varieties lower the effect of diseases and therefore should be incorporated as part of integrated pest and disease management practice and therefore should be encouraged among farmers in improving common bean production.

The seed quality test conducted on bean seed from different sources showed that the quality of the farm saved seeds before planting did not meet the ISTA recommended 95% purity and 85% minimum germination percentage. High proportions of shriveled, discolored and insect damaged seeds; other bean varieties and high of bacterial pathogens were isolated from such seeds. The results show that farmers are unaware of proper post-harvest seed handling practices and seed storage conditions for availability of healthy seed to farmers in the next season. Samples from bean intercropped with maize had lower bacterial contamination and met the minimum recommended germination percentage of 85%. This is therefore, an indication that intercropping prevents buildup of seed borne pathogens hence the increased germination capacity and seedling vigor.

There was high intensity of both fungal and bacterial diseases of common bean in Butula compared to other study sites. Soil fertility was also poor in Butula unlike other sites. This shows that improved soil fertility has an indirect effect in reducing disease pressure. Disease intensity was lower in bean intercropped with maize compared to the mono crops. This implies that intercropping system prevents buildup of soil borne pathogens, and prevents the spread of wind-blown inocula thereby lowering diseases and improving growth and yield of the crop. Intercropping system is also known to improve soil fertility, reduce weeds, pests, and diseases therefore improving yield.

5.3 Recommendations

Based on the study findings, the following are recommended:

i. Farmer training on the use of clean seed through the process of sorting to remove shriveled/ discolored seeds and insect damage seeds in order to reduce disease inoculum.
ii. The incorporation of intercropping system, crop rotation and field sanitation as common bean disease management and soil fertility improvement measures.
iii. Price reduction of bean certified seed for affordability by small scale farmers.
iv. Farmer training on improved post-harvest and storage practices.
v. Further studies should be conducted to determine the link between different cropping systems and severity of common bean diseases.

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APPENDICES

Appendix 1: Average temperature (°C), precipitation (mm) and relative humidity (%) in Kakamega in 2016

Month	Total precipitation	Maximum temperature	Relative humidity 06Z	Relative humidity 12Z
January	3.4	31	60	31
February	52.2	32.6	60.6	31.2
March	210.6	32.4	55.2	33
April	368.3	28	83.2	65.4
May	302.5	27.6	84	66
June	230.7	26.9	87.9	64.4
July	146	28.1	82	54
August	198.8	28.8	77	52
September	110.5	28.8	77	57
October	195.6	28.2	*	*
November	*	*	*	*
December	132	27.6	*	*

Appendix 2: Average temperature (°C), precipitation (mm) and relative humidity (%) in Kisumu in 2016

Month	Total precipitation	Maximum temperature	Relative humidity 06Z	Relative humidity 12Z
January	3.5	30.7	57	40
February	53.4	33	53	35
March	205.9	33.6	54	34
April	284.9	28.6	81	58
May	175.3	28.6	78	59
June	49.8	28.3	76	55
July	84.9	29.9	69	47
August	21.7	30.9	62	43
September	154.5	30.2	64	48
October	200.3	30.5	*	*
November	143.6	28.6	*	*
December	218.9	28.1	*	*

Appendix 3: Map of Western Kenya showing Busia County