EFFECT OF LEGUME DIVERSITY INTERCROP AND VARIETIES ON POPULATION AND SEVERITY OF DAMAGE BY FOLIAGE BEETLES (*Ootheca spp*. and *Medythia sp*.) ON YIELDS OF COMMON BEANS (*Phaseolus vulgaris* L.) IN WESTERN KENYA

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A Thesis Submitted to the Graduate School in Partial Fulfillment for the Requirements of the Master of Science Degree in Crop Protection of Egerton University

EGERTON UNIVERSITY

JULY, 2018

DECLARATION AND RECOMMENDATION

Declaration

I declare that this is my original work and has not been presented wholly or in part for any award in this or any other institution.

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Recommendation

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DEDICATION

To my loving parents Mr. J. Obanyi Maragia & Mrs Billiah Moraa Ombasa and treasured daughter Lindah Kerubo.

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First and foremost, I am grateful to the Almighty God for granting me good health, strength, willpower and ability to do my work to completion. Secondly, I would like to thank Egerton University for giving me a chance to pursue this degree. My deepest gratitude and sincere appreciation goes to my supervisors; Prof. Alice W. Kamau and Dr. John Ogecha for their guidance and encouragement in the design, research and final thesis write-up. I wish to sincerely thank Kenya Agricultural and Livestock Research Organization (KARLO) for the study leave granted and International Centre for Tropical Agriculture (CIAT) for funding the study through financial support from Mc Night foundation. Special thanks go to entire AADARP staff, particularly Boniface and Benjamin for their facilitation in logistical support, giving a hand in data collection, and in the helping to mobilize the participating farmers.

ABSTRACT

Bean Foliage beetles (*Ootheca spp*.) are a major constraint to common bean production in Kenya. Two studies were carried out during the long and short rain seasons of 2015 to determine the effect of mixtures of bean varieties and other legume species and also to investigate the effect of different bean varieties on bean foliage beetle incidence, population density and severity of damage and grain yield. Field experiments were conducted in six sites (Madola, Bujumba, Busire, Nyalara and Alupe) in Busia County and in Bondo, Siaya County. A total of 21 farmers participated in the first study and 7 in the second study. Treatments in the mixed cropping trial included Rosecoco monocrop, mixture of bean varieties and mixtures of bean varieties planted with cowpea and groundnut. Treatments in the second trial were Rosecoco, KATX56, KK8 and KATX69 bean varieties. The first trial was planted in randomized complete block design with different farmers acting as replicates. The variety trial was planted in an RCBD arrangement in each farmer's field. The mixed cropping comprising of the three common bean varieties, groundnut and cowpea recorded the least damage severity (1.0) in both seasons compared to Rosecoco monocrop. The highest grain yield (1.73 ton ha^{-1}) was recorded on the Rosecoco monocrop but was not significantly different from three mixtures of bean varieties together with the groundnut and cowpea (1.42 ton ha^{-1}). Mean foliage beetle severity was significantly lowest in KATX56 (1.0) than Rosecoco bean variety (2.0). The KATX56 variety recorded significantly higher grain yield during both seasons (0.98 ton ha^{-1} and 0.89 ton ha^{-1} respectively) compared to Rosecoco variety. This study showed that mixed cropping of the bean varieties and mixtures of bean varieties, cowpea and groundnuts significantly reduced bean foliage beetle percent incidence and severity of damage and increased the yield of common beans. The choice of common bean variety influences the foliage beetle incidence, severity and the yields of the common bean.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEZ	Agro Ecological Zone
ANOVA	Analysis of Variance
BCMV	Bean common mosaic virus
BFB	Bean Foliage Beetle
CIAT	Centro Internacional de Agricultural Tropical
DMRT	Duncan Multiple Range Test
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GoK	Government of Kenya
ICIPE	International Centre of Insect Physiology and Ecology
IPM	Integrated Pest Management
KALRO	Kenya Agricultural and Livestock Research Organization
KARI	Kenya Agricultural Research Institute
KAT	Katumani (Bean Tolerant Selections)
KK	Kakamega (Bean Tolerant Selection)
M.a.s.l	Meters above sea level
RCBD	Randomized Complete Block Design
SARI	Selian Agricultural Research Institute
SAS	Statistical Analysis Software
UM	Upper Midland
MoA&L	Ministry of Agriculture, Livestock & Fisheries
USD	United States Dollar

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Food legumes in Sub-Saharan Africa play a vital role by being a source of livelihood for millions of people and offer tremendous potential to contribute to the alleviation of malnutrition among resource poor farmers (Wortman *et al*., 2004). They contribute to the sustainability of cropping systems and soil fertility. Common beans (*Phaseolus vulgaris* L.) is the most widely grown grain legume, second to maize in importance as source of cheap protein and energy for most poor people in Sub Saharan Africa and also in the World (Katungi *et al.*, 2010). Beans are also important as cheaper source of protein, and have a high amount of carbohydrates, dietary fiber and also rich in vitamins, iron and zinc (Muthomi and Nyamongo, 2010). Common beans are mainly grown for their dry seeds but the green ripe seeds, pods and green tender leaves are also consumed as vegetables. The threshed pods and stalks are fed to animals and used as fuel for cooking (Lipper *et al*., 2006).

The main common bean growing areas in Kenya are Western Kenya, Rift valley, Nyanza, Eastern and Central provinces at altitude between 1500- 2500 m.a.s.l, (Wortman *et al*., 1998). At the coast region, production is mainly around Taita hills (Lipper *et al*, 2006). Eastern region accounts for 35% of the total country`s common bean production (Okwiri *et al*., 2009). Nyanza and Western regions, each accounts for 22% of the national output. According Katungi *et al.*, (2010), the trend in bean production increased between years 1970 to 1990, with 5.7% increase in area under production and yield increase of 1.4% during the same period. However between the altitudes of 1990 - 2000, there was significant yield decline of about 7%. The decline was attributed to declining soil fertility, drought, pests and diseases constraints that severely affected production in some areas.

Bean Foliage Beetles (BFB), *Ootheca spp*. and *Medythia sp*. are among the most important insect pests that attack the bean crop. Their abundance and significance have increased in the recent years primarily due to the rapid increase in legume production. The Bean Foliage Beetle belongs to the order Coleoptera and family Chrysomelidae. Presently they are regarded as the most important chrysomelid defoliators of beans (Abate and Ampofo1996; Hillocks *et al*., 2006). The beetles skeletonize the bean leaves, reducing photosynthetic activity and sometimes killing seedlings. Adults also feed on the pods causing scarring. Pod damage can decrease yield and reduce seed quality (Carrillo *et al*., 2009). Damaged pods are also predisposed to secondary infection by bacteria and fungi which may cause rotting and discoloration. BFB are also vectors of some cow pea viruses including cow pea mosaic and mottle virus (Loughran and Ragsdale, 1986). The emerging larvae also damage roots and root nodules by removing secondary roots and causing injury to the primary roots while feeding. They also eat nodules and cause defoliation to bean seedlings. The damage caused to root systems disrupts nutrient flow from the soil and causes plants to senescence prematurely and to bear a few pods each with few seeds. Although this feeding activity can probably reduce nitrogen fixation, its economic importance remains unclear. The larvae pupates within the soil after the beans are harvested but and adults undergo diapause until the beginning of the rains when they emerge to feed on newly planted beans.

Records from the insect collection at Kenya Museum of Natural History show that the *O. bennigeseni* is prevalent in high altitude environment (>1000m above sea level) while *O. mutabilis* (Plate 1) is found in lower altitude areas. The adults are shiny beetles, black or brown or black with an orange head, oval in shape and about 7mm long (Abate and Ampofo, 1996). *Medythia sp.* (Plate 2) is known to occur in the forest zone of West and Central Africa where it is a sporadic pest but has lately been reported in the Eastern parts of the Kenya (Mwangombe *et al.*, 2013).

Plate 1: *Ootheca mutabilis*. **Plate 2:** *Medythia sp.*
Source: www.pestproducts.comSource: www.alluganda.info

Its distribution is less wide than *Ootheca spp*. The adult is about 4 mm long and striped longitudinally with white and light brown markings and attacks mostly the leaf margins. Bean yield losses as a result of Bean Foliage Beetle range from 18% to 31% (Bean *et al*., 2007).

Research on control of these beetles is primarily centered on the use of synthetic insecticide (Alexandra and Eric, 2001). Insecticides have made a great contribution to control insects but the widespread and long term use results in insecticide resistance and bio-magnifications and aggravation of pest problem by eradicating their parasites and predators (Paul *et al*., 2007). However not all farmers practice use of insecticide because of the cost involved and unavailability at the rural areas. Therefore it is essential to explore alternative cheap methods of pest control such as simple cultural practices and use of host plant resistance among the common bean cultivars. Growing mixtures of bean varieties and species in the same area is common practice in Africa, where farmers cultivate more than one crop of different species or varieties together. It is an aspect of introducing heterogeneity into the farming systems based on the ecological principles and has the potential of providing pests and disease suppression in a sustainable manner (Ssekandi *et al.*, 2015; Zhu *et al*., 2000). This study seeks to explore the effect of crop diversity and varieties on incidence and severity of bean damage by bean foliage beetle.

1.2 Statement of the Problem

The common bean (*Phaseolus vulgaris* L.) is the most widely grown legume in Kenya, second to maize in importance as a staple food crop. Demand for the crop is ever increasing due to increasing population. Unfortunately, this demand cannot be met because of certain production constraints attributed to abiotic and biotic factors. Bean foliage beetles are considered among the important pests constraining bean production in the country. From the recent survey conducted to profile legume pests and diseases, in western Kenya, bean foliage beetles were ranked among the most important insect pests of common bean that were widely distributed in all agro ecological zones in western Kenya. The change in pest status of bean foliage beetle is attributed to changes in farming practices and climate change that favour abundance and damage of the insect pest. Efforts are therefore required to manage and control the pest in order to increase bean production in the country and sustainably be able to feed the growing population. Current control strategies for BFB regularly rely upon synthetic Agro-pesticide applications and enormous use of pesticides can expose farmers and animals to health risks and pollute the environment.Therefore there is need to address the information gap of controlling the pest using integrated management strategies in Kenya.

1.3 Objectives

1.3.1 General objective

To contribute towards increased bean production by generating information on improved management of bean foliage beetles.

1.3.2 Specific Objectives

i. To determine the effect of legume diversity on bean foliage beetle population, incidence, severity of damage and grain yield of common bean.
ii. To determine the effect of bean varieties on bean foliage beetle population, incidence, severity of damage and grain yield of common bean.

1.4 Hypotheses

i. There is no cause effect of legume diversity on bean foliage beetle population, incidence, severity of damage and grain yield of common bean.
ii. There is no cause effect of bean varieties on bean foliage beetle population, incidence, severity of damage and grain yield of common bean.

1.5 Justification of the Study

Bean foliage beetles are increasingly becoming a threat to bean production causing yield losses of about 18% to 31%. They have become important because of the increased area under bean production and changing farming practices as well as climate change that favour population increase and the damage they cause. They are highly polyphagous and they attack a wide range of legume crops. Current control strategies for BFB are limited and mainly depend on synthetic agro-pesticide applications. Excessive use of pesticides in production is associated with negative environmental impact such as pollution of ecosystems, human poisoning and pesticide related illnesses such as cancer. There are similarly reports of development of resistance by insect pests to various classes of chemical compounds. Use of host plant resistance and increase of plant species diversity have potential of pest suppression in a sustainable manner. However, there is knowledge gap on their effect on bean foliage beetle.

CHAPTER TWO

LITERATURE REVIEW

2.1 Importance and utilization of beans

The common bean (*Phaseolus vulgaris* L.) is an important component of the production systems and a major source of protein for the people in Eastern and Southern Africa. Beans contribute up to 57% of recommended dietary protein and 23% of energy to the nutrition of some African people (Shellie-Dessert and Bliss, 1991). Poor people rely on a diet of beans instead of meat that is unaffordable (Wortman *et al*., 1998). Although largely grown for subsistence, mainly by women, approximately 40 percent of production is marketed at a market value of USD 452 million (Wortman *et al*., 2004; David *et al*., 2000). The crop serves various purposes: its grains are consumed by man as cheap plant protein. The young green succulent pods are used in paste with other foods and eaten as vegetable in some African communities. Dry grains are boiled, fried or baked and eaten in mixtures with cereals grains such as maize. The threshed pods and straw are burnt to ash from which leachate is prepared and used as a tenderizer in meat and other mature and hard to cook vegetables. Other uses are in the areas of restoration of soil fertility and also as cover crop in farms that have erosion problem. Beans also play an important role as a source of animal feed in small-holder livestock systems and formulation of feeds in industries for livestock when mixed with cassava (Lipper *et al*., 2006). Beans have higher prices, compared to cereals and are increasingly grown to supplement farmers' income. The important and diverse role played by beans in the farming systems and in diets of poor people make them ideal crops for achieving developmental goals of reducing poverty and hunger, improving human health and nutrition, and enhancing ecosystem resilience.

2.2 Bean Production in Kenya

In terms of area, Kenya is the leading producer of common bean in Africa followed by Uganda and Tanzania. Malawi and Ethiopia rank eighth and ninth, respectively according to FAO statistics (FAO, 2014). However, in terms of production, Kenya comes second after Uganda, with Tanzania keeping its third position. Common bean yields are higher in Uganda than in Kenya because of a relatively favorable biophysical environment (such as weather condition) in Uganda compared to Kenya. Beans are mainly produced in the highlands and midlands of Central, Eastern, Rift Valley, Western and Nyanza regions. In terms of output, the Rift valley contributes 33% of the national output followed by Nyanza and Western region accounting for 22% each and about 60% of beans produced in Rift valley are intercropped with cereals (Lipper *et al*., 2006). Eastern region accounts for 35% of the total country`s common bean production (Okwiri *et al*., 2009). Bean production is mainly done by small scale farmers either in monoculture or inter cropped with maize, coffee, bananas, sorghum, millet, potatoes or cassava.

The yield of beans vary greatly from place to place depending on the climate, soil condition, seed quality level, efficiency in insect pests and disease management and general crop management. In general, the yields are low and average about 0.450t ha^{-1} in mono crop and 0.370t ha^{-1} when produced under intercrop with maize (Katungi *et al*., 2010; MoALD, 2004). However, under experimental conditions, yields of over 5t ha^{-1} in mono crop and 2t ha^{-1} when intercropped with maize have been achieved (Mwang'ombe *et al*., 1994). The current trends of common bean production suggest low to stagnant growth, though demand is expected to continue growing. In the last ten years, production of common bean in Kenya has been growing at a rate of 5.2 percent with the area expansion at an average rate of 3.3% per year. The area is forecast to continue to increase although with some moderation in the rate of increase to below the current rate of 3.3% in the next 10 years due to land shortage associated with population pressure (Lipper *et al*., 2006). Siaya farmers produce about 0.531t ha^{-1} while in Bondo production is about 0.351t ha^{-1}. Former Siaya district area of bean production is 39,104 having a production of 352 kg ha^{-1}. Former Busia district area of production is about 19,815ha giving a production of 178 kg ha^{-1} (Country Food Production Statistics 2012 Publication).

2.3 Bean Production Constraints

In recent years, bean production trend has not kept pace with the annual growth rate (estimated above 2 percent) in population in some countries due to a number of biotic, abiotic and socio-economic constraints (Xavery *et al*., 2007). Among the abiotic constraints, drought is the most important and occurs across Eastern and Southern Africa. Farmers also face a major problem in un-availability and lack of access to seed of improved bean varieties to plant. Lipper *et al*., (2006) defined availability as having sufficient quantity of seed physically within reasonable proximity and in time for planting while accessibility refers to whether people have adequate information, income or other resources to acquire the seed that is available. The available information suggests that both availability and accessibility are constraining the adoption of new varieties in Africa.

Bean production in Kenya has been thought to be on decline due to the severity of ever increasing abiotic and biotic constraints (Katungi *et al*., 2010; Wagara and Kimani, 2007). Kenya small scale farmers rely on rain fed agriculture; this dictates the production patterns especially when variations are high. Thus rainfall variability has hindered bean production as it accounts for over 50% of the total bean yield loss in Kenya. This is true owing to the fact that bean production has expanded to marginalized areas of Lower Eastern (Okwiri *et al*., 2009). This is in response to population increase and shrinking farm sizes in high potential areas. These marginal areas are prone to variability of key climatic conditions necessary for production to take effect. Karel *et al*., (1980) reported that substantial proportions of beans are lost to pest damage in Africa. These pests are often found in complexes and cause damage and reduction in yields. These pests are often classified in categories according to stage of plant growth or plant part attacked. Their economic importance varies from one environment to another. Some of the most destructive bean pests in Kenya include; bean stem maggots-*Ophiomyia spp. (*Diptera: *Agromyzidae*); leaf beetles-*Ootheca. bennigseni* Weise, *Ootheca. mutabilis* and *Medythia quaterna* (Fairmaire) (Coleoptera: Chrysomelidae); pod borers-*Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) and *Maruca vitrata* (Fabricius) (Lepidoptera: Pyralidae); pod-sucking bugs- *Clavigralla sp*. and *Anoplocnemis curvipes* (Fabricius) (Heteroptera: Coreidae); a few species of thrips (Thripidae); and aphids-*Aphis fabae Scopoli* and *A. craccivora* Koch (Sternorrhyncha: Aphididae) (Abate and Ampofo 1996; Wortman *et al*., 2004; Okwiri *et al*., 2009).

2.4 Importance and Distribution of Bean Foliage Beetles

Bean foliage beetles are presently regarded as one of the two most important chrysomelid defoliators of beans (Abate and Ampofo, 1996; Hillocks *et al*., 2006). Karel and Rweyemamu (1984) regard it as a pre flowering defoliator pest of legumes. The beetles skeletonize the bean leaves, reducing photosynthetic activity and sometimes killing seedlings. Minja *et al*., (2003) observed this as a conservative estimate when one considers that bean plants are subjected to larval and adult attack in the same season. Adults appear to be most active in the mornings and late afternoons (Ochieng *et al*., 1978). Adults also feed on the pods causing scarring. Pod damage can decrease yield and reduce seed quality (Carrillo *et al*., 2009). Damaged pods are also predisposed to secondary infection by bacteria and fungi which may cause rotting and discoloration. BFBs are known to transmit bean pod mottle virus, cowpea mosaic virus and southern bean mosaic virus. Larval development stage also feed on roots and nodules that may interfere with nitrogen fixation although this still remains unclear. Although this feeding can reduce nitrogen fixation, its economic importance remains unclear.

According to Dalin *et al*., (2010) BEB feeding and injury starts at early growth stages and continues throughout the later growth stages causing significant CUP stand reduction and yield loss. Similar injury resembling BFB defoliation at a seedling stage resulted to 12% yield decrease when seedling defoliation reached 68%. Economic injury levels are sometimes reached at late season and are associated with pod injury. Yield losses in the range of 18-31% were attributed to *O. bennigseni* in Tanzania, including complete crop loss in the wide range of crops, common beans, cow pea, soybean, majorly the fabacea The BFB *Ootheca mutabilis* and *O. benningsenii* species is endemic to Africa and it has historically been regarded as a minor pest in the East Africa (CABI, 1987). Medythia quartena is another species that attacks legumes in Africa (Iroch *et al*., 2003; Grobbetacus *et al*., 2008).*Ootheca spp*. have also been reported to be a key pest in Zambia, Malawi, Kenya, Burundi and Rwanda. Bean Foliage Beetles belongs to the genus *Ootheca* and *Medythia* (Chrysomelidae: Galerucinae) and appears to be restricted to Africa. The two species are widely distributed in Africa and attack beans, cowpeas, other leguminous crops as well as okra and other members of the hibiscus family. Young seedlings are most susceptible to bean leaf beetle damage. Bean leaf beetles have also been documented infesting other crops including pumpkins, squash, and cucumber, but serious infestations have not been regularly reported.

The pest causes damage as a result of feeding activity of both larvae and adults and affect all the growth stages of the crop growth causing significance yield loss. The adults can cause 68% leaf defoliation in seedling resulting in upto 12% yield loss (Dalin *et al*., 2010). The larvae of BFB destroy the root tissue of the newly planted beans and with heavy infestation causing complete crop destruction. Seed loses as a result of *Ootheca* spp infestation range from 18% to 31% (Karu and Rweyemamu, 1984). BFB are also vectors of some viruses including cowpea mosaic and mettle (Longhran and Rags dale, 1986).

2.5 Biology of Bean Foliage Beetles

Total developmental time of BFB from egg to adult normally ranges from 25 to 40 days. Studies of the life History of BFB *sp*. (Bean *et al*., 2012; Ampofo and Massomo 1998) show that: Adults lay eggs in the upper two inches of soil near the roots of the host usually within three inches of the plant stem. According to Paul *et al*., (2007) up to eight batches of about 60 eggs per batch are deposited in the soil close to bean plants. Eggs hatch in 4-14 days, depending on soil temperature. Larvae emerge after two to three weeks and undergo three instars which last between 5 and 11 weeks each. Pupation takes place in the soil during the dry season and the teneral adult remains in an earthen cell until the rains resume. The adults emerge with early rains to coincide with the emergence of the new crop of beans to which they cause damage by foliar feeding. They also poach nodules causing damage to rooting system disturbs nutrient flow from the soil and causes plants to senescence prematurely and bear few pods, each with few seeds. Teneral adults go into diapause until the onset of the rainy season the following year, when they emerge and start feeding on leaves of the newly planted beans (Paul *et al*., 2007).

In Kenya the life of BFB cycle starts during the month of March and April when adult emergence in synchrony with rains and planting of beans causing defoliation to bean seedlings. Adults mate and oviposit in soil near bean plants, larvae emerges and live in the soil throughout the three instars and develop to pupae in about 23 days. Warmer soil temperatures can shorten larval developmental time. BFB larvae are left in the soil and development continues after the beans are harvested if land is left fallow and populations may exceed $100/m^2$. During the month of August, pupation starts and is completed in about a week but remains in soil and undergoes diapause allowing for adult emergence in September (Bean *et al*., 2007). In October to March/April, adults remain in diapause until the beginning of the rains when they emerge to attack newly planted beans.

2.6 Symptoms of Damage

Adult beetle feeding is associated with above ground damage, while larvae feed on roots. The extent of damage caused by the larval stage has not been studied extensively, and their behavior remains poorly understood (Lundgren and Riedell, 2008). The symptoms of damage to the beans caused by beetles include round holes on the leaf surfaces. Abate and Ampofo, (1996) reported that the adult beetle can cause extensive defoliation and with heavy infestation they may completely destroy a crop. According to Mwanauta *et al*., (2015) 13% leaf area loss may occur as a result of feeding activities by *O. bennigseni.* BFB may cause leaf feeding injuries to most stages of the bean crop, but the damage is most severe in the seedling stage. Additionally, the feeding of the larvae on lateral roots causes wilting and premature senescence in bean plants. Larval feeding on roots causes patches of yellow looking plants in the field. Such plants are stunted, dry up prematurely and may bear empty pods. Pod injury includes removal of the pod walls down to the endocarp and peduncle feeding which may cause pods to dislodge from plants. Both feeding patterns may result in reduced yields (Smelser and Pedigo, 1992).

2.7 Control Methods of BFB

2.7.1 Biological Control

The use of natural enemies is recommended for the control of insect pests in ecosystems where there is abundance of predators (Ezueh *et al*., 1991). Bean foliage beetles have few known natural enemies in East Africa and even less is known about the use of these organisms to combat them. Natural enemies recorded on foliage beetles include tachnid flies, mites, fungi and nematodes (Bradshaw *et al*, 2003). High percent of parasitization of foliage beetle adults by natural enemies have been reported in the United States of America. About 22% of overwintered adult beetles were parasitized by tachinid flies in Lousiana State. Other natural enemies of foliage beetles include two species of fungi *Beauveria* and *Metarhizium*, *Trombidium* mites that attack up to 40% of foliage beetles. Un-identified nematode has also been reported but little is known on the level of parasitization (Bradshaw *et al*., 2003). Besides the mentioned species as potential natural enemies of foliage beetles, there is limited information on the natural enemies of BFB species endemic to Africa and more research effort is needed.

2.7.2 Cultural Control

Cultural practices by farmers play an important role in the integrated pest management of bean pests (Abate and Ampofo, 1996). Cultural control of insect pest has been appropriately defined; as the tactical use of regular farm practices to delay or reduce insect pests attack (Ogecha *et al*., 2000). This involves manipulation of the environment to make it less favourable for insect pests and more favourable for crop growth. These practices have become integral components of integrated pest management. Various cultural practices have been found to influence infestation of plants by insect pests.

The most important cultural practice employed widely to manage common bean pests include adjusting the planting dates so that it's most susceptible growth stage coincides with the times when the pest is least abundant. Abate *et al*., (2000); Byabagambi, (1998); Ezueh *et al*., (1991); Nderitu *et al*., (1990), observed that delayed sowing of crops made susceptible stages of the crop to avoid insect pest population.

Diversification farming is another integrated pest management strategy that relies on ecological principles through habitat and landscape manipulation to suppress pests and diseases. It seeks to make positive use of ecosystem services by manipulating the environment in space and time of the domesticated plants (Pretty and Bharucha, 2015). Crop diversification can improve resilience in a variety of ways: by suppressing pest outbreaks and dampen pathogen transmission, which may worsen under future climate scenarios, as well as by buffering crop production from the effects of greater climate variability and extreme events. The other benefits of diversification include, improved soil fertility, weed control and yield stability (Mulumba *et al*., 2012; Smith *et al*., 2008; Li *et al*., 2007, Nielsen *et al*., 2007), labour, land use efficiency and profit maximization, (Oyewale and Bamaiyi, 2013).

Diversification that includes intercropping and crop rotation in agricultural systems help replenish the soil structure and function and can significantly reduce the vulnerability of production systems to greater climate variability and extreme events and market volatility, thus protecting rural farmers against vulnerability and improve agricultural production (Li *et al*., 2009). Crop rotation with non-hosts like maize or sun flower reduced the emerging adult population of BFB and affected the development cycle. According to Bean *et al*., (2007) continuous planting of beans on the same field without rotation is a key factor that promotes bean foliage beetle populations build up.

Growing mixtures of varieties and species of legumes is the norm in Africa, where farmers cultivate more than one crops of different species or varieties together. It is an aspect of introducing heterogeneity into the farming systems based on the ecological principles and has the potential of providing pests and disease suppression in a sustainable manner (Ssekandi *et al*., 2015; Zhu, 2000). Multiple crops can be a powerful component of cultural pest control, provided that it satisfies the farmer's socio-economic objectives (Songa *et al*., 2007).

According to Bean *et al*., (2007) intercropping which is a form of diversification of different crops in the landscape is the most important cultural practice widely practiced by most farmers in Sub-Sahara Africa (Risch, 2005; Abate *et al*., 2000). Several studies have indicated that intercropping pigeon pea and castor reduced insect pest damage (Srinivasa *et al*., 2004). According to Srinivas *et al*., (2012) it reduces the damage caused by pests and diseases ensuring greater yield stability. Intercropping is reported to support lower specialized herbivore loads than monocultures (Altieri *et al*., 1999). Studies have demonstrated reduced number of insect pests on common beans intercropped with maize (Byabagambi, 1998). Increasing vegetation bio-diversity in agro ecosystem can reduce the impact of pests and disease by the following mechanisms; Stimulo deterrent, diversion, disruption of spatial cycle, allelopathy, effects on crop physiological resistance and conservation of natural enemies (Ratnadas *et al*., 2012).

There is limited information on the effect of diverse cultivars of common beans on foliage beetles damage. However, according to Kisetu *et al*., (2014) intercropping cowpea with maize increased severity of foliage beetle damage on cowpea. More research is needed to determine effect of crop diversification on foliage beetle. Adjustment of time of planting to avoid peak foliage beetle population may be one of the possible options considering that they attack early sown crops. Field sanitation and removal of alternative plants such weeds especially those in Malvacea family that have been observed to be preferred to feeding by the foliage beetle can help to reduce the insect population and damage. Diversity has potential of pest suppression in a sustainable manner although there is limited data on its effect on foliage beetles. There is knowledge gap in cultural control strategies in foliage beetle management as an alternative control measure and this is an area that requires further investigations.

2.7.3 Chemical Control

Bean foliage beetle management has mainly relied on chemical insecticide (Wright *et al*., 1996). However this method is not sustainable due to pesticide misuse by farmers as well as environmental pollution and effect on non-target beneficial organisms (Benbrook *et al*., 1996). Synthetic chemical pesticides are the most widely used method of pest control. The four major problems encountered with conventional pesticides are toxic residues, pest resistance, secondary pests and pest resurgence (Lewis *et al*., 1997). Commercial bean growers who have had problems with bean foliage beetles in the past have used imidicloprid insecticidal seed treatment at planting. Organic growers have been reported using rotenone, pyrethrum or neem oil insecticide, while fenvalerate, carbaryl and permethrin are used by farmers who do not practice organic farming (UW-Extension publication A3422). Application of botanical pesticides such as neem (*Azadirachta indica*) seed extracts deter infestation and reduces the damage. Neonicotinoid insecticides are widely used in the management of stripped cucumber beetle in USA (Acalynma vitamins) a chrysomatol and closely related to been foliage beetle. They represent fastest growing launch of pyrethroids and replaced earlier classes that were more toxic to humans and harmful to the environment (White horn *et al*., 2012). In East Africa, use of cow urine and botanical extracts has been reported to reduce the past incidence of common beans (Paul *et al*., 2007). Although urine was more effective in reducing abundance, its effect was short lived. The effect of vernonia lasted at least 7 days. Lambda cyhalothrin, a commercial insecticide, had a fast knock down effect and reduced insect abundance highly for at least 7 days. Lambda cyhalothrin had a repellent effect on BFB.

2.7.4 Host Plant Resistance

Host plant resistance or tolerance offers a promising solution to foliage bean beetle control as a long-term strategy. Common bean varieties have been reported to vary in their level of susceptibility to insect pests (Byabagambi *et al*., 1998, Ampofo *et al*., 1995, Mueke *et al*., 1979). Byabagambi *et al*., (1998) reported variation of common bean varieties in the level of infestation by bean fly and aphids in Uganda that was attributed to variation in leaf area and stem diameter. The resistant soybean accessions to bean flies in Taiwan were observed to have small unifoliate leaves and with high trichome densities, and had smaller purplish stems (Talekar *et al*., 1988; Talekar and Tengkano, 1993). Chiang and Norris (1984) had similarly earlier noted purple colouration in the stems of the resistant soybean varieties which they identified as anthocyanidin and polyphenols as the cause of purple colour. Dharmasena *et al*., (1988) reported that the resistant cowpea varieties to bean flies had smaller leaf area, small stem diameters and low moisture contents. Chiang and Norris (1983) reported that resistant soybean varieties had shorter stem internodes which were correlated with earlier differentiation, and development of lignified stem tissues which were associated with overall physical hindrance effects on larval stage of bean flies. Ogecha *et al*., (2000), reported some level of resistance to bean fly in the following lines in Western Kenya, EXL52, EXL55, Tbf (b) P151, G8047, G20854 and G23070.

Karel *et al*., (1984) observed that none of the improved common bean varieties was resistant to foliage beetle. Tiroesele *et al*., (2013) reported variation in foliage beetle infestation and different growth stages of common bean varieties to BFB and in grain yield on Butter beans than Envy Soy bean varieties in the United States of America. Variations in the levels of susceptibility and grain yields of common beans to foliage beetle damages have been observed. The mechanism of resistance was attributed to non-preference in T8 and Mexican 142 varieties and tolerance Dalin *et al*., 2010).

2.7.5 Integrated Pest Management

Integrated pest management (IPM) is an ecosystem approach to crop production and protection that combines different management strategies and practices to grow healthy crops and minimize the use of pesticides FAO (2014). Other definitions of IPM according to the United States Environment Protection Agency 2012, involves an effective and environmentally sensitive approach to pest management that relies on a combination of common sense practices. The word 'integrated' in IPM initially referred to the simultaneous use of combination maintaining a single pest species below its economic injury level.

Alastair *et al*., (2003) defined IPM as a method of rationalizing pesticide use to prevent or delay the resurgence of pest populations that had become resistant to pesticides and to protect beneficial insects. There is increasing regional and global concern on the effect of agricultural activities on food safety, environmental health. Pest and disease management has depended on pesticide use that lowers the quality standards and pollution of the environment.

Recommendations for insect pest management on common beans range from simple cultural practices of sowing dates, intercropping, soil fertility improvement, use of resistant genotypes, biological to chemical control (Abate and Ampofo, 1996). These individual control methods have their limitations and none is sufficient to adequately control particular insect pests. Integrated pest management advocates minimal use of insecticides in combination with other methods in order to minimize environmental pollution and harm to non-target organisms. It is based on the ecological principles or studies aimed at understanding factors that cause changes in pest population and use the knowledge to formulate strategies to suppress the pest population and damage through utilization of all the available control methods in an integrated manner while taking into consideration the ecological soundness of the methods and the economic factors of the production. Traditional IPM strategies such as intercropping, early planting, choice of growing season, cultural practices and mixture of seeds of different cultivars have been employed in the past to manage insect pests especially bean fly on beans (Lewis *et al*., 1997; Muhammed and Teri *et al*., 1989).

Abate and Ampofo, (1996) reported that the combinations of seed dressing, early planting and increased plant densities of beans from 100,000 to 300,000 plants/ha had the best results in bean fly control. In Tanzania, pesticide seed dressing, mulching and application of fertilizer in combinations were more effective in reducing bean fly damage than when applied individually (Ampofo and Massomo, 1998). Efforts have been made to develop and disseminate or transfer the IPM technologies or knowledge of bean fly to farmers in some parts of Tanzania and Western Kenya (Ogecha *et al*., 2000). The main deficiency of the IPM recommendations is that they are too complicated to traditional small-scale farmers.

Some examples of possible foliage beetle IPM strategies based on preliminary, field observations (Ogecha personal, communication) include; pre-plant selection of resistant or less susceptible varieties for growing in bean foliage beetles prone areas such as KK15 and local land races of improved bean varieties, delayed sowing by a few weeks after the onset of rains to desynchronize adult emergence and crop phenology and crop rotation. However, there has been limited research work on integrated pest management of foliage beetles in Kenya.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was conducted at five sites in Busia and Siaya Counties during the long and short rains 2015. The sites in Busia county were located between 34° 7′ and 34° 20′ East and Latitude 0°10′ and 0° 29′ South and at the altitude ranging 1125 and 1240 m.a.s.l, while sites in Siaya County were located between 34° 17′ and 34° 18′ East and Latitude 0°14′ and 0° 15′ South and at the altitude ranging between 1151 and 1166 m.a.s.l. The rainfall distribution is bimodal (March and continues to May/June while the short rain season starts in August and ends in October) (Jaetzold *et al*., 2009) with a mean annual average of 1500mm. The study was located in areas Low Midland 1(LM_1) to Low Midland 4(LM_4). The soils in Busia county areas are shallow to moderately deep of low fertility and classified as Ferrallisols (Jaetzold *et al*., 2009), while the sites in Siaya (Bondo sub county) have fertile black cotton soil (GoK, 2010). The cash crops grown were mainly sugarcane, tobacco and cotton.

3.2 Experiment 1: Effect of mixed cropping common bean varieties, cowpea and groundnut on Bean Foliage Beetle population, incidence, severity of damage and on yield of beans.

3.2.1 Treatments under study

i. Maize + Bean (Rosecoco)
ii. Maize + Beans (KK8, KAT X56, Rosecoco)
iii. Maize + Beans (KK8, KAT X56, Rosecoco) + Cowpea (K80) + Groundnut (Red Valencia)

3.2.2 Experimental design and field layout

The study was conducted at five locations (Madola, Bujumba, Busire, Nyalara and Alupe) in Busia county western Kenya. A total of 22 farmers participated in the experiment work during the two rain seasons. The sites were selected using geographical positioning systems (GPS) to capture socio economic and environmental variability in the study area. All sites have bimodal rainfall averaging between 900-1200 mm per annum. Three common bean varieties (Rosecoco, KATX56, KK 8) and Red Valencia groundnut and K80 cowpea legumes were used as treatments. The legumes were planted between maize rows at 0.3×0.15m inter-row and intra-row spacing respectively in plots measuring 10×10m as shown in appendix II and plate 3. Diammonium phosphate (DAP) fertilizer was applied at the rate of 33 kg ha^{-1} instead of the recommended 50 kg ha^{-1} to minimize confounding effects on foliage beetle infestation on the treatments. The experimental design was randomized complete block design (RCBD) with different fields acting as replicates. The experimental field layout is shown in figure 1.

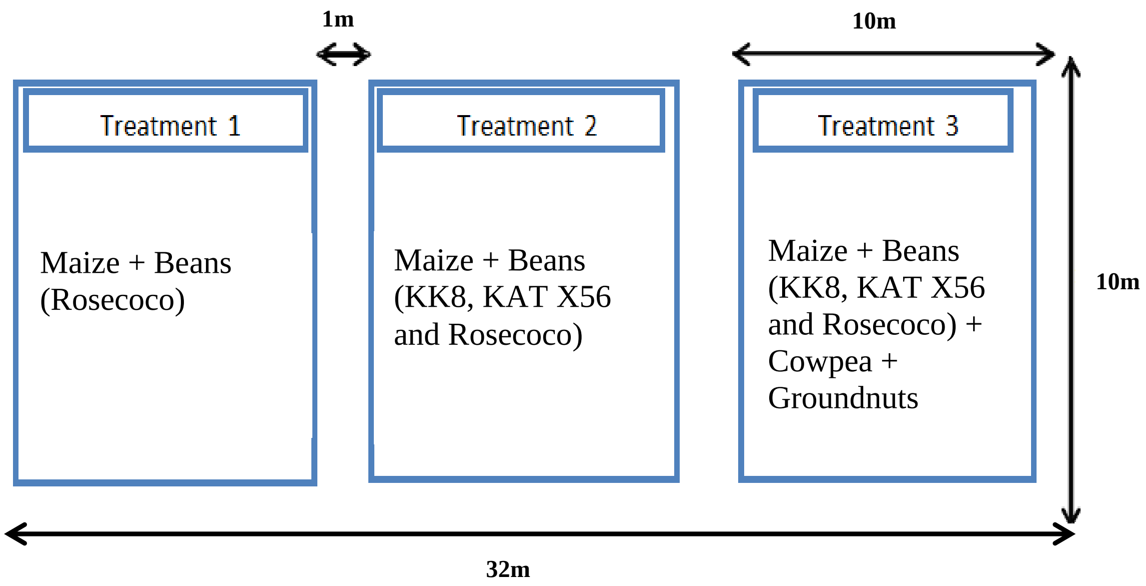


Figure 1: Field Layout for Experiment 1

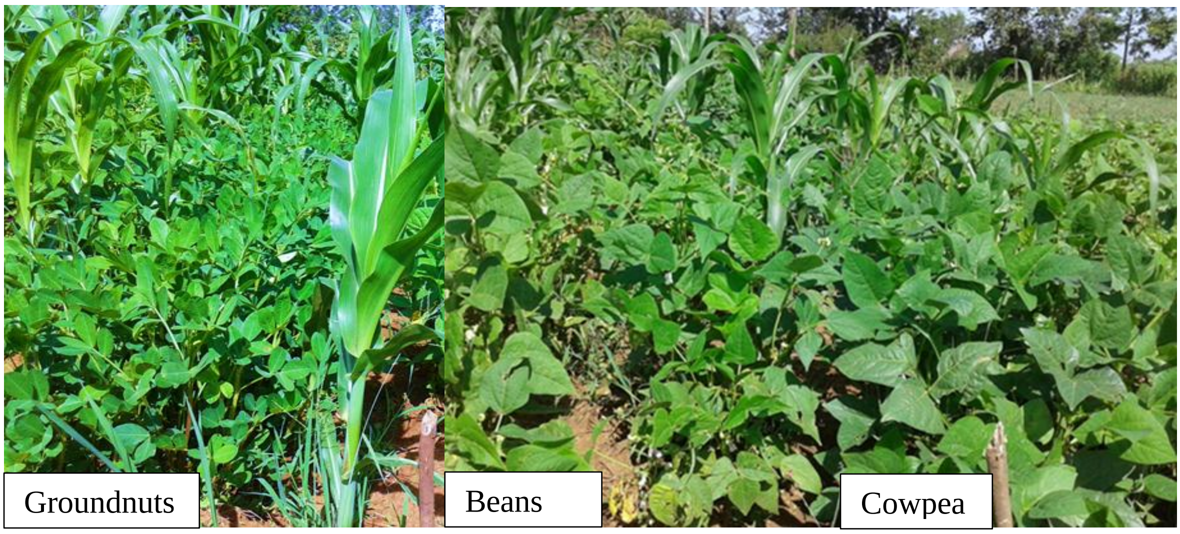


Plate 3: Experiment 1: Field crop layout for treatment three in one of the farms at Alupe site

3.2.3 Data Collection

Data collection was done by in-situ observation (visual counts and assessment of damage on the plant) by the bean foliage beetles. Ten plants per plot were randomly selected from the net plot starting at two weeks after emergence, with the second, third and fourth counts done at four, six and eight weeks after mergence (seedling, vegetative, flowering and podding stages respectively). The first 20 and last 20 plants in each row were not sampled to avoid field margin effects. The bean foliage beetle presence, severity of damage and counts were determined by counting those present on ten randomly selected plants per row in a plot. The randomly selected plants were examined for the following variables:

Variables measured

1. **Plant stand count**

Plant stand count on all the bean plants was taken at 10 days after emergence (D.A.E) and at harvest.

2. **Mean number of BFB per plant**

Ten plants were randomly selected from the center rows examined for the presence of BFB, their numbers counted and recorded.

3. **BFB % incidence**

After the counting of BFB, same plants were examined and the Incidence of pest damage was calculated using a formula: the number of plants with the pest damage expressed as a percentage of total number of plants observed

$$\text{BFB incidence (\%)} = \frac{\text{Number of damaged plants}}{\text{Total number of plants observed}} \times 100$$

4. Severity of damage

The severity of pest damage was assessed based on the percentage leaf, pod and seed area damaged by the BFB. Damage on the beans by the BFB was rated at seedling, vegetative and flowering stages on a scale of 1-5 According to Augustine *et al.*, 2004 where:

1. No infestation or damage
2. Light damage and infestation < 5% plant parts damaged or infested
3. Average damage and infestation> 5 and < 50 % plant parts damaged
4. High infestation and damage > 50 and <75% plants parts damaged and severe stunting or wilting

5. Severe infestation >75% damage resulting in dead plants or badly damaged plants with high infestation level.

Seedling damage signs are as shown in Plate 4A

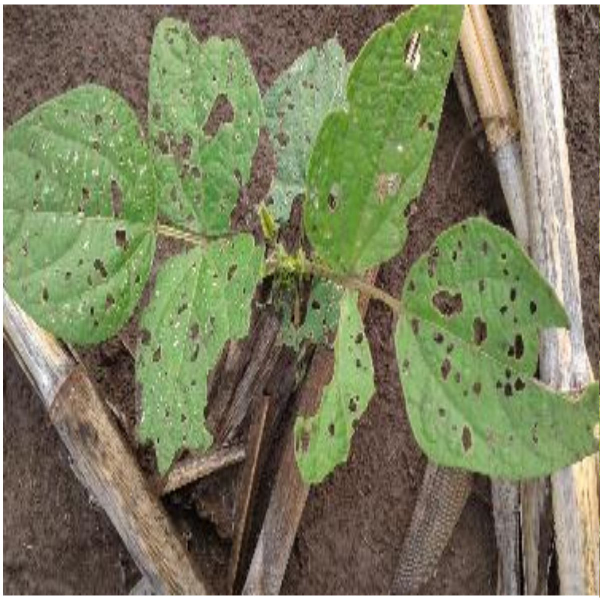


Plate 4A: Severe leaf damage caused by bean foliage beetle at seedling stage

Plate 4B: Severe pod and leaf damage by Bean Foliage Beetle

5. Pod damage

Bean foliage beetle pod damage (Plate 4B) was assessed at the end of the R6 stage (when pods started to change to a yellowish color). This was done for each treatment, by randomly picking 10 plants from the net plot. All pods from each selected plant were then assessed and evaluated visually for BFB damage on a scale of 1 to 5 score according to Augustine *et al*., 2004.

6. Grain yield

Plants from the net plot were harvested, threshed and sun dried to a moisture level of 13% and weighed.

The total weight and converted to tons per hectare using the formula;

$$\text{Yield (tons)} = \frac{\text{Field weight per plot (kg)} \times 10{,}000\text{m}^2}{\text{Harvest area (m}^2\text{)} \times 100{,}000\text{(kg)}}$$

3.2.4 Data Analysis

The model for analysis of variance was:

$$\mathbf{Y_{ijklm} = \mu + \alpha_i + \beta_j + \tau_k + R_l + \alpha\beta_{ij} + \alpha\tau_{ik} + \alpha\,\beta\tau_{ijk} + \sum_{ijkl}}$$

μ = overall mean

α_i = Effect due to the i^{th} season

β_j = effect due to the j^{th} environment

τ_k = Effect due to the k^{th} treatment

R_l = Effect due to the l^{th} replicate

$\alpha\beta_{ij}$= Effect due to the i^{th}season in the j^{th} environment

$\beta\tau_{jk}$ = Effect due to the j^{th} environment in the k^{th} treatment

$\alpha\tau_{ik}$ = Effect due to the i^{th} season in the k^{th} treatment

$\alpha\beta\tau_{ijk}$ = Effect due to the i^{th} season in the j^{th} environment in the k^{th} treatment

$\sum_{ijkl}$= Random experimental error

The data collected was subjected to analysis of variance (ANOVA) using the SAS version 9.1 procedural PROC GLM (SAS Institute Inc., Cary, 2002). The means were separated using Least Significant Difference (LSD) at a significance level of $P<0.05$.

3.3 Experiment 2: Effect of common bean cultivars on Bean Foliage Beetle population, incidence, severity of damage and grain yield

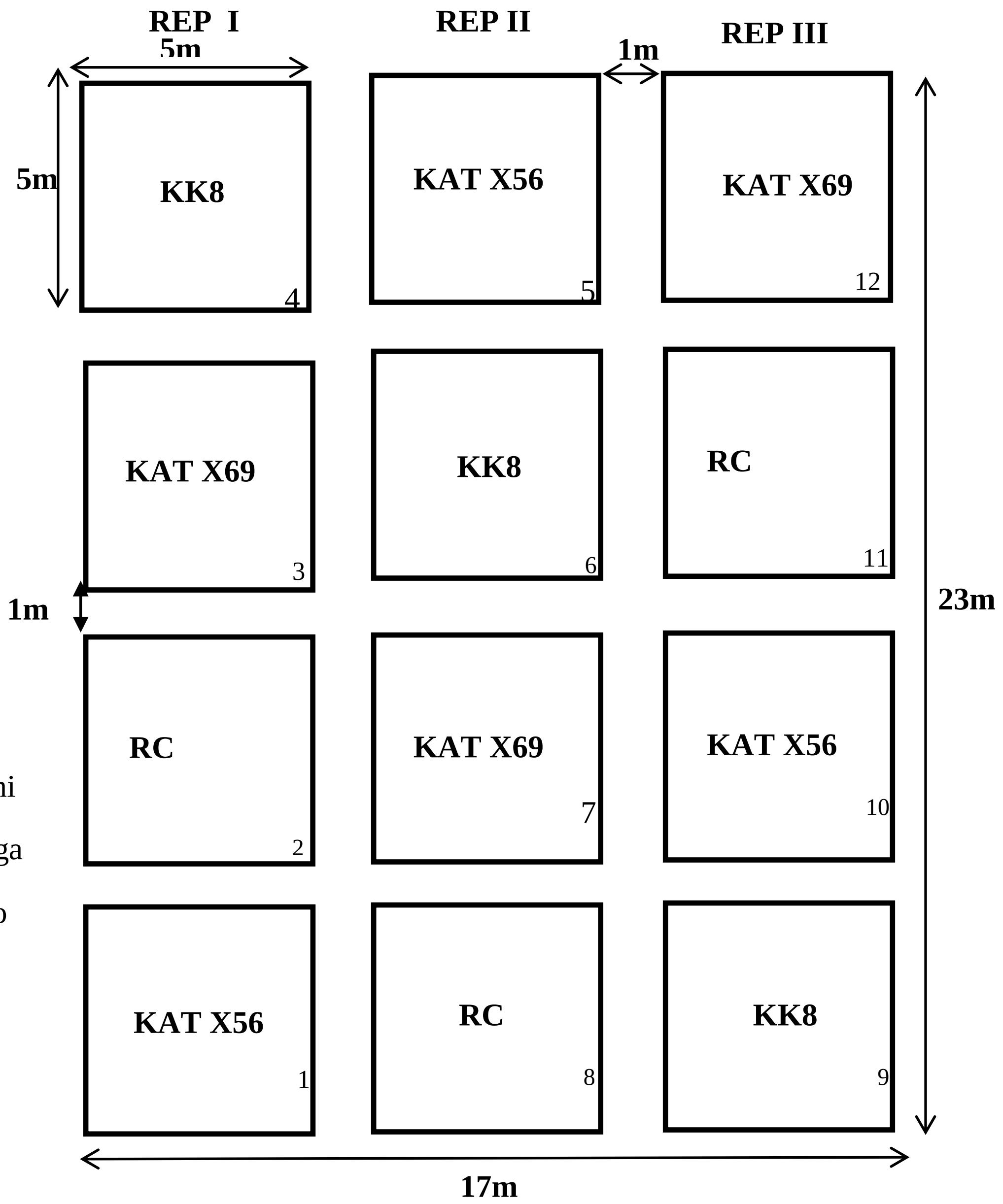
3.3.1 Experimental design and layout

The experiment was carried out in the same sites as experiment 1. There were four sites (Busire, Nyalara, Nakaywa and Alupe) in Busia County western Kenya and in one location in Siaya County (Bondo Sub County). A total of 7 farmers participated in the experiment during the long and short rain seasons of 2015. Four bean varieties were planted in each farm at a spacing of 0.45× 0.15m row to row and plant to plant respectively in plots measuring 5×5m. Diammonium phosphate (DAP) fertilizer was applied at the rate of 33 kg ha^{-1} instead of the recommended 50 $kgha^{-1}$ to minimize confounding effects on foliage beetle infestation on the treatments. The experimental design was randomized complete block design (RCBD) with three replications in each farm as shown in Figure 2 and Plate 6.

The treatments included:

1. Rosecoco
2. KATX56
3. KK8
4. KATX69

The treatments were assigned randomly within the plots in each individual farmer fields as in Figure 2.



Key:

KAT – Katumani

KK – Kakamega

RC – Rosecoco

Figure 2: Experiment 2 field layout

The crop field layout appeared as shown in Plate 5

Plate 5: Experiment 2: Field crop layout in one of the farms in Nyalara site

3.3.2 Data Collection

Data collection was done by in-situ observation (visual counts and assessment of damage on the plant) by the bean foliage beetle. Ten plants per plot were randomly selected from the net plot starting at two weeks after emergence, with the second, third and fourth counts done at four, six and eight weeks after mergence (seedling, vegetative, flowering and podding stages respectively). The first 20 and last 20 plants in each row were not sampled to avoid field margin effects. The bean foliage beetle presence, severity of damage and counts were determined by counting those present on ten randomly selected plants per row in a plot. The randomly selected plants were examined for the following variables:

Variables measured

1. Plant stand count

Plant stand count on all the bean plants was taken at 10 days after emergence (D.A.E) and at harvest.

2. Mean number of BFB per plant

Ten plants were randomly selected from the net plot and examined for the presence of BFB, their numbers counted and recorded.

3. BFB % incidence

After counting the BFB, same plants were examined and the Incidence of pest damage was calculated using a formula: the number of plants with the pest damage expressed as a percentage of total number of plants observed

$$\text{BFB incidence (\%)} = \frac{\text{Number of damaged plants}}{\text{Total number of plants observed}} \times 100$$

4. Severity of damage

The severity of pest damage was assessed based on the percentage leaf, pod and seed area damaged by the BFB. Damage on the bean by the BFB was rated at seedling, vegetative, flowering podding and harvesting stages on a scale of 1-5 According to Augustine *et al*., 2004 where:

1 No infestation or damage
2 Light damage and infestation < 5% plant parts damaged or infested
3 Average damage and infestation>5 and < 50 % plant parts damage
4 High infestation and damage > 50 and <75% plants parts damaged and severe stunting or wilting
5 Severe infestation >75% damage resulting in dead plants or badly damaged plants with high infestation level.

5. Pod damage

Bean foliage beetle pod damage was assessed at the end of the R6 stage (when the pods started to change to a yellowish color). This was done by randomly picking 10 plants from the net plot in each treatment plot. All pods from each selected plant were then assessed and evaluated visually for BFB damage scale on a 1 to 5 score, according to Augustine *et al*., 2004.

6. Grain yield

Plants from the net plot were harvested, threshed and sun dried to a moisture level of 13% and weighed.

The total weight was then and converted to tons per hectare using the formula;

$$\text{Yield (tons)} = \frac{\text{Field weight per plot (kg)}}{\text{Harvest area (m}^2\text{)} \times 100{,}000 \text{ (kg)}} \times 10{,}000\text{m}^2$$

3.3.3 Data Analysis

The model for analysis of variance was:

$$\mathbf{Y_{ijklm} = \mu + \alpha_i + \beta_j + \tau_k + R_l + \alpha\beta_{ij} + \alpha\tau_{ik} + \alpha\,\beta\tau_{ijk} + \sum_{ijkl}}$$

$\boldsymbol{\mu}$ = overall mean

$\boldsymbol{\alpha_i}$ = Effect due to the i^{th} season

$\boldsymbol{\beta_j}$ = effect due to the j^{th} environment

$\boldsymbol{\tau_k}$ = Effect due to the k^{th} variety

$\mathbf{R_l}$ = Effect due to the l^{th} replicate

$\boldsymbol{\alpha\beta_{ij}}$= Effect due to the i^{th} season in the j^{th} environment

$\boldsymbol{\beta\tau_{jk}}$ = Effect due to the j^{th} environment in the k^{th} variety

$\boldsymbol{\alpha\tau_{ik}}$ = Effect due to the i^{th} season in the k^{th} variety

$\boldsymbol{\alpha\beta\tau_{ijk}}$ = Effect due to the i^{th} season in the j^{th} environment in the k^{th} variety

$\sum_{ijkl}$= Random experimental error

The data collected was subjected to analysis of variance (ANOVA) using the SAS version 9.1 procedural PROC GLM (SAS Institute Inc., Cary, 2002). The means were separated using Least Significant Difference (LSD) at a significance level of $P<0.05$. Total seed weight per hectare was correlated with mean number of BFB per plant, incidence and severity of damage.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Experiment 1: Effect of mixed cropping of common bean varieties, cowpea and groundnut on Bean Foliage Beetle population, incidence, severity of damage and on yields of bean

The study showed that there were two bean foliage beetle species that attacked common bean in Western Kenya. *Ootheca sp*. (Plate 6A and 6B) which was present during the two rain seasons and *Medythia sp*. which was observed to be more destructive on bean leaves (Plate 7) and Pods (Plate 8) during the short rain season. These findings were in line with those of Minja *et al*., (2005) and CABI (1987), who reported that there are more than one species of bean foliage beetles that are endemic in Africa, where they attack beans, cowpea and other legume species. Other research findings by Oyewale *et al*., 2013; Grobbelaar *et al*., 2008; Koch *et al*., 2003 found *Medythia quaterna* endemic in West Africa and in some other African countries, where it was reported to be infesting cowpea crop. Mwangombe *et al*., 2013 also documented *Medythia quaterna* infesting cowpea in Eastern Kenya.

Plate 6A: Bean foliage *Ootheca sp* feeding on bean leaf at seedling stage

Plate 6B: Orange coloured *Ootheca sp* on bean leaf

Plate 7: Leaf damage caused by bean foliage beetle *Medythia sp*.

Plate 8: Bean foliage beetle *Medythia sp* feeding on bean pods

4.1.1 Bean foliage beetle incidence, severity of damage and population density at different locations in mixed cropping of common bean varieties, cowpea and groundnut during the long and short rain season 2015 in Western Kenya

The analysis of variance (ANOVA) results showed that the foliage beetle incidence was significantly affected by the season, the site and the stage of crop growth. The mixed cropping treatment did not have a significant effect on the percent foliage beetle incidence. There was also significant season*site and site*growth stage interaction, but no significant effect was observed for the site*treatment and season*treatment interactions respectively (Table 1; Appendix III). In terms of the foliage beetle severity, there were significant effects from the season, site, mixed cropping treatment and the stage of crop growth. The interactions between the site, season, mixed cropping treatment and stage of crop were significant except for the season*treatment interaction (Table 1). The foliage beetle density per plant was significantly affected by the season, site, stage of crop growth and the site*stage interaction. The mixed cropping treatment did not have a significant effect on the numbers of foliage beetle per plant (Table 1).

Table 1: Mean squares for foliage beetle incidence, severity and counts for mixed cropping of common bean varieties, cowpea and groundnut

Source of variation	**df**	**Foliage beetle incidence**	**Foliage beetle severity**	**Foliage beetle density**
Replicate	9	1343.3	0.92	1.97
Season	1	38819.7**	23.86**	32.97**
Site	4	24461.0**	3.2**	2.85**
Treatment	2	146.4ns	252.3**	0.73ns
Stage	2	229348.3**	4.89**	9.11**
Season*site	3	5723.4**	1.24**	0.53ns
Site*treatment	8	129.7ns	0.08ns	0.18ns
Site*stage	7	6142.3**	1.39**	8.93**
Season*treatment	2	533.6ns	4.38**	0.20ns
Error	850	592.9	0.26	0.74
R^2		0.57	0.72	0.79
CV (%)		28.5	20.8	25.0

**- significant at p≤ 0.01; ns- not significant

4.1.2 Effect of season and site on the bean foliage incidence, severity and counts, pod incidence, pod severity and yield of common bean in mixed cropping of common bean varieties, cowpea and groundnut

The foliage beetle incidence was significantly higher (p≤0.05) in long rain season compared to the short rain season. The same trend was observed in terms of the foliage beetle severity and their densities with the long rain season recording higher foliage beetle severity and density respectively (Table 2).

Table 2: Effect of season on the foliage beetle incidence, severity and density on common bean leaves in mixed cropping of common bean varieties, cowpea and groundnut

Season	Foliage beetle incidence (%)	Foliage beetle severity	Foliage beetle density (number/plant)
Long rain	72.5a	3a	2a
Short rain	58.6b	2b	1b
LSD (p≤0.05)	**3.4**	**0.7**	**0.1**

Means followed by the same letters in the same column are not significantly different from each other (p≤0.05).

The highest foliage beetle incidence was recorded at Madola (75.8%) that was significantly different from the other sites. It was followed by Bujumba with 64.1% foliage beetle incidence. There was no significant difference among the other sites namely; Nyalara, Alupe and Busire. The least foliage beetle incidence was recorded at Busire recording 52.2% incidence (Table 3). Madola and Bujumba recorded a significantly higher foliage beetle severity (3.0) compared to the Nyalara, Alupe and Busire sites (2.0). In terms of the foliage beetle density, Madola reported significantly highest number of foliage beetle per plant than the other four sites (Table 3).

Table 3: Effect of site on the foliage beetle incidence, severity and density on common bean leaves in mixed cropping of common bean varieties, cowpea and groundnut

Site	Foliage beetle incidence (%)	Foliage beetle severity	Foliage beetle density (number/plant)
Madola	75.8a	3a	2a
Bujumba	64.1b	3a	1b
Nyalara	51.7c	2b	1b
Alupe	54.5c	2b	1b
Busire	52.2c	2b	1b
LSD (p≤0.05)	**9.9**	**0.2**	**0.4**

Means followed by the same letters in the same column are not significantly different from each other (p≤0.05).

The presences of a malvacea family weed, an alternate host plant to *Ootheca* spp was common in Madola and this would have been the possible reason for higher percent BFB incidences and damages on the beans. The low numbers recorded in Alupe area would have been due to the fact that it had more farms growing groundnuts a non- preferred crop by BFB than the other locations. It was shown that variation in environmental conditions influence severity of pest and disease intensity on common beans. In other research findings differences in locations and seasons showed variation in bean stem maggot infestation and grain yield across two locations at different rain seasons in common bean crop (Wortman *et al*., 1989; Ogecha *et al*., 2012). These research findings were attributed to variation in soil fertility and farming practices. Mugo *et al*., (2011) also reported variation in thrip abundance in common bean in different environments of Kenya and he attributed the pest abundance with relative humidity and rainfall. Different agro ecological zones and altitudes have varying farming practices, population density, soil types, relative humidity, temperature and rainfall regimes (Jaetzoldt *et al*., 2009).These factors especially rainfall and temperature affect population increase and subsequent damage by insect pests.

4.1.3 Bean foliage beetle incidence, severity of damage and density at different stages of crop growth and development in mixed cropping of common bean varieties, cowpea and groundnut in Western Kenya

The foliage beetle incidence was significantly higher during the vegetative stage of growth (82.9%), followed by the seedling stage (77.8%). The reproductive stage recorded the least foliage beetle incidence (Table 4). In terms of the foliage beetle severity and densities, the vegetative stage recorded significantly higher severity scale and numbers respectively compared to both the seedling and reproductive stage of growth (Table 4).

Likewise, there was a significant site* growth stage interaction effect on the foliage beetle incidence. In all the sites, the reproductive stage recorded significantly the least foliage beetle incidence. However, there were differences in the beetle incidence during the seedling and vegetative stage among the sites. In Alupe and Nyalara, there was no difference in the foliage beetle incidence between the seedling and vegetative stage, but in Madola, Busire and Bujumba, the vegetative stage had significantly higher incidence than the seedling stage (Figure 3A). Similarly, there was a significant site* growth stage stage interaction effect on the foliage beetle severity. For instance, in Alupe, the severity was significantly higher during the vegetative stage compared to the seedling and reproductive stage while in Nyalara, the reproductive stage recorded the highest foliage beetle severity compared to the seedling and vegetative stage (Figure 3B).

Table 4: Effect of stage of growth on the foliage beetle incidence, severity and density on common bean leaves in mixed cropping of common bean varieties, cowpea and groundnut

Stage of growth	Foliage beetle incidence (%)	Foliage beetle severity	Foliage beetle density (number/plant)
Seedling	77.8b	1b	1b
Vegetative	82.9a	2a	2a
Reproductive	37.2c	1b	1b
LSD (p≤0.05)	**4.2**	**0.08**	**0.15**

Means followed by the same letters in the same column are not significantly different from each other (p≤0.05).

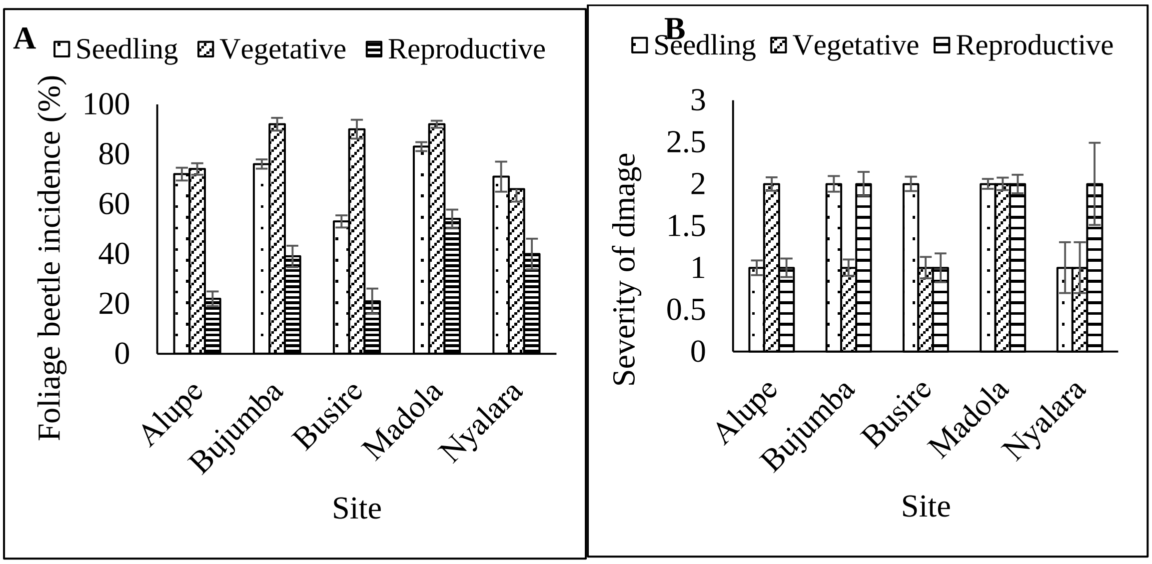


Figure 3: Effect of site* growth stage interaction on the foliage beetle incidence (A) and severity of damage (B) of common bean. Error bars represents the standard error of the means.

Possible explanation is that during the long rains season beans were planted late and these coincided with the two peak population of BFB the first at vegetative stage and the second at podding stage. The second peak was due to resurgence of BFB late in the season and the first was due to population build up after emergence at seedling. The second emergence affects the bean quantity and quality prompting timely harvesting.

In the short rain season timely planting allowed the beans to escape the second BFB cycle peak at podding stage hence low percent incidences and damage were recorded. The first beetle population peak that was observed at seedling stage was not likely to affect bean growth and development as it has been reported that beans are capable of withstanding extensive defoliation before they suffer serious economic injury (Hunt *et al*., 1994). They can also compensate for defoliation by producing excessive leaves (Higley and Boethel, 1994). These results confirmed that bean foliage beetles are foliar defoliators which feed heavily at seedling and vegetative stages except for the late planted beans which had high infestation at podding stage. Abate and Ampofo, (1996); Hillocks *et al*., (2006) regarded them as one of the two most important chrysomelid defoliators of beans. Karel and Rweyemamu (1984) referred them as pre-flowering defoliation by adult.This showed that the best time to control and manage the BFB is at the seedling stage and at the vegetative stage.

4.1.4 Effect of mixed cropping of common bean varieties, cowpea and groundnut on bean foliage beetle severity of damage on bean leaves in Western Kenya

The mixed cropping significantly affected the foliage beetle severity on the bean leaves. The Rosecoco variety planted as a sole crop recorded significantly higher severity than the other common bean treatments. The least foliage beetle severity was recorded in the mixed cropping that included the three common bean cultivars together with groundnut and cowpea (Figure 4A). For the season*mixed cropping interaction, the sole Rosecoco bean variety (Treatment 1) showed the significantly highest damage severity during both seasons. The mixed cropping comprising of the three common bean varieties, groundnut and cowpea (treatment 3) recorded the least damage severity in both seasons (Figure 4B).

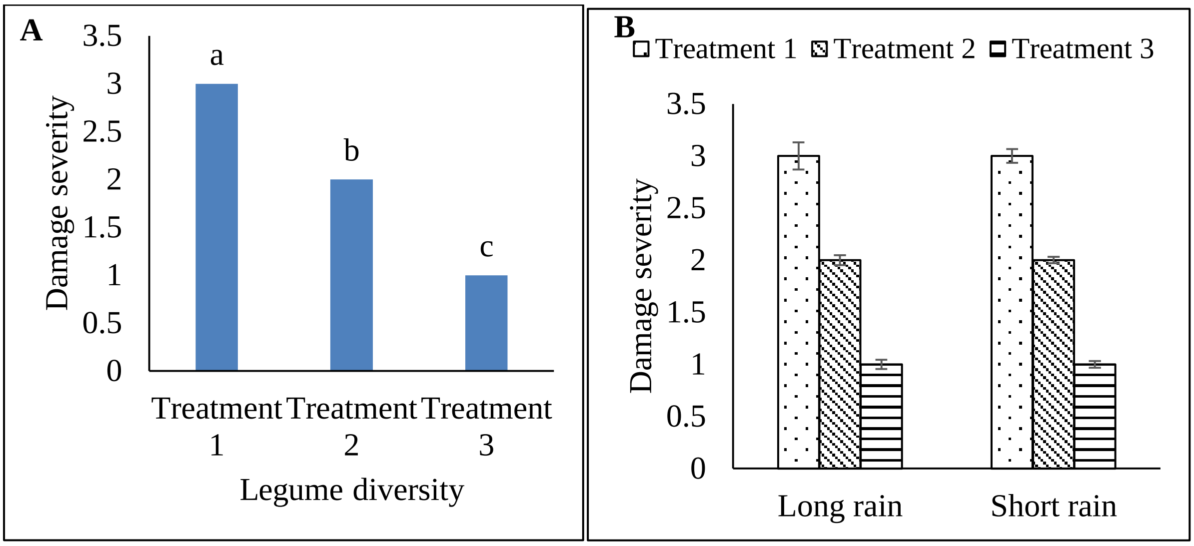


Figure 4: Effect of mixed cropping (A) and season*mixed cropping interaction on damage severity on leaves of common bean. Error bars represents the standard error of the means.

Key: Treatment 1- Rosecoco mono crop; 2- Three bean varieties (Rosecoco KAT X56, KK 8); 3 - Three bean varieties + Cowpea + groundnuts

Mixtures of common bean varieties with other legume species in the same area reduced the incidence and severity of foliage beetle. This could be attributed to increased genetic heterogeneity and increased resistance in the variety mixtures leading to reduced infestation and damage. Previous studies have demonstrated reduced number of insect pests on common beans intercropped with maize that was attributed to change in reduced light intensity, inability to locate the host plants Kyamanywa and Ampofo., (1988). These results are in line with those from other studies such as Ssekandi *et al*., (2015), who reported reduced pest infestation and damage in the mixed cropping systems compared to monoculture. However these results are in disagreement with observations made by Kisetu *et al*., (2014) who reported more foliage beetle infestation in intercropped cowpea than monoculture in Tanzania. The reduced pest abundance in mixed cropping systems compared to monoculture have similarly been attributed to efficacy and abundance of natural enemies (Nderitu *et al*., 2009; Ogenga-latigo *et al*., 1992) and in differences in food or resource concentration that makes it difficult for the insect pests to locate the host plants (Hooks and Johnson, 2003).

Mixed cropping reduced the incidence and severity of foliage beetle but it had no significant influence on the foliage beetle density in the two seasons. The underlying mechanisms or explanation is not clear but could partly be explained by the biology of the insect that has parts of its life cycle spent in the soil. The continuous planting of maize and legume mixtures in the same fields in most of the seasons may have contributed to even distribution of the pest in experimental plots and farmers' fields.

4.1.5 Bean foliage beetle percent incidence, severity of pod damage and grain yield in mixed cropping of common bean varieties, cowpea and groundnut at different locations during the long and short rain seasons of 2015 in Western Kenya

The ANOVA results from this study indicated that the percent beetle incidence was significantly affected by the season, site, mixed cropping treatment and the site*season interaction. There was no significant interaction between the season*treatment, site*season and season*site*treatment interactions respectively (Table 5; Appendix III). For the severity of damage on the bean pods, only the season and the site had a significant effect. The common bean grain yield was significantly affected by the season, site and the mixed cropping treatment. There was also a significant season*site, season*treatment and site*treatment interactions (Table 5; Appendix IV).

Table 5: Mean squares for foliage beetle incidence on pods, severity and yields on mixed cropping of common bean varieties, cowpea and groundnut

Source of variation	df	Percent beetle incidence	Damage severity	Grain yield
Replicate	8	2735.2	0.62	3.90
Season	1	135510.7**	18.88**	76.83**
Site	5	1099.0**	0.47**	5.39**
Treatment	2	1130.1**	0.01^{ns}	2.59**
Season*site	4	521.5*	0.05^{ns}	2.11**
Season*treatment	2	241.9^{ns}	0.01^{ns}	2.64**
Site*treatment	10	246.8^{ns}	0.14^{ns}	1.74**
Season*site*treatment	8	46.1^{ns}	0.04^{ns}	0.31^{ns}
Error		197.7	0.11	0.45
R^2		0.7	0.6	0.58
CV (%)		27.1	16.6	25.6

***- significant at p≤ 0.05 and p≤ 0.01 respectively; ns- not significant

4.1.6 Effect of mixed cropping of common bean varieties, cowpea and groundnut and season on pod damage incidence and grain yields of common bean

The foliage beetle incidence on the pods was highest (53.5%) when the Rosecoco variety was planted as a sole crop. This was however not significantly different from the mixture of three bean cultivars (52.2%). The mixture of the three bean varieties together with groundnut and cowpea recorded the significantly the least foliage beetle incidence (Table 6). The highest grain yield (1.73 tons ha^{-1}) was recorded on Rosecoco monocrop. However, it was not significantly different from the yield obtained in the treatment plot where the mixture of bean varieties, groundnut and cowpea were grown together (1.42 ton ha^{-1}). The mixture of the three bean varieties recorded the least yield (Table 6).

Table 6: Effect of mixed cropping of common bean varieties, cowpea and groundnut on the foliage beetle incidence and yields of common bean

Legume diversity	Foliage beetle incidence (%)	Yield (tonha^{-1})
Rosecoco monocrop	53.5a	1.73a
Mixture of three* bean varieties	52.2a	1.32b
Mixture of bean three* varieties, groundnut and cowpea	45.6b	1.52ab
LSD (p≤0.05)	**4.3**	**0.22**

Means followed by the same letters in the same column are not significantly different from each other (p≤0.05).

The grain yield of common bean varied across the sites for each of the mixed cropping treatment. In Alupe, the Rosecoco sole crop (treatment 1), recorded the highest yield but not significantly different from the plot having mixtures of three bean varieties, groundnut and cowpea (treatment 3). In Bujumba, the Rosecoco sole crop recorded significantly higher grain yield compared to the other two mixed cropping treatments. In Madola, mixed cropping of three bean varieties, groundnut and cowpea (Treatment 3) recorded significantly higher grain yield than the other two treatments. In Busire, there were no significant differences among the mixed cropping treatments (Figure 5A). In terms of the seasons, differences were also observed among the mixed cropping treatments. For example, in the long rain season, treatment 3 recorded the highest grain yield followed by treatment 2 while treatment 1 recorded the least grain yield. However during the short rain season, treatment 1 recorded significantly highest grain yield followed by treatment 3 and lastly by treatment 2 (Figure 5B).

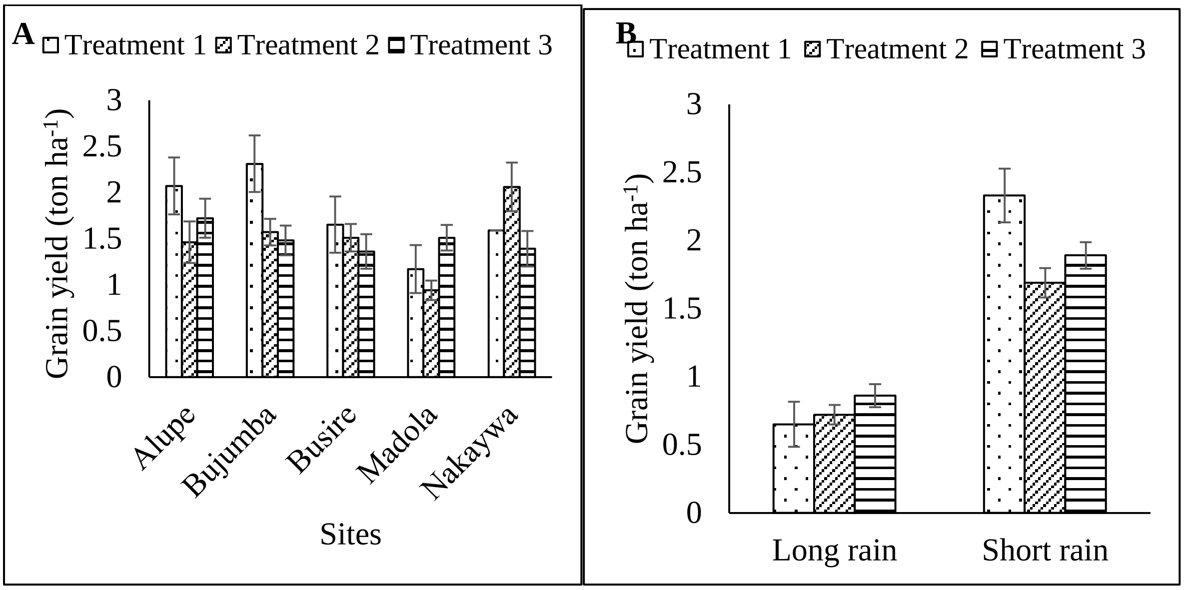


Figure 5: Effect of treatment*site interaction (A) and treatment*season interaction on the grain yield of common bean. Error bars represents the standard error of the means.

Key: Treatment 1- Rosecoco mono crop; 2- Three bean varieties (Rosecoco KAT X56, KK 8); 3 - Three bean varieties + Cowpea + groundnuts

The pod damage incidence was significantly higher (77.8%) in the long rain season compared to the short rain season (35.2%). Similarly, the pod severity was significantly higher in the long rain season than in the short rain season. In terms of the grain yield, the short rain season recorded significantly higher yield than the long rain season (Table 7). The season*site interaction showed that during the long rain season, Madola recorded the highest foliage beetle incidence percentage compared to the other sites while Nyalara recorded the least percent foliage beetle incidence (Figure 6). In Alupe and Bujumba, there was no significant difference on the foliage beetle incidence between the two seasons. However, in Busire and Madola, the long rain season recorded significantly higher foliage beetle incidence than the short rain season (Figure 6).

Table 7: Effect of season on the foliage beetle pod incidence, pod severity and yields of common bean in mixed cropping of common bean varieties, cowpea and groundnut

Season	Pod damage incidence (%)	Pod damage severity	Yield (tonha^{-1})
Long rain	77.8a	2a	0.90b
Short rain	35.2b	1b	2.03a
LSD (p≤0.05)	**3.0**	**0.07**	**0.30**

Means followed by the same letters in the same column are not significantly different (p≤0.05).

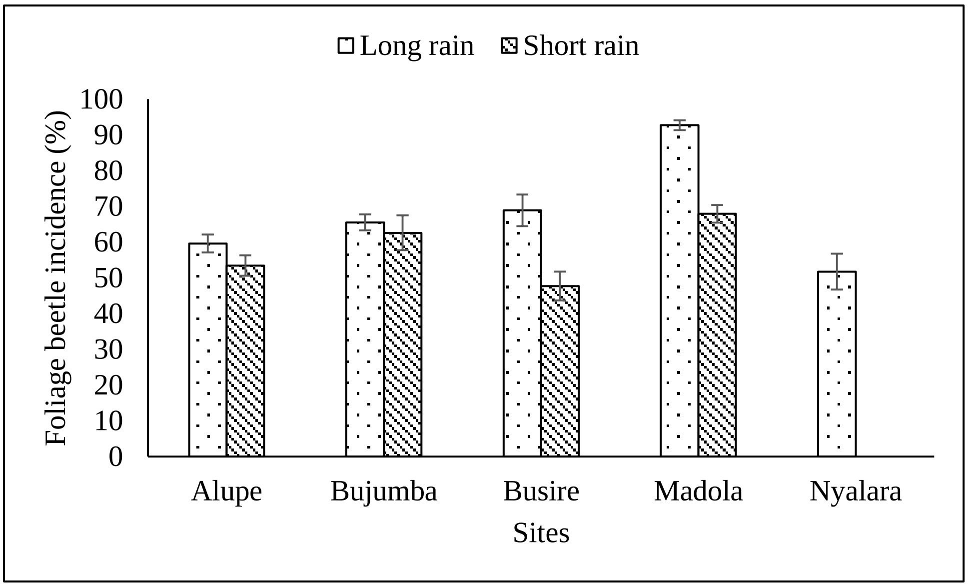


Figure 6: Season*site interaction effect on the foliage beetle incidence on common bean pods. Error bars represents the standard error of the means.

A general agreement exists among authors that adequate soil nutrients is critical requirements for high legume yields (Waswa *et al*., 2015; Shank *et al*., 2015; Ogecha *et al*., 2012). Madola location falls under Mumias sugarcane out growers' zone. Some of the farms had previously been contracted to grow sugarcane that might have led to depletion of soil nutrients whereas soils in Alupe are shallow with a hard pan layer of marram and generally of low fertility level and probably would explain the relatively low yield in the two locations. The results show that for effective management of BFB a combination of options have to be in place. Early planting helps the crop escape the late emergence attacks. Removal of alternate host plants to reduce pest population which acts as a source on infestation for the next season. There is need to improve soil fertility to increase crop vigour to withstand pest attack and increase yields.

There were higher grain yields in the short rains compared to long rains these could be attributed to timely planting in the short rain season. Compared to national average 0.55t ha^{-1}, the yields recorded in the two seasons were above average ranging from 0.5 to 2.4t ha^{-1}. Grain yield were higher in monoculture suggesting increased diversification may compromise overall productivity probably due to competition. According to Sastawa *et al*., (2004), more complex mixed cropping systems led to reduction of soybean pests but decreased yield which they attributed to competition and shading by the intercropped plants. Mulumba *et al*., (2012) measured the effect of crop varietal diversity on pest and diseases incidence in farmers' fields in four agro ecological areas of Uganda and found that average levels damage by pest and disease and incidences decreased on crops with higher levels of diversity in production systems. The result show that mixed cropping system has no adverse effect on yields of beans and can be adopted as option for management of bean foliage beetles.

4.2 Experiment 2: Effect of Common bean (*Phaseolus vulgaris*) varieties on Bean Foliage Beetle (*Ootheca spp*.) incidence, damage and grain yield in Western Kenya

4.2.1 Bean foliage beetle incidence, severity of damage and population densities of different bean varieties in different locations during the long and short rain seasons of 2015 in Western Kenya

The analysis of variance (ANOVA) results showed that the season, AEZ, variety and stage of crop growth did not have a significant effect on the foliage beetle incidence. However, the AEZ* growth stage interaction had a significant effect on the foliage beetle incidence (Table 8). In terms of the foliage beetle severity, the season, AEZ and the AEZ* growth stage interaction showed a significant effect. The foliage beetle density was not significantly affected by the factors under consideration (Table 8; Appendix V).

In terms of seasonal effects, there was significantly higher foliage beetle severity damage in the short rain season than in the long rain season (Figure 7). For the AEZ* growth stage interaction, the foliage beetle incidence was higher during the seedling and vegetative stage compared to the reproductive stage in LM_1. However, in LM_4, there was higher incidence during the reproductive stage than in the vegetative stage (Figure 8).

Table 8: Mean squares for foliar beetle incidence, severity of damage and densities for four bean varieties

Source of variation	df	Foliage beetle incidence	Foliage beetle severity	Foliage beetle density
Replicate	2	69.1	0.51	0.28
Season	1	0.46^{ns}	55.08^{**}	0.97^{ns}
AEZ	1	394.15^{ns}	3.84^{*}	0.24^{ns}
Variety	3	179.87^{ns}	0.05^{ns}	0.12^{ns}
Stage	1	774.92^{ns}	0.11^{ns}	0.17^{ns}
Season*variety	3	573.39^{ns}	0.32^{ns}	0.07^{ns}
AEZ*variety	3	12.15^{ns}	0.15^{ns}	0.94^{ns}
AEZ*stage	1	3185.24^{**}	71.10^{**}	0.46^{ns}
Variety*stage	3	50.04^{ns}	0.40^{ns}	0.85^{ns}
Error		417.35	0.73	0.42
R^2		0.48	0.49	0.53
CV (%)		24.7	29.0	29.5

***- significant at p≤ 0.05 and p≤ 0.01 respectively; ns- not significant

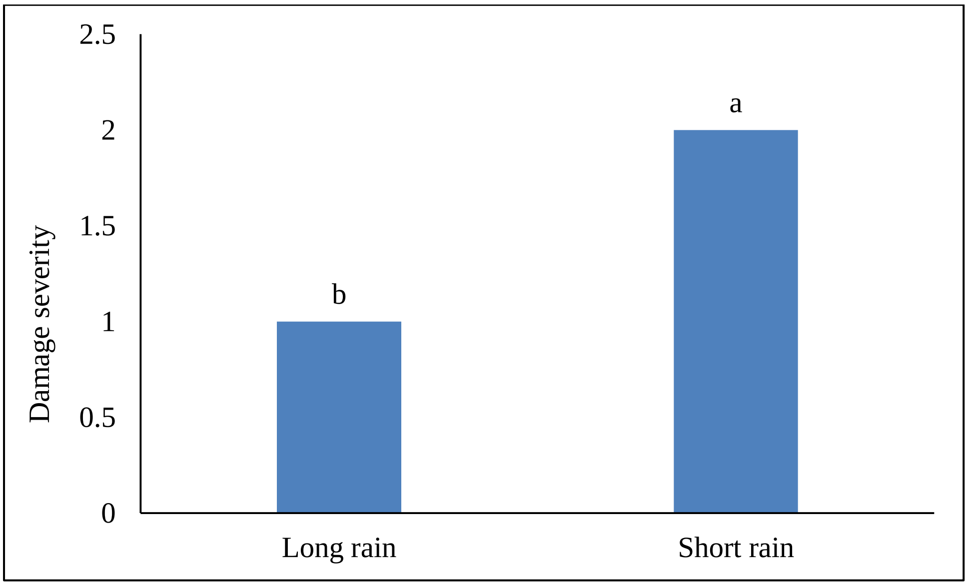


Figure 7: Effect of season on the foliage beetle severity of common bean. Means followed by the different letters are not significantly different from each other (p≤0.05)

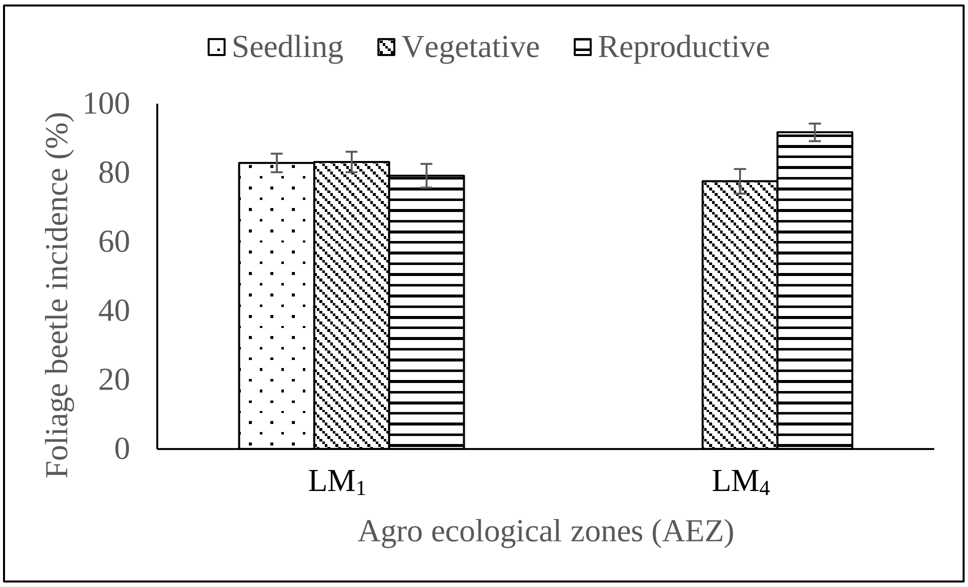


Figure 8: Effect of AEZ* growth stage interaction on the foliage beetle incidence. Error bars represents the standard error of the means.

Bean foliage beetle population density did not vary significantly among the locations during the short rain season. The current results are consistent with past findings and reports that support the argument that environment is a major factor which affect the distribution of biotic stressors on legumes (Egho *et al*., 2011; Wortman *et al*., 1998; Allen *et al*., 1996). These agro ecological zones are characterized by variation of temperature and relative humidity that probably favoured the rapid increase of the insect pest population and damage (Jaetzoldt *et al*., 2009). Like in the experiment 1 the study confirmed that the bean foliage beetle is a foliar pest whose population densities build up with the crop growth stages with the vegetative stage having higher populations. This is because the emergence of the pest is prompted by the emergence of the new bean crop leading to increase abundance of foliage beetle feeding damage. These results are in agreement with those of Ochieng *et al*., (1978), who reported that; adults emerge with early rains to coincide with the emergence of the new crop of beans at the seedling stage to which they caused damage by foliar feeding. Even when leaf injuries recover BFB persists through most stages of the bean crop. Damage was most severe in the seedling stage. Ampofo and Massomo (1998) found out that BFB adults emerged soon after the emergence of the host crops and started feeding almost immediately, even though feeding was less severe on the young seedlings (>V2) than on the older ones. Adults were observed to show a preference for seedling older than V2 when the choice was available. The study confirms that BFB destroys most parts of the common bean but feeding damage occurs primarily because the adult bean foliage beetle prefers young, tender tissues such as cotyledons, leaves, and pods.

KK8 is a late maturing variety with broad leaves and pods that remained succulent for a long time predisposing it to more infestation. KATX56 is an early maturing bean cultivar bred for tolerance to drought and has purple pigmentation identified as anthocyanin that probably conferred resistance to BFB. Anthocyanins are water soluble glucosides that give pigmentation to plants parts such as flowers and fruits for defence against herbivorous insect. The red to purple pigmentation are encoded in the plant by genes and can be used as markers for identifying resistant genes to foliage beetle. Host plant resistance or tolerance offers a promising solution to foliage beetle control as a long-term strategy. Some morphological, biochemical, and physiological characteristics have been reported to contribute to bean fly resistance. Trichrome densities on the leaves, and purple colouration in the stems of plants, identified as anthocyanin were shown to confer resistance in soybean to bean flies (Talekar *et al*., 1988; Talekar and Tengkano, 1993).

This study shows that choice of bean varieties can help to reduce the impacts of bean foliage beetle infestations. KAT X56 was not highly infested by bean foliage beetle at the critical growth stages during both the short and long rain seasons compared to the other varieties even though it was not significantly different from the other varieties ($p \leq 0.05$). Timely harvesting of these cultivars can also help reduce the damage caused by bean leaf beetle. The use of early maturing varieties like KAT X56 and early planting can be recommended when the bean foliage beetle populations are likely to increase as the season progress. It can, therefore, be hypothesized that the host plants suitability due to difference in physiological conditions and resistance to foliage beetle may be attributed to the observed results.

4.2.2 Mean grain yields of different bean varieties in different locations during the long and short rains 2015 in Western Kenya

The ANOVA results indicated that the site, season and the season *variety had significant effect on the grain yield of common bean. There was however no significant effect of common bean varieties in grain yield (Table 9; Appendix VI). In terms of the sites, Bondo recorded significantly highest grain yield compared to the other sites. Nyalara recorded the least grain yield (Figure 9).

Generally, the long rain season recorded significantly higher grain yield (0.79 tons ha^{-1}) than the short rain season (0.65 tons ha^{-1}). During the long rain season, KATX56 variety recorded significantly higher grain yield (0.98tons ha^{-1}) compared to KATX69 and KK8 (0.73tons ha^{-1} and 0.74 tons ha^{-1} respectively). However, there was no significant difference between KATX56 and Rosecoco variety (Figure 9). Similarly, during the short rains, KATX56 recorded the highest grain yield (0.89 tons ha^{-1}) that was significantly different from Rosecoco (0.63 tons ha^{-1}). There was no significant difference between the KATX56 variety and KATX69 and KK8 varieties (Figure 10).

Table 9: Mean squares for yield for the four bean varieties

Source of variation	df	Yield
Replicate	2	8.87
Site	3	0.32^{**}
Season	1	1.01^{**}
Variety	3	0.09^{ns}
Site*season	1	0.0002^{ns}
Site*variety	9	0.06^{ns}
Season*variety	3	0.13^{*}
Error		0.05
R^2		0.84
CV		27.6

***- significant at $p \leq 0.05$ and $p \leq 0.01$ respectively; ns- not significant

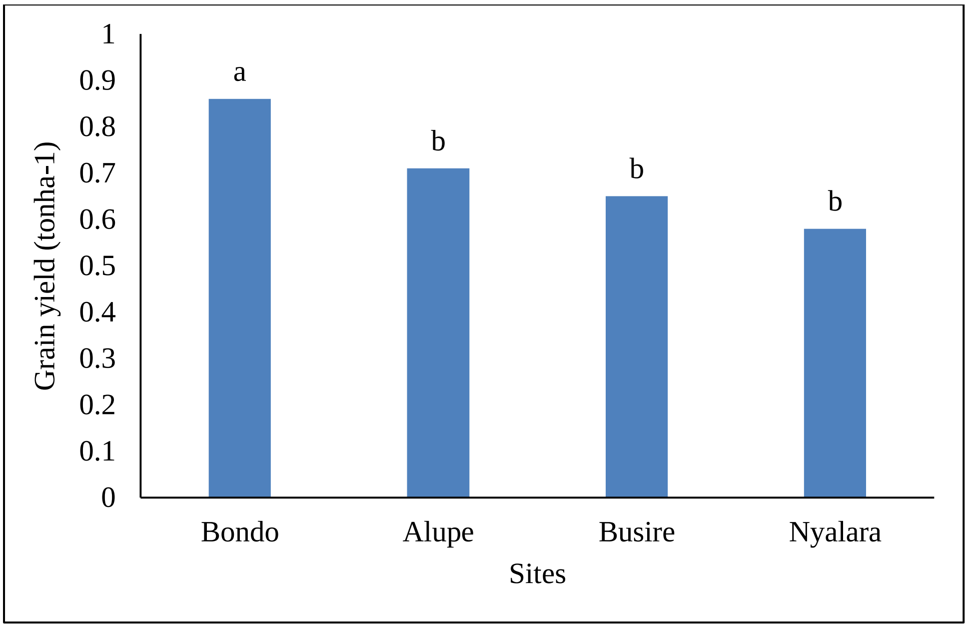


Figure 9: Effect of site on the yield of common bean varieties. Means followed by the different letters are not significantly different from each other (p≤0.05).

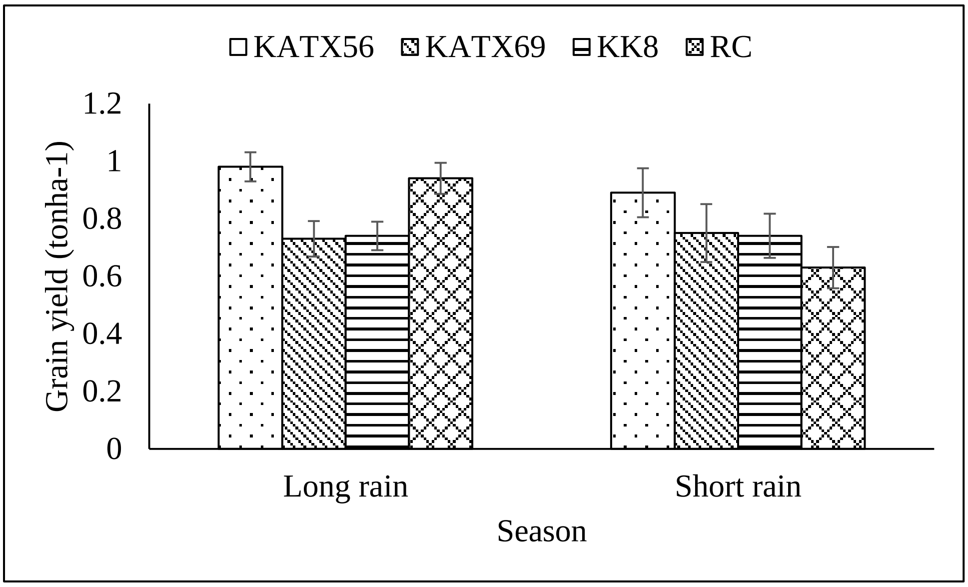


Figure 10: Effect of season*variety interaction on the grain yield of common bean. Error bars represents the standard error of the means.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Mixed cropping of the bean varieties and mixtures of bean varieties, cowpea and groundnuts significantly reduced bean foliage beetle percent incidence and severity of damage during the long and short rain seasons respectively however they were no significant difference among the beetle population. Grain yields recorded in the two seasons were above average with the long rain season recording lower yields compared the short rains and these would be attributed to timely planting in the short rain season leading to bean foliage beetle peak population escape. Grain yield were higher in monoculture suggesting increased diversification may compromise overall productivity probably due to competition.

There was significant variation in the percent incidence and severity of damage among varieties with KAT X56 showing a higher tolerance ability compared to the others. This would have been due to the fact that; KATX56 is an early maturing bean variety bred for tolerance to drought and has purple pigmentation identified as anthocyanin that probably conferred resistance to BFB. The population density was not significantly different across the two seasons, however grain yields varied across two seasons with KAT X56 giving higher yields than the rest of other varieties and this would be attributed to its early maturing attributes.

5.2 Recommendations

1. Legume mixture cropping system is a common practice in western Kenya and it showed promising results in management of BFB. Therefore there is need to repeat the experiment under moderate and high infestation of BFB to identifying suitable plant arrangement in the mixed cropping systems that will lead to pest suppression and improved yield.
2. The present common bean varietal trial included only four varieties. Future research efforts should focus on screening more suitable varieties acceptable to farmers and tolerant to the pest under moderate and high BFB infestation.

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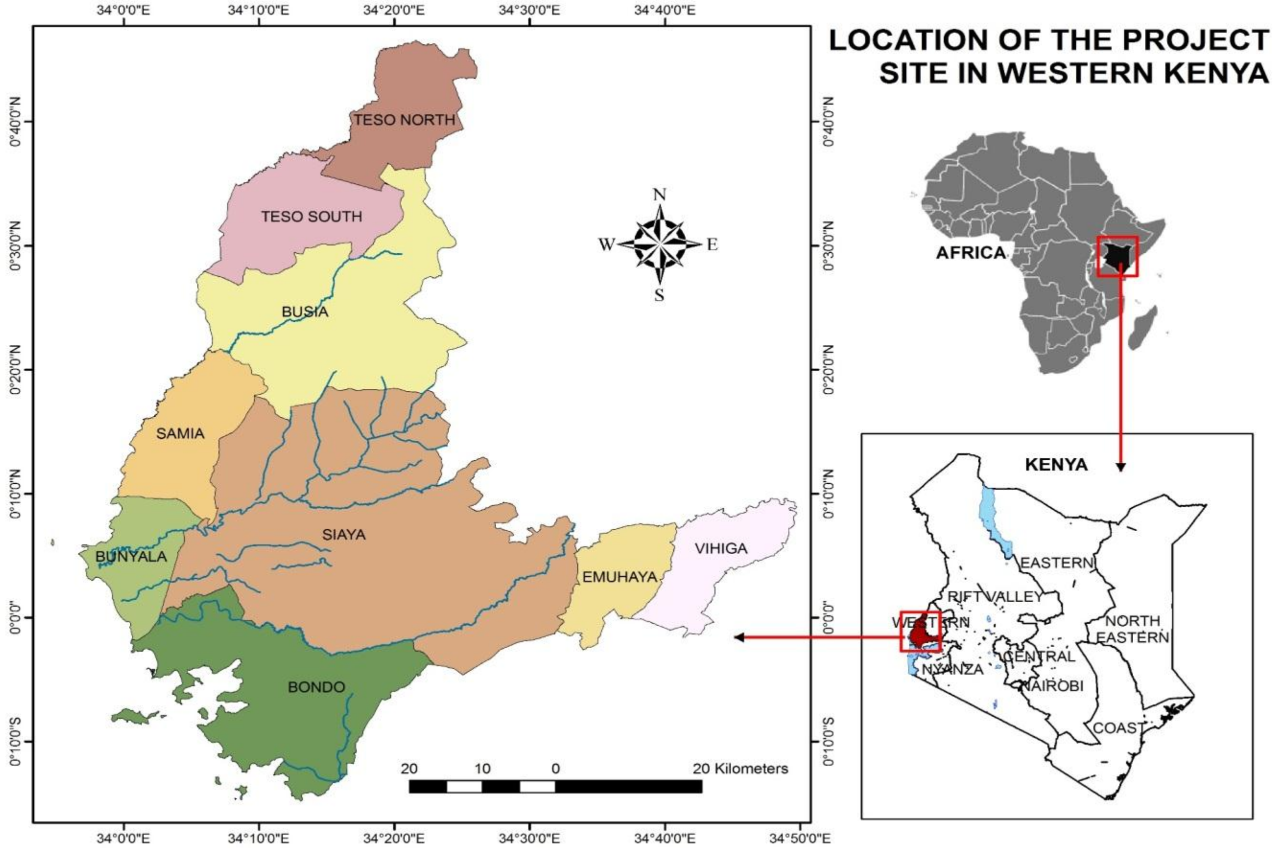
APPENDICES

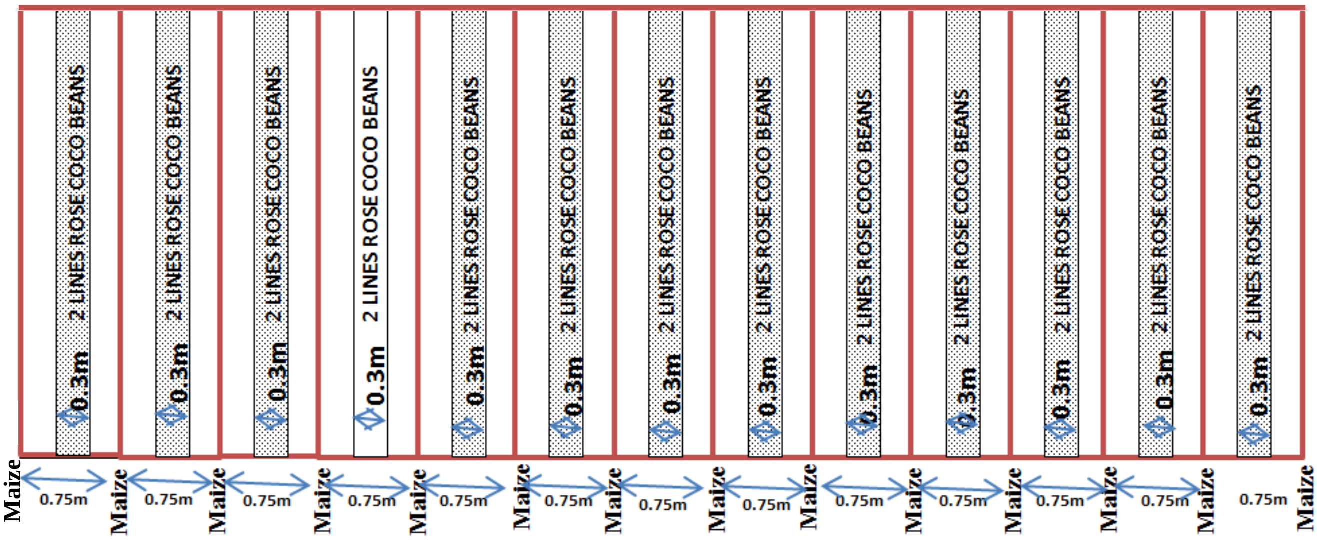
APPENDIX I: MAP OF THE STUDY AREA



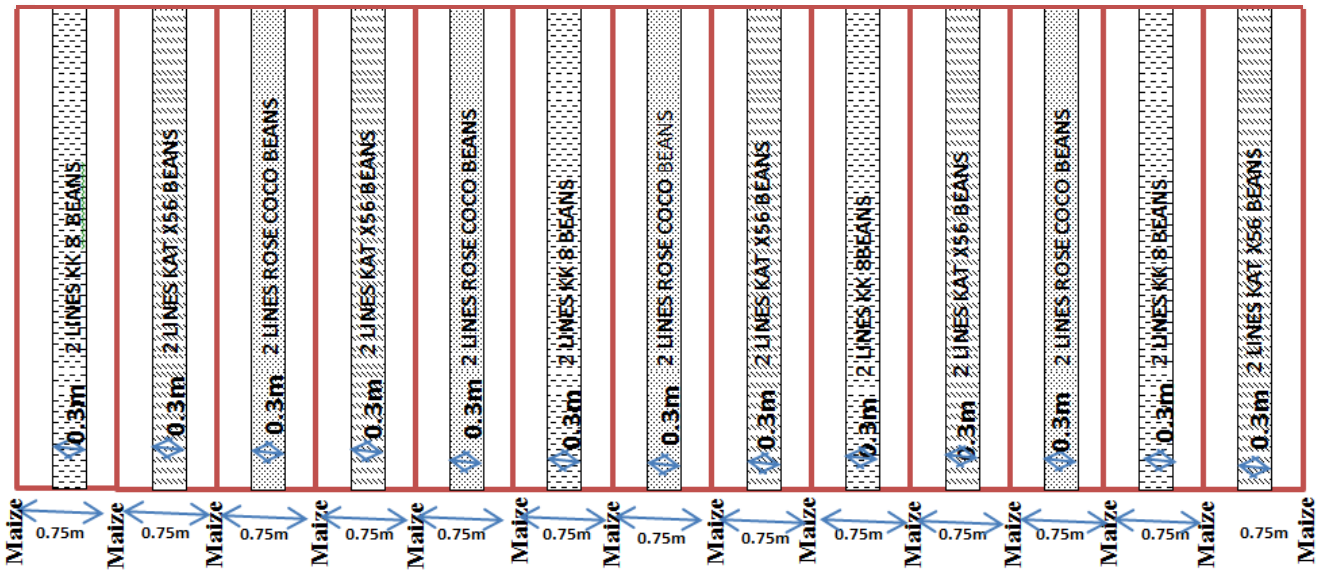
Source: Layer credits: ESRI, virtual Kenya DIVA GIS

APPENDIX II: FIELD LAYOUT EXPERIMENT 1

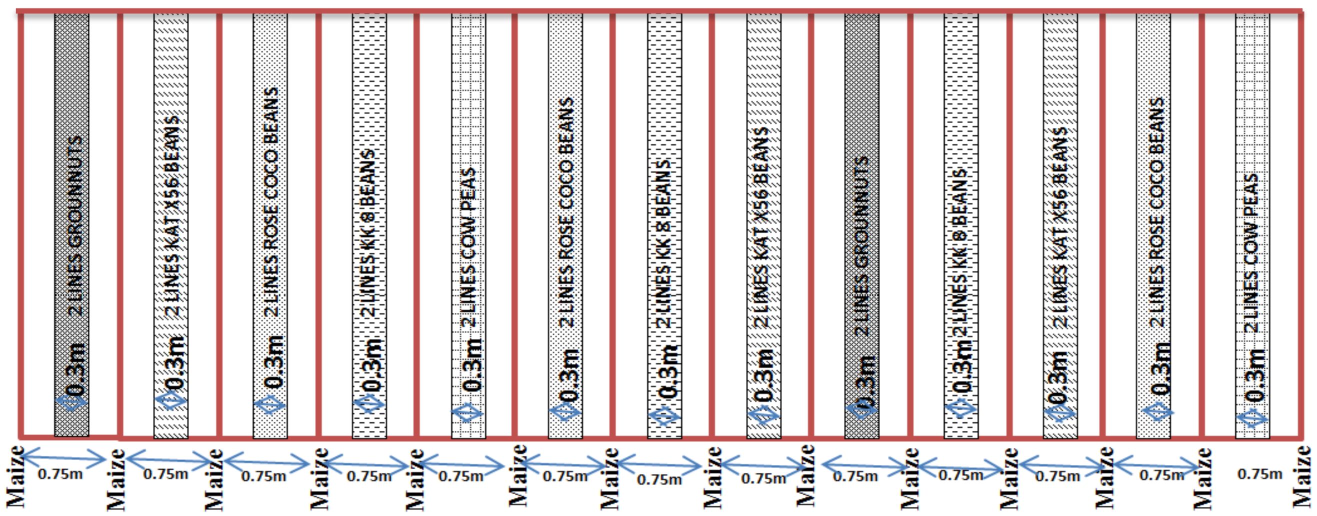
Treatment 1



Treatment 2



Treatment 3



APPENDIX III

SAS ANOVA OUTPUT FOR THE FOLIAGE BEETLE INCIDENCE, SEVERITY AND COUNTS

The SAS System 22:09 Tuesday, July 17, 2018 1

The GLM Procedure

Class Level Information

	Class	Levels	Values
SEASON	2	1	2
SITE	5	Alupe Bujumba Busire Madola Nyalara	
TREATMENT	3	1 2 3	
REP	10	1 2 3 4 5 6 7 8 9 10	
STAGE	3	1 2 3	

Number of observations 889

The SAS System 22:09 Tuesday, July 17, 2018 2

The GLM Procedure

Dependent Variable: BFB Incidence

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	38	658013.176	17316.136	29.21	<.0001
Error	850	503954.956	592.888		
Corrected Total	888	1161968.133			

R-Square	Coeff Var	Root MSE	BFB Inc Mean
0.566292	28.47724	24.34930	63.28234

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SEASON	1	82041.3747	82041.3747	138.38	<.0001
SITE	4	53955.5271	13488.8818	22.75	<.0001
TREATMENT	2	248.6176	124.3088	0.21	0.8109
REP	9	10084.1382	1120.4598	1.89	0.0501
STAGE	2	280584.2875	140292.1437	236.62	<.0001
SEASON*SITE	3	16334.8820	5444.9607	9.18	<.0001
SITE*TREATMENT	8	1289.1790	161.1474	0.27	0.9750
SITE*STAGE	7	42995.8517	6142.2645	10.36	<.0001
SEASON*TREATMENT	2	1067.1453	533.5726	0.90	0.4070

The SAS System 15:03 Tuesday, July 17, 2018 2

The GLM Procedure

Dependent Variable: BFB Severity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	38	575.9837710	15.1574677	58.66	<.0001
Error	850	219.6202785	0.2583768		
Corrected Total	888	795.6040495			

R-Square	Coeff Var	Root MSE	BFB Sev Mean
0.723958	20.78591	0.508308	2.445444

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SEASON	1	29.0225031	29.0225031	112.33	<.0001
SITE	4	12.6433381	3.1608345	12.23	<.0001
TREATMENT	2	166.2206965	83.1103483	321.66	<.0001
REP	9	1.4348943	0.1594327	0.62	0.7832
STAGE	2	8.2746432	4.1373216	16.01	<.0001
SEASON*SITE	3	4.4865816	1.4955272	5.79	0.0006
SITE*TREATMENT	8	0.3013930	0.0376741	0.15	0.9969
SITE*STAGE	7	9.7126620	1.3875231	5.37	<.0001
SEASON*TREATMENT	2	8.7570118	4.3785059	16.95	<.0001

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The GLM Procedure

Dependent Variable: BFB Counts

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	38	147.7622572	3.8884805	5.26	<.0001
Error	850	628.3704762	0.7392594		
Corrected Total	888	776.1327334			

R-Square	Coeff Var	Root MSE	BFBcounts Mean
0.790383	25.35448	0.859802	2.431946

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SEASON	1	27.87230939	27.87230939	37.70	<.0001
SITE	4	1.03408969	0.25852242	0.35	0.8443
TREATMENT	2	0.37889523	0.18944761	0.26	0.7740
REP	9	18.98441942	2.10937994	2.85	0.0026
STAGE	2	15.36280210	7.68140105	10.39	<.0001
SEASON*SITE	3	6.41155231	2.13718410	2.89	0.0346
SITE*TREATMENT	8	1.38497306	0.17312163	0.23	0.9845
SITE*STAGE	7	62.49134064	8.92733438	12.08	<.0001
SEASON*TREATMENT	2	0.40359892	0.20179946	0.27	0.7612

APPENDIX IV

SAS ANOVA OUTPUT FOR FOLIAGE BEETLE INCIDENCE AND SEVERITY ON PODS

The SAS System 17:50 Wednesday, July 18, 2018 32

The GLM Procedure

Class Level Information

Class	Levels	Values
SITE	6	Alupe Bujumba Busire Madola Nakaywa Nyalara
REP	9	1 2 3 4 5 6 7 8 9
TREATMENT	3	1 2 3
SEASON	2	1 2

Number of observations 353

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The GLM Procedure

Dependent Variable: Legume Diversity Pod Incidence

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	40	170578.3733	4264.4593	21.57	<.0001
Error	312	61680.3412	197.6934		
Corrected Total	352	232258.7145			

R-Square	Coeff Var	Root MSE	LD Pod Inc Mean
0.734433	27.09567	14.06035	51.89150

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REP	8	3900.49875	487.56234	2.47	0.0133
SITE	5	3308.07020	661.61404	3.35	0.0058
TREATMENT	2	1716.21234	858.10617	4.34	0.0138
SITE*TREATMENT	10	2433.19395	243.31940	1.23	0.2703
SEASON	1	64766.86267	64766.86267	327.61	<.0001
SITE*SEASON	4	1322.87747	330.71937	1.67	0.1561
TREATMENT*SEASON	2	480.84038	240.42019	1.22	0.2978
SITE*TREATMENT*SEASON	8	369.10975	46.13872	0.23	0.9845

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The GLM Procedure

Dependent Variable: Legume Diversity Pod Severity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	40	28.03350081	0.70083752	6.24	<.0001
Error	312	35.04519607	0.11232435		
Corrected Total	352	63.07869688			

R-Square	Coeff Var	Root MSE	LD Pod Sev Mean
0.644421	16.56965	0.335148	2.022663

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REP	8	4.30238166	0.53779771	4.79	<.0001
SITE	5	0.10794592	0.02158918	0.19	0.9654
TREATMENT	2	0.04555322	0.02277661	0.20	0.8166
SITE*TREATMENT	10	1.45900777	0.14590078	1.30	0.2300
SEASON	1	9.33688986	9.33688986	83.12	<.0001
SITE*SEASON	4	0.12788938	0.03197234	0.28	0.8879
TREATMENT*SEASON	2	0.03560521	0.01780261	0.16	0.8535
SITE*TREATMENT*SEASON	8	0.29615501	0.03701938	0.33	0.9543

APPENDIX V

SAS ANOVA OUTPUT FOR YIELD OF COMMON BEAN

The GLM Procedure

Class Level Information

Class	Levels	Values
SITE	5	Alupe Bujumba Busire Madola Nakaywa
REP	9	1 2 3 4 5 6 7 8 9
TREATMENT	3	1 2 3
SEASON	2	1 2

Number of observations 287

The SAS System 16:28 Monday, July 23, 2018 2

The GLM Procedure

Dependent Variable: Yield

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	31	159.4699358	5.1441915	11.43	<.0001
Error	255	114.8085248	0.4502295		
Corrected Total	286	274.2784606			

R-Square	Coeff Var	Root MSE	Yield Mean
0.581416	25.57869	0.670991	1.472160

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REP	8	31.79381960	3.97422745	8.83	<.0001
SITE	4	19.93225904	4.98306476	11.07	<.0001
TREATMENT	2	0.68842657	0.34421328	0.76	0.4666
SITE*TREATMENT	8	15.19303719	1.89912965	4.22	<.0001
SEASON	1	55.83252060	55.83252060	124.01	<.0001
SITE*SEASON	2	4.85241944	2.42620972	5.39	0.0051
TREATMENT*SEASON	2	4.50201156	2.25100578	5.00	0.0074
SITE*TREATMENT*SEASON	4	1.23854166	0.30963541	0.69	0.6010

APPENDIX VI

SAS ANOVA OUTPUT FOR FOLIAGE BEETLE INCIDENCE, SEVERITY AND COUNTS

The SAS System 16:31 Monday, July 23, 2018 1

The GLM Procedure

Class Level Information

Class	Levels	Values
SEASON	2	1 2
AEZ	2	LM_1 LM_4
REP	3	1 2 3
VARIETY	4	KATX56 KATX69 KK8 RC
STAGE	3	1 2 3

Number of observations 216

The SAS System 16:31 Monday, July 23, 2018 2

The GLM Procedure

Dependent Variable: BFB Incidence

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	18	6938.49306	385.47184	0.92	0.5508
Error	197	82218.82176	417.35443		
Corrected Total	215	89157.31481			

R-Square	Coeff Var	Root MSE	BFB Inc Mean
0.477823	24.66584	20.42925	82.82407

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SEASON	1	0.455840	0.455840	0.00	0.9737
AEZ	1	394.146673	394.146673	0.94	0.3323
REP	2	138.259259	69.129630	0.17	0.8475
VARIETY	3	539.611111	179.870370	0.43	0.7310
STAGE	1	774.016005	774.016005	1.85	0.1748
SEASON*VARIETY	3	1720.181197	573.393732	1.37	0.2520
AEZ*VARIETY	3	36.448565	12.149522	0.03	0.9933
AEZ*STAGE	1	3185.244907	3185.244907	7.63	0.0063
VARIETY*STAGE	3	150.129497	50.043166	0.12	0.9483

The GLM Procedure

Dependent Variable: BFB Severity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	18	133.9264220	7.4403568	10.24	<.0001
Error	195	141.7231107	0.7267852		
Corrected Total	213	275.6495327			

R-Square	Coeff Var	Root MSE	BFBSEV Mean
0.485858	29.19018	0.852517	2.920561

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SEASON	1	55.07853704	55.07853704	75.78	<.0001
AEZ	1	3.84088650	3.84088650	5.28	0.0226
REP	2	1.02684061	0.51342030	0.71	0.4947
VARIETY	3	0.15184534	0.05061511	0.07	0.9761
STAGE	1	0.10573835	0.10573835	0.15	0.7033
SEASON*VARIETY	3	0.96052028	0.32017343	0.44	0.7243
AEZ*VARIETY	3	0.46346855	0.15448952	0.21	0.8876
AEZ*STAGE	1	71.10498845	71.10498845	97.83	<.0001
VARIETY*STAGE	3	1.19359684	0.39786561	0.55	0.6504

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The GLM Procedure

Dependent Variable: BFB counts

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	18	8.34895473	0.46383082	1.09	0.3603
Error	195	82.64754060	0.42383354		
Corrected Total	213	90.99649533			

R-Square	Coeff Var	Root MSE	BFB counts Mean
0.531750	29.48558	0.651025	2.207944

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SEASON	1	0.97149533	0.97149533	2.29	0.1316
AEZ	1	0.23571429	0.23571429	0.56	0.4567
REP	2	0.56213111	0.28106555	0.66	0.5164
VARIETY	3	0.37190163	0.12396721	0.29	0.8308
STAGE	1	0.16888904	0.16888904	0.40	0.5286
SEASON*VARIETY	3	0.19859611	0.06619870	0.16	0.9256
AEZ*VARIETY	3	2.84390462	0.94796821	2.24	0.0853
AEZ*STAGE	1	0.45948398	0.45948398	1.08	0.2991
VARIETY*STAGE	3	2.53683862	0.84561287	2.00	0.1160

APPENDIX VII

SAS ANOVA OUTPUT YIELD OF COMMON BEAN VARIETIES

The SAS System 22:09 Tuesday, July 17, 2018 26

The GLM Procedure

Class Level Information

Class	Levels	Values
SITE	4	Alupe Bondo Busire Nyalara
REP	3	1 2 3
SEASON	2	1 2
VARIETY	4	KATX56 KATX69 KK8 RC

Number of observations 104

The SAS System 22:09 Tuesday, July 17, 2018 27

The GLM Procedure

Dependent Variable: Yield

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	22	20.94245226	0.95192965	19.21	<.0001
Error	81	4.01376493	0.04955265		
Corrected Total	103	24.95621719			

R-Square	Coeff Var	Root MSE	Yield Mean
0.839168	27.56661	0.222604	0.728260

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SITE	3	0.44684216	0.14894739	3.01	0.0351
REP	2	17.65468348	8.82734174	178.14	<.0001
SEASON	1	0.51638143	0.51638143	10.42	0.0018
VARIETY	3	0.31408906	0.10469635	2.11	0.1050
SITE*SEASON	1	0.02989370	0.02989370	0.60	0.4396
SITE*VARIETY	9	0.40302808	0.04478090	0.90	0.5262
SEASON*VARIETY	3	0.38538345	0.12846115	2.59	0.0583