EVALUATION OF MAIZE-LEGUME COMPATIBILITY AND THE MANAGEMENT OF FALL ARMYWORM (*Spodoptera frugiperda) IN KENYA*

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DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION

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DECLARATION

This thesis is my original work and has not been submitted for the award of a degree in any otheruniversity.

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DEDICATION

This thesis is dedicated to my family. My beloved wife, Mrs. Akima Ayuel Garang, mother, Mrs. Akoi Agook Mabior, elder brother, Mr. Samuel Maketh Lual, and finally to my niece Aguet Alek Lual for their encouragement and financial support throughout this study that led to the completion of this thesis.

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LIST OFABBREVIATIONS AND ACRONYMS

^{0}E	Eastern coordinate
^{0}S	Southern coordinate
ANOVA	Analysis of variance
CABI	Centre for Agriculture and Bioscience International
CIMMYT	International Maize and Wheat Improvement Center
Mha	Metric ton per hectare
CAN	Calcium ammonium nitrate
DAP	Diammonium phosphate
FAO	Food and Agriculture Organization of United Nations
FAW	Fall armyworm
IPM	Integrated pest management
IRRI	International Rice Research Institute
KALRO	Kenya Agricultural and Livestock Research Organization, formerly Kenya Agricultural and Livestock Institute
LER	Land equivalent ratio a
LSD	Least significance difference
M.A.S.L.	Metres above sea level
MNLD	Maize necrosis lethal necrosis
MOA	Ministry of Agriculture, Kenya
NPK	Nitrogen phosphorus potassium
PAR	Photosynthetically active radiation
SSA	sub-Sahara Africa
UNESCO	Unite Nation Educational and Scientific Cultural Organization
RCBD	Randomized complete block design
USAID	United States Agency for International Development
DFID	UK Department for International Development

ABSTRACT

Smallholder farmers in East Africa generally intercrop maize (*Zea mays L.*) with grain legumes to intensify cropping, improve soil fertilizer, reduce pests and disease pressure, and control weeds. However, the compatibility of maize with the majority of legume species is only partiallyunderstood, particularly with regards to yield-limiting factors that arise from the intra-specific competition. Intra-specific competition between maize and legumes could be alleviated through both the spatial and temporal arrangement of the companion crops. On the other hand, legumes are frequently integrated into push-pull crop arrangements to suppress field pests in maize such asthe stalk borer and lately the fall armyworm. However, the push-pull technology predominantly integrates non-food legumes such as desmodium but evidence shows that food legumes are also effective in manipulating the pest habitat. In addition, the use of food and perhaps dual-purpose legumes could be more attractive to farmers in comparison with the use of desmodium. Further, the efficiency of this technology could be improved through the temporal arrangement of maize and legumes, particularly by relaying maize into established legumes, albeit with knowledge limitations. In the context of these knowledge gaps, a study was carried out with two objectives: (1) to evaluate the compatibility of maize with a diverse range of legumes species in both simultaneous and relay intercrop system; and (2) to assess the effect of simultaneous and relay intercropping of maize with different legumes species on the suppression of Fall armyworm (*Spodoptera frugiperda*) in maize. Field experiments were carried out at the Kenya Agricultural and Livestock Research Organization (KALRO) in Kiboko and the Kabete farm of the University of Nairobi. In each site,two experiments were carried out, and both experiments consisted of nine legume species: common bean (variety Rosecoco), pigeon pea (Kat 80), dolichos lablab (DL1002), groundnut (ICGV 9704), soybean (SB19), green gram (N26), cowpea (M66) and green leaf desmodium, in addition to sole maize as control. In the first experiment, crops of maize and legumes were sown simultaneously while in the second trial maize was relay cropped into

established legumes. Both experiments were laid out in a randomized complete block design and replicated three times. In the maize-legume compatibility study, measurements included crop growth traits, yield components and intercropping productivity indices while the second objective comprised leaf feeding damage, dead heart incidence, ear damage rating, and the number of pest larvae, as well as yield components. Analysis of variance showed significant differences among treatments ($p \leq 0.05$) in maize-legume compatibility and fall armyworm infestation. Intercropping maize with pigeon pea, lablab in relay cropping system in Kabete, significantly ($p \leq 0.05$) increased yield by 35% and 70% respectively whereas in simultaneous cropping system in Kabete, desmodium and beans increased maize stand count at harvest by 17.6% and 18.5%, respectively. At the same site, simultaneous intercropping of cowpea recorded significantly the highest maize stand count at harvest (113 plants per an area of 180m2) than relay cropping system at (89 plants at the same area). Similarly, in Kiboko, simultaneous intercropping of maize with green gram, lablab recorded the highest maize stand count at harvest by 35 and 40 plants respectively more than relay croppingsystem. In addition to fall armyworm (FAW) infestation data, simultaneous intercropping of maize with cowpea, lablab, bean, and desmodium significantly ($P \leq 0.05$) reduced FAW damage in maizeleaf by 46.6, 47.0, 73.0, and 73.1% respectively at both vegetative and flowering stage at the twosites. Relaying maize into established cowpea, lablab, beans and desmodium significantly ($P \leq 0.05$) reduced FAW infestation in maize leaf by 65.9, 75.6, 78.0 and 87.8% respectively from vegetative to the flowering stage at both sites. More ever, establishing maize simultaneously witheither lablab, green gram, beans and desmodium significantly ($P \leq 0.05$) reduced the number of FAW pest larvae in maize plant by 42.6, 69.6, 70.0, and 87.0% respectively in all physiological stages across the two sites. Similarly, relay establishment of maize into lablab, cowpea, beans, and desmodium significantly ($P \leq 0.05$) reduced the number of FAW pest larvae in maize plant by 62.2, 70.0, 77.8, and 100% respectively in all stages of growth in both sites. In this study, relaying maizeinto an already

established lablab, bean and desmodium reduced FAW infestation or damage on maize plants at nearly all physiological stages compared with other legumes in all the sites. In conclusion, when comparing means of lablab and bean with desmodium, it shows there are no significant differences between those three legumes. Therefore, it is highly recommended to use lablab and bean instead of desmodium in the management of FAW in maize.

Keywords: Intraspecific compatibility, intercropping, cropping systems, infestations, desmodium

CHAPTER ONE: INTRODUCTION

1.1 Background information

Maize (*Zea mays* L.) is grown primarily for food, feed, and fuel, (Anderson, 2014). It is a commonplace food crop in lots of sub-Saharan Africa international and it is a source of carbohydrates and vitamins (Kavas *et al*., 2013). In Kenya, 1.6 million hectares are grown with maize while its production is estimated at 3.0 million metric tons annually, (MoA, 2018). Globally, maize is ranked third after rice and wheat and it is grown in very diverse climatic areas, (FAO 2018). Approximately 75% of the total maize production in Kenya are produced by Small holders' farmers while 25% of it being produced by mechanized farming (Omodho, 2008). The Kenya agro-ecological zone is categorized into five main different zones namely, high potential, medium potential, semi-arid, Arid and very arid. But the best productiveness is inside the wet humid and cold highlands which are high potential zone while the very low potential regions are in semi-arid and very arid lowlands.

The agriculture sector is the base of Kenya's economy, it contributed 5.4% of the GDP growth in 2006 (K'alumu *et al.*, 2007). Approximately 75% of Kenyans get their livelihood from agriculture. Kenyan population relies on maize, it constitutes a dominant portion of a standard diet in the country and its production is mainly for both commercial and subsistence purposes.

The country can produce about 34 million bags in a good season and may drop to about 18 million bags when there is drought, diseases, or pests, an outbreak of Shortage of maize in the country is considered as famine. Though maize is the main food crop, its output per unit area in Africa remained the leastin the world. Food and Agricultural Organization (FAO, 2018) reported average yield for maize per hectare I s about 4 metric tons.

In sub-Sahara Africa (SSA) maize production is big, it has been researched extensively for genetic improvement for more than a half-century in the sub-region of Malawi and Zambia which led to maize development (Byerlee and Eicher, 1997). However, maize yield continues to decline due to both biotic and abiotic factors. Abiotic factors include drought, salinity, temperatures, wind, chemical elements, and biotic include diseases, birds, fungi, and insect pests (White *et al.,* 2011). Maize and other cereals are vulnerable to many pests and diseases (Drinwater *et al*., 2002). Which means intercropping of food legumes with cereals seems to be a completely proven technique for the control of pests and diseases because it’s generally accepted that one-factor crop grown together with the companion crop can additionally appear as an obstacle against the spread of insects and diseases.

Maize has been identified as a staple crop used in most maize-legumes combination in the tropics (Ijoyah, 2012). There is larger leaf area index (LAI) and higher interception of solar radiation for the maize in an intercrop over mono-cropping (Fawusi and Wanki, 1982). However, yield reduction in intercrop system arise from both inter and intra-specific competition among the companion crops (Thole, 2007). Intraspecific competitions occur when plants share the same growth conditions and having the same distances between in the same environment competing for limited resources. Also, soil productivity issues are the most challenging to the production of field crops because of limited nutrients, hence intercropping cereals with legumes enhances the nutrient's availability especially the nitrogen through fixation of fixed nitrogen by legumes (Chemining’wa and Nyabundi, 1994).

Fall army worm (*Spodoptera frugiperda)* recent outbreak in the region particularly in Kenya in 2017 led to significant yield losses. Maize damages caused by fall armyworm at various stages of its lifecycles render the maize useless as it is difficult to control it (Prasanna *et al.*, 2018). Indeed, if management measures are not taken into use, fall armyworm has been estimated to potentially reduce Africa's maize deliveries between 83 and 20.6 million tons per year (Abrahams *et al.*, 2017).

1.2 Statement of the problem

Historically, smallholder farmers in SSA intercrop maize with legumes such as beans, pigeon pea, and cowpea among others. However, crop yield in these systems continues to decline, perhaps dueto the wrong choice of intercrop legume species. In mixtures, crops compete for water, nutrients, and light while allelopathic constraints reduce yield (Olowe and Adeyemo, 2009). Interspecific competition between maize and common beans is lower than that of maize and pigeon pea (Gastal*et al.*, 2002). This is potentially attributed to the growth morphology of the companion crops. In addition to interspecific competition constraints when maize is intercropped with food legumes that are not compatible with Maize, maize grain is also limited by pests and diseases. Pests accountfor 31% of maize yield loss globally (Oerke, 2006). Economically important field pests include stem borers (*Chilo partellus*, *Busseola fusca*) and the recent outbreak of fall armyworm (*Spodoptera frugiperda*) is a threat to maize production globally. The emergence of Fall armyworm which is an invasive pest drastically reduced maize yield in SSA (Prasanna *et al*., 2018)and it needs much attention to counter the threats posed. The pest could lead to up to 100% yield loss depending on the stage of the crop and pest population.

1.3 Problem Statement Justification

Maize-legume compatibility issues in smallholder farmers in Sub-sahara Africa (SSA) is addressed by choosing the right choice of legumes that are compatible with maize. Previous work mostly compared crop growth and yield of maize under an intercrop system with different varieties of legumes. However, less emphasis has been given to the understanding of the drivers of crop compatibility between maize and different legume species, therefore this study will assess the compatibility of maize with a diverse range of food legumes in enhancing maize vegetative growth yields. Previous studies by (Chemining'wa and Nyabundi, 1994) suggest, intercropping appeared better than sole cropping in several ways, for example, the roles of legumes in solving the problem of nitrogen deficiency but the best choice for maize-legumes intercrops remained a challenge that needed to be addressed.

The management of FAW with chemicals isn't always the best to approach and is not highly recommended because it is harmful to the surroundings. Thus, cheap and environmentally friendly methods of controlling FAW are required. Push-pull technology integrates the intercropping of maize with desmodium as a repellent and brachia grass as trap crop controls stalk borer in maize (Midega *et al*., 2011). However, this technology has not been sufficiently tested on FAW. In addition, push-push technology employs a feed-legume and little data is available on the potency of food legumes in the management of FAW. In this crop arrangement, food legumes could be more attractive to farmers compared with non-food counterparts. Further, manipulation of the pest population requires the adjustment of its habitat through crop arrangements. The effect of relaying maize into established legumes on the management of FAW is only partially understood (Yang *et al.*, 2014).

1.4 Objectives

The broad objective of the study was to improve the yield and identify potential food legumes for the management of FAW in maize. The specific objectives were:

i. To evaluate the compatibility of maize with a diverse range of legumes species in both simultaneous and relay intercrop system

ii. To assess the effect of simultaneous and relay intercropping of maize with different legumes species on the suppression of Fall armyworm (*spodoptera frugiperda*) in maize

1.5 Hypotheses

i. Crop growth and yield of maize is not affected or compatibles with legume species in an intercropsystem

ii. Food legumes are competitively effective in the management of FAW in comparison with desmodium and relaying arrangements are more efficacious than simultaneous intercropping

CHAPTER TWO: LITERATURE REVIEW

2.1 Importance and ecology of maize

Maize is one of the important annual plants globally, its domestication started in America. It belongs to the family of Poaceae. Maize is used as a source of carbohydrate for human and animal as feed internationally due to its excessive nutritive content (Undie *et al*., 2012). It is also use to produce biofuel. It is also readily palatable for use as a feed factor and can make contributions to at least ninety percent starch, sixty percent energy, thirsty percent protein in animal weight loss programs (Dado, 1999).

Maize can be successfully grown in different types of soil beginning from clay loam to sandy loam to blank or red cotton soil. To obtain a better yield of maize it requires fertile, nicely drained mild loam soil. However, it can also do well in a different type of soils. Maize does well in well-drained soil with a pH of 5.5-7.0. Maize also preferred warm temperatures of 15 degrees centigrade. It does well with an excessive rainfall of 2,500 mm. However, maize additionally flourishes in many regions with different rainfall and at instances, it can also do well with the total amount of rainfall totals around 635 mm to 1,145 mm or from time to time adapt to regions with low rainfall beneath 380mm.

2.2 Maize production and constraints in Kenya

Maize production in Kenya is mostly affected by both biotic and abiotic factors. Abiotic include unreliable rainfall, low soil fertility, poor agronomic practices, and drought as some of the main causes of low returns (Wokabi, 1997; Nyoro *et al.*, 2004). And biotic factor includes diseases like the maize streak virus, maize stem borers, smut, MDVD, Striga, the maize lethal necrosis disease and maize chlorotic mottle virus (MoA, 2013). And the recent outbreak of fall army worm in 2017. Production of maize in most parts of Kenya and Africa in general is done by small scale farmers majority of whom have limited resources (Faruq, 2008). Insufficient supply of fertilizers, insect pests and diseases result to low yields (Cassman *et al*., 2003; Faruq, 2008 ;).

Kenyan maize yield rose in 1994 as smallholder farmers had the opportunity to get won get fertilizers through private cooperatives, maize meal prices have been deregulated, and import tariffs were removed. Another gained in yield become in 2010 turned into preceded via an Economic Stimulus Program, adoption of a National Land Policy, and an input subsidy and distribution application. Though national agriculture spending rose after the advent of those packages, it has sooner or later decreased, and yields have remained consistent because 2010 (Auricht, *et al.,* 2014).

2.3 Maize-legume intercrop systems

Maize-legume intercrop systems are predominant being practiced by smallholder farmers in SSA. Intercropping is the growing of two or more crops in mixtures (Seran and Brintha, 2010). Common legumes used in this system are groundnuts, soybean, cowpea, green grams, common beans, dolichos lab lab, pigeon (Matusso *et al*., 2012). Many small-scale farmers practice Intercropping because it has been proven to be better than monoculture (Waddington *et al*., 2007; Egbe, 2010; Osman *et al*., 2011; Ijoyah, 2012). Growing two or more crops in mixtures considered the arrangement of plants in a spatial way that facilitates the effective usage of soil moisture in the land, solar energy and Minerals, (Gurigbal., 2010). Which in return gives a better yield than when it is solely planting (Lithourgidis *et al*., 2006). Intercropping prevents pests and diseases as it will control the growth of unwanted plants and therefore preserve and enhance improved productivity of the soil (Sanginga and Woomer, 2009,).

There are many cropping arrangements considered in an intercrops system, row intercropping which is about planting crops simultaneously in rows or straight lines, either singly or in multiple rows. Mixed cropping is the growing of two or more crops simultaneously on the same piece of land without specific row association at the same time. Relay intercropping is the planting a quick-developing plant with a sluggish-growing plant, in order the early maturing crop is harvested before the sluggish-developing crop (Li *et al*., 2013).

2.4 Benefits of intercropping

2.4.1 Yield advantages

In intercropping, land will be effectively utilized, and hence yield improved (Mashingaidze, 2004). When legumes are grown together with cereals, the yield of cereals Improved in comparison when growing sole cereal (Brintha and Seran,2008), due to the fact Intercropping lessen the condition for competing for the resources and thus promote the state of being complementarities to growth basic productiveness (Gurigbal, 2010). The most usual index adopted in intercropping is land equivalent ratio which measures the land productiveness and its frequently used as an indicator to determine the effectiveness of growing two or more crops in mixtures (Seran and Brintha, 2009b). Land equivalent ratio suggests advantages of cereal-legume being grown in an intercropping way (Mandal *et al*., 1990). Because growing of legumes in mixtures with cereals is considered extra efficient than growing sole crop (Tsubo *et al*., 2005), due to the fact when 5 vegetation are grown collectively there is an increase in yield yields due to variations in the utilization of the resources (Willey *et al*., 1983). There is 48% percent yield increase when growing maize together with soya beans in comparison with growing only one crop in the field, (Mohta and Dey, 1980), which means that maize yield become no longer tormented by growing maize together with soya beans. The largest yield benefit and complementary impact occur while aspect plants have certainly different types developing intervals to demand their calls on resources at exclusive times (Ijoyah, 2012).

2.4.2 Management of crops pests and diseases

Maize and other cereals are vulnerable to many pests and diseases (Drinwater *et al*., 2002). Growing of legumes in mixtures with cereals seems to be a proven technique for the control of pests and diseases because it's generally accepted that one factor crop grown together with the companion crop can additionally appears as an obstacle in opposition to the spread of insects and diseases. Growing maize-cowpea together will decrease the spread of maize stem borer (Henrik and Peeter, 1997). Insect issues are lots much less on vegetation being grown in aggregate, specifically with pigeon pea, cowpea, maize and other non-cereal (Caswell and Raheja, 1972; Hayward, 1975). The two legumes of groundnut and soybean do better in putting down the threat of termite scare than usual beans (Sekamatte *et al*., 2003). It has been realized monocropping desires greater chemical to govern pest and disease than intercropping, (Singh and Acelloni 2002).

2.4.3 Resource use efficiency

The most common reason for intercrop system is that the different types of plants are able to use natural resources in a different way and make better use of natural sources than when grown solely (Willey, 1979). The natural way of growing two or more crops in mixtures involves supplementary of resources utilized by different plants (Barhom, 2001). Soil fertility low level limited the production of field crops because of limited nutrients, hence intercropping cereals with legumes enhances the nutrients availability especially the nitrogen through fixation of fixed nitrogen by legumes (Chemining'wa and Nyabundi, 1994).

The leaves of a plant of each different species do not compete at once for daylight in area and time because They have different orientation in contrast to the leaves of plants of the identical species that are at once opposite and developing on the same rate as each other therefore compete for light (Waddington and Edward, 1989).

Intercropping is considered to better in water conservation because of early excessive leaf vicinity index and better leaf region (Ogindo and Walker, 2005). Different root system within the soil reduces water loss, increases water uptake and will increase transpiration, enable the creation of microclimate cooler than environment (Innis, 1997). Intercropping additionally improves conservation of the soil; it covers more ground than monocropping. It is far useful in lowering runoff and soil loss on sloping semi-arid Kenya (Kinama *et al.*, 2007), it increases active radiation as well as biomass formation (Kinama *et al.*, 2011).

2.4.4 Weed control

Intercropping improves weed control, insects and diseases. Unwanted plants populace became decreased in groundnut-brinjal intercropping (Srikrishnah *et al*., 2008). The plant species, population density, sowing geometry, period, growth rhythm of the element crop, the moist and soil productivity reputation and cultivation effect the unwanted plant life in cropping system. Intercropping permits to lessen unwanted plant populations as soon as the plants are set up (Beets, 1990). Provision of Shade confirmed as enormous reducing the unfold of Cyprus rotundus (Patters01L, 1982). Leafy legumes can be grown together with maize to prevent unwanted plants in the tropics and increase productivity (Makindea *et al*., 2009). Growing of maize and legume together significantly decreased the unwanted plants population density differentiated with sole maize via reduction in solar energy interception for unwanted plants in comparison to sole plants (Dimitrios *et al*., 201

2.5 Disadvantages of intercropping

Yield reduction in intercrop system arise from both inter and intra-specific competition among the companion crops (Thole, 2007). Intraspecific competitions occur when plants share the same growth conditions and having the same distances between in the same environment competing for limited resources. The fundamental morphological and a change in the normal function of a living organism and agronomics features like the used of the fertilizers, sowing time, and crop aggregate percentage became number one determinants of competition amongst plants. Interspecific competition occurs between the plants of different species, for example cereal and legumes. When intercropped cereals with legumes, it has superior development rate, peak benefit, and an extra great rooting system that give it its advantage in its competition with related pulse crops. The yield of the pulse crops decreases normally by 52% of the purely crop output while the pulse crop yield has become reduced by only eleven%. Notably. Ofori and Stern (1987), this is due to the reason the legume in an intercrop are being covered by cereal and hence reduces the light interception.

Allopathy effects is also another problem to intercropping system which is defined as mechanism which led to crops interference or reduction in plant growth over time due to the present of another plant releasing secondary products to the rhizosphere. Those secondary products like phytotoxins can be released into the environment in enough portions to have an effect on the growth of neighbouring plant (Weston *et al*., 2003). These allopathic capabilities are found in almost all plants and their respective tissue.

2.6 Intercrop productivity assessment indices

Assessments of crop aggregate enhance the critical position in growing of two or more crops together. Plant density, shading and nutrients competition amongst plant life reduces the yield of sole planting. Plant competition is not reduced only through spatial affiliation, however, by selecting those plants having capacity to take advantage of minerals in the soil (Fisher, 1977b). Mucuna (*Mucuna utilis*) can dwindled maize yield, on the equal time as cowpea (*Cigna sinensis*), green gram I (*Phaseolus aureus*) and calopo (*Calopogonium tnucunoides*) are less impacted and resistant to maize shading (Agboola and Fayemi, 1971). Growing both cereals and legumes crops in mixtures is commonly done in Africa, South America and Asian (Vander Meer, 1992; Maluleke *et al*., 2005). Maize became observed to be easy to manipulate in maize-pigeon pea intercropping (Rrantz, 1981).

2.6.1 Partial land equivalent ratio (LER)

The ratio of the area under sole cropping to the area under intercropping needed to give the same quantity of yield at the same surrounding level is what called Land equivalent ratio (LER). The partial land equal ratio for cowpea reduced in a maize-cowpea intercrop while that of maize increased with an increase in soil nitrogen stage. Intercropping has shown a higher land equivalent ratio (LER) values over sole maize (Sebetha *et al.,* 2016). It indicated that, among the treatment in intercropping arrangement, the higher LER become observed in simultaneous sowing of maize and fodder cowpea. When LER value is equivalent to 1, it means that there is no yield benefit, but when LER is more than one, it indicated that, there's a yield benefit (Reddy et al., 2016) According to Wiley, 1979; Rao and Willey, 1980, The LER gives a comparative degree of natural performance and combined species cropping structures calculated in units of land area, and perhaps interpreted because the relative land area required below monocropping to supply the harvested yields carried out in an intercrop. High LER have been reported in diverse crop mixtures and environments (Brazil *et al*., 1995; Fininsa, 1997). LER for intercrop have become along way above that of sole planting with appropriately yield advantage of 28%. LER is computedas shown in Equation1.

$$LER = \frac{Yield\ of\ intercrop\ maize}{Yield\ of\ sole\ maize} \qquad Equation\ 1$$

2.6.2 Aggressivity index

Aggressivity(A) determines the competition index between (2) crops in a mixture (which represents how to measure the relative yield growth in a single crop which is better than the alternative when they are grown in mixtures (Willey, 1979). Aggressivity index is computed as shown in Equation

Aggressivity index $=\frac{1}{2}[(A_{mix}/A_{mono}) - (B_{mix}/B_{mono})]$ (Equation 2)

2.6.3 Competitive ratio

Willy and Rao, 1980 defined competitive ratio (CR) as an indicator used to assess competitive ability of different species in intercropping and suggests which crop is more aggressive over the other. Competition ratio is computed as shown in Equation 3.

Competitive ratio= $(A_{mix}/A_{mono})/(B_{mix}/B_{mono})$ (Equation 3)

2.7 Effect of maize-legumes combination on growth and yield of maize

Maize has been identified as a staple crop used in most maize-legumes combination in the tropics (Ijoyah, 2012). There is larger leaf area index (LAI) and higher interception of solar radiation for the maize in an intercrop over mono-cropping (Fawusi and Wanki, 1982). A rise in maize plant density can seriously have an impact on the LAI when maize and soybean are grown in mixtures (Prasad and Brooks, 2005). Thus, an increase within the growth of maize changed (Adesoji *et al*., 2013). The yield of maize is believed to have improved when it is grown in mixtures with groundnut and green gram (Reddy and Reddi, 2007. The biomass of maize become decreased with growing population of lab lab (Maluleke *et al*., 2005). The increase in the companion crop isaffected when they are grown in mixtures (Mangasini *et al*., 2012). An intercrps of maize and legumes no longer affected the maize yield (Thayamini and Brintha, 2010).

Growing of maize and cowpea in mixtures seriously lower ear period, dry grain yield, cob length, dry cob weight and the overall plant dry matter (Egbe *et al*., 2010). Yield improvement has considerably changed, and it has been observed in a maize/soybean strip intercropping arrangement because of the sudden rise in the wider lines of maize together with soybeans (Li *et al*., 2001). Density of the plant influences every internal and external competition and has mainly a sturdy effect on output of maize (Flores-sanchez *et al*., 2013). Growing of maize and legume together have considerably up the great standard and increase amount animal feeds crops (Ali and Mohammad, 2012). It has been observed that farmers' farm had large amount of plant dry matter when planting together with maize (Amos *et al*., 2012).

2.8 Role of intercropping on soil fertility improvement

Soil productivity capacity is not only the problem in production, but additionally being related strongly to monetary and culturally problems. Intercropping of more than two crops have solved numerous soil productivity problems, for example negative agricultural practice like monocropping, shifting cultivation and use of chemicals (Adeleke and Haruna, 2012). When cowpea and maize planted together it increases nitrogen fixation, it also increases phosphorus and potassium to soil in relation to sole cropping (Dahmardeh *et al*., 2010, Vesterager *et al*., 2008). Legumes act as cover crops for soil management that encourages less disturbance of soil, In addition, legumes also enrich the soil through biological nitrogen fixation and restore soil organic matter and reduction in pests and diseases. (Adeleke and Haruna, 2012).

2.9 Biomass production

Solar radiation is an important resource to crop productivity (Jeyakumaran and Seran, 2007). The maize canopy chlorophyii intercepted greater amount of solar radiation when grown in mixtures with different plants (Metwally *et al*., 2012). The amount of crop dry matter development is a function of total radiation intercepted by leaves and on the radiation use efficiency (Oyewole, 2010). An impact on the crops cover due to plant shading comes as result of intercropping, or other elements which impacted yield. Weeds competition is also well – recognized due to its growth condition (Dimitrios *et al*., 2010). It has been found further that the dry mater above the ground is not affected by intercropping legumes with cereals neither within the sole cropping of maize nor when maize and roselle are grown in mixtures (Flores-sanchez *et al*., 2013).

2.10 Fall armyworm

Fall armyworm (*Spodoptera frugiperda*) is also known as corn leaf-worm. It is of order Lepidoptera and family Noctuidae (Pogue, 2002). The pest is commonly found in the tropical and subtropical Americas (CABI, 2017). The pest is known to attack over 186 plant species belonging to 27 families in North and Central America and with a desire for a wild and cultivated grasses (Casmuz *et al*., 2010). FAW is a quarantine pest, and thus, its presence in many African countries and Americas has increases to the extent of reaching to different areas of the continent but its infestation is different in tropical and subtropical areas of Asia and Europe (USAID, 2017). The suitable environment along the Mediterranean coastal countries of Algeria, Morocco, Libya and Tunisia, increases the chances of the spread of FAW to southern Europe, while suitable climate in E. Africa makes the Middle East and Asia vulnerable to the spread of fall army worm. The outbreak of Fall Armyworm n Africa has brought a lot of problems and is threat to global food disaster (Guardian, 2017). The UK Department for International Development (DFID) approved CABI to records an evidence report, which was posted through CABI in September 2017 (Abrahams *et al*., 2017).

2.11 Fall armyworm distribution

The fall armyworm is found in over 30 African nations, giving a massive risk to meal stability, profits and livelihoods (Prasanna *et al*., 2018). The moths of FAW have a wandering and suitable dependency and it can manage to travel long distance by over 500km before oviposition and it move very fast when wind pattern is proper (Rose *et al*., 1975; Prasanna *et al*., 2018). In North America areas, FAW used to comes every season and it cannot manage to survived in cold wintry weather periods, however in many African countries, FAW generations have the ability to survive through the year provide that the host flora are there, and thus provided that the cold seasons and irrigated crops and climatic situation are favorable. To-date, FAW is found in nearly all of sub-Saharan Africa, except in Eritrea, Lesotho and Djibouti. The pest was first seen in Sudan, Libya and Egypt were informed of the imminent threats (Goergen *et al*., 2016; FAO, 2018).Central and Western African countries were the first countries where FAW infestation was detected in early 2016 follow Nigeria, Benin and Togo and Sao Tome and Principe), it became popular in late 2016 and 2017 in many other countries, and it is expected to be more severe. African continent presents favorable climatic situations for a steady duplicate of the pest that led to extreme damage to plants (Goergen *et al*., 2016) and in such it has been recommended that FAW has potential to become an epidemic pest in Africa and the presence of FAW in Africa is irreversible (FAO, 2017).

2.12 Biology and ecology of fall armyworm

Adult FAW is noctuid and feeds for a period which extends from shortly after dusk to well two hours after sunset depending on temperature and time of the cropping season (Luginbill, 1928). Previous research findings indicate that FAW is always active in the warm and humid conditions (Sparks, 1979). The adult starts movement in the evening towards the host plant for feeds, oviposition and mating (Luginbill, 1928). Virgin female moths begin signaling male moths for mating by emitting windborne pheromones to portray their readiness for mating (Luginbill, 1928). The female undergoes pre-oviposition period ranging between three to four days (Luginbill, 1928). Active oviposition starts from the initial four to five days of life (Sparks, 1979). Females oviposit on the underside of the leaves, however, in the event of high FAW population density, oviposition can be anywhere of the plant parts or plant debris (Luginbill, 1928). The average adult lifespan lasts only ten days with an average range of 7 to 21 days (Sekul and sparks, 1976).

2.12.1 Life cycle of fall armyworm

Fall armyworm egg is dome-shaped and the base is flat (Luginbill, 1928). Egg measures 0.4mm in diameter and 0.3mm in height (Sparks, 1979). Female moths often lay eggs on light colored surfaces such as fence rails, trees trunks and the underside of the tree limbs (Luginbill, 1928). Eggs-laying occurs in four to nine days of female pupation. The egg mass is covered by greyish scales of female's body. Eggs within the same mass hatch at the same time (Sparks, 1979) and the eggs contained per egg mass range are between 100-200 depending on the moth strains. The female moth produces an average of 1500 to 2000 eggs in its lifespan Hatching of eggs takes only2- 3 days during the warm months of the summer.

Fall armyworm larval stage is the longest cycle in the pest lifecycle (Luginbill, 1928). The cycle comprises of 6 larval instars, larvae are greenish in color and it has black head which changed to orange in the second instar (Sparks, 1979). The stripes run across the length of the segments (FAO, 2017). The larvae initiate feeding on the fourth day after molting and last for about 14 days in summer and 30 days in winter implying that larvae stage development in warm summer is temperature driven. The net average development time period for first instars is 3.3 days, second instars is 1.7 days, third instars is 1.5 days, fourth instars is 1.5 days, fifth instars is 2.0 days and sixth instars are 3.7 days at the temperature of 25 degree Celsius (Pitre and Hogg, 1983). When larvae hatch from eggs, they eat the shell; initiate feeding on the host plants and progress to inflict foliage damage until 6 instars are completed and pupated (Luginbill, 1928).The 6 instars drop to the ground and get pupated at 1.3 inches deep in the soil depending on the soil texture, moisture, and temperature (Vickery, 1929). Pupation varies from 7 – 37 daysdepending on soil mean temperature at 25 degree Celsius (Luginbill, 1928), this pupation will take8-9 days for the duration of heat summer time but it will take 20 to 30 days for the duration of cooler weather (Pitre and Hogg, 1983). Pupation process in FAW start at 2-8 cm depth in the soil(Luginbill, 1928). Pupa emerges out from the soil after 10 days in warm summer (Spark, 1979). As the pupa emerges from pupal stage, they get out of the soil depth to the surface of soil and clingonto plant (Sparks, 1979). They then stretch out their wings and become adult moths (Luginbill, 1928). Adult stage; the 32-28mm wing span of an adult Adults is probably harassed with other *Spodoptera spp*. However, in *S. Frugiperda* the veins of the hind-wings are brown and awesome,and in the male forewings are faded and orbicular stigma and it has a suggested faded 'tail' distallyand valve is square and marginal notch at the placement of the tip of the harpe. (Sparks, 1979). Fall armyworm moths are active in the evenings and hide during the day. Sometimes they hide insorghum whorls and between the leaves (FAO, 2017).

2.13 Identification of fall armyworm

Larval stage identification in the field requires expertise and skills as fall armyworm is easily confused with other family members such as African armyworm (*Spodoptera exempta*), African bollworm (*Helicoverpa. armigera*), cotton leaf worm (*Spodoptera littoralis*), Spotted stem borer (*Chilo partellus*), lesser armyworm (*Spodoptera exigua*), as well as African maize stalk borer (*Busseola fusca*) (USAID, 2017). However, there are certain marks developed by taxonomists for identifying the FAW. These include; head with dark net-like pattern and inverted white 'Y' marking, four dark spots at the eighth abdominal segment and the broad, pale band running alongthe top body, contrasted by dark stripes at both sides (USAID, 2017).

2.14 Fall armyworm damage on maize

The larvae of the pest feed on the lower part of the leaves gregariously. It scarps the chlorophyll content material. Third and fourth instar larvae damage the internal part of leaves and reduce the crucial whorl and make it into portions. Parallel shot holes at the newly emerged leaves and excreta are determined. Check for small to large irregular and elongated holes on the leaves. Windowpanes of translucent patches are cause by small FAW in the 1st – 2nd instars while large irregular elongated holes on leaves are caused by big FAW in the 3rd – 6th instars. Sawdust-like material ("frass") in the maize funnel or on the leaves, tassels and cobs showing heavily infestation in the plant.

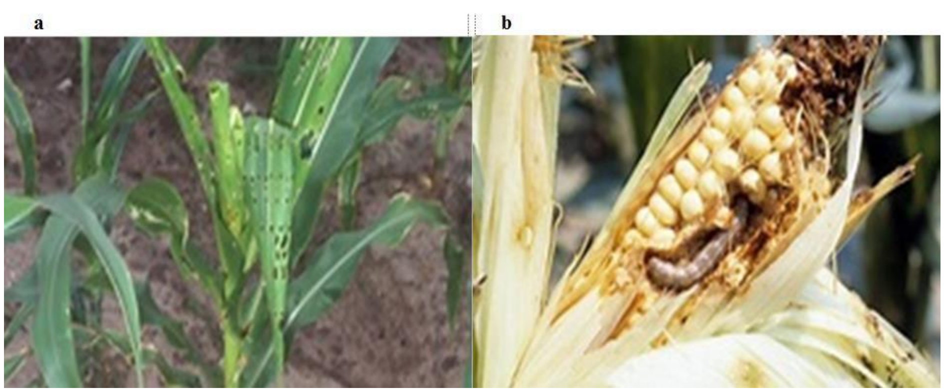

Figure 2.1: Maize leaf (a) and ear (b) damage by fall armyworm

2.15 Management of fall armyworm

It is consequently critical to broaden an efficacious, harmonized, and broader technique to control infestation of FAW across the continent. Such a method ought to be informed by using sound scientific proof, to improve beyond revel in preventing the spread of FAW in different location ofthe earth, and be suitable throughout an extensive of an African contexts range in especially for low-aid smallholder. An integrated pest control (IPM) technique affords a beneficial framework to obtain those desires (FAO, 2017; Prasanna *et al*., 2018). Large scale elimination efforts are neither good nor viable. The managements strategies listed below are used in many African countries and other places in the continent.

2.15.1 Cultural methods

Very many cultural practices strategies had been adopted and used by farmers in lots of African nations, this include use of early maturing varieties, applying sand sawdust or soil inside the whorlof maize, plant early intercrop maize & beans, cast off weeds, cleared crop residues, , tilling to expose larvae & pupae, handpicking egg hundreds and rotate with non-hosts, larvae,. Most of thecontrol measures conform with condition to manipulate the pest behavior. There is rising evidencewhich shows effective control towards FAW infestation in Africa, specifically push -pull tactics of managing FAW in an intercrops system. The importance of cultural and panorama control procedures often get up from the interaction of ecological elements across quite a number of plot arrange in spatial scale subject to the farm land to panorama that interfere and manage the pest at more than one levels at some stage in its existence cycle (Veres *et al*., 2013; Martin *et al*., 2016).

2.15.1.1 Intercropping

Intercropping, sustainable agriculture, and agroforestry enhance the effective growth of the crop and provide better conditions for production of alternative meals resources eaten harbal enemies and decrease the capacity of larvae of FAW to move amongst host vegetation. The ecological and cultural control alternatives are particularly well matched when using the biological and host plant resistance manage techniques (Martin *et al*., 2016; Pumariño *et al*., 2015; Stevenson *et al*., 2012). However, the food legumes suitable to reduced fall armyworm infestation has not been tested, so it is necessary to test many food legumes to see their effectiveness in reduction of fall armyworm infestation. Many research showed that maize-legume combination control pest infestation which includes FAW in the United States of America, it increases the appearance of beneficial arthropods (Baliddawa, 1985; Altieri, 1980a, 1980b; Altieri and Letourneau, 1982; Risch *et al*., 1983; Trenbath, 1993). Intercropping can lessen pest harm with the useful resource of (I) enhancing soil productivity. Promoting active and healthy plant growth due to nitrogen fixation in intercrops (Sida et al., 2018b), (ii) inhibiting motion of larvae amongst flora (van Huis, 1981), (iii) stopping female moths from laying eggs, through seen or chemical disruption (Khan et al., 2010), and (iv) presenting habitat for herbal enemies (Midega et al., 2006).

2.15.1.2 Host-plant resistance

Historically, better trial attempt had been undertaken within the Americans to reproduce variety of maize which is resistant to FAW. The same strategies had currently started in Africa, in adherents to the identity on the continent in 2016 of FAW (Georgen *et al*., 2016). However, currently no Africa- made variety of maize which is technically proven to be tolerant to FAW. The use plants which produce some chemicals which stops moths from laying eggs made some variety become resistant to FAW and other insects (Khan *et al*., 2010) and some host plants which provide habitat which harbors natural enemies to Fall army worm.

2.15.2 Integrated pest management

Integrated management techniques are preferred as the best control alternatives. These encompass tracking of the inspection of the plants weekly for remedy choice making and early detection. Proper practices, like the use of early growing species, intercrop maize with legume, early planting, removal of unwanted plants, do away with all crop residues, rotate maize with legumes to expose pupae and larvae, handpicking egg population and larvae, a non-host, using sand (blended with lime or ash), soil or sawdust within the circular arrangement of the leaves and many more (Tindo *et al*., 2017). Authorities of many countries with FAW presence must right now promote attention of FAW, its identity, harm and control, offer emergency/temporary registration for the encouraged pesticides, (Abraham *et al*., 2017).

2.15.3 Push-pull technology

Push–pull technology includes using locally already there as perennial intercrops and lure plants in an assorted cropping structure. The arrangement is predicated on intensity information on agro biodiversity, chemical, ecology and pest -plant interactions. The fundamental crop which is used as an intercrop is desmodium which pushes stemborer moths away and draws their herbal competitors (Khan *et al*., 1997). An attractant entice plant, Napier grass (pull), is planted as a border crop round this intercrop to pull the pest. These partner crop vegetation release conduct-editing stimuli (semi chemicals) that manage the movement and presence off stembores and other useful insects for manipulate of the pests (Hassanali *et al*., 2008). This climate adapted push-pull technique is used for the management of cereal stemborers, and it correctly led to Manipulation of fall armyworm in small-scale cropping practices in East Africa (Midega *et al.,* 2018). The technology has the capability for enlargement inner many African countries to govern important pests adverse cereal crops cultivated inside the Africa as a continent. Technology is efficacy within the fall armyworm control with the related maize grain output can be elevated, and represent the primary registration of a era of technology that may be right now put in place for manipulating of the pest in East Africa and plenty of various countries in sub-Sahara Africa (Midega *et al.*, 2018). The generation is notably suitable for smallholder farmers who do no longer buy periodic inputs, and has therefore been followed by way of over 30,000 farmers in the East African region up to now with pretty small assets expended on new innovation transfer so far.

2.15.4 Production of semio-chemicals

Plant Semio-chemicals compounds are known to produce various responses which changes behaviors in insects. In many cases those compounds can attract predators to attacking insects and therefore, acts as defending mechanism. These chemicals include secondary metabolites like pyrrolizidine alkaloids (PAs) (Winter *et al.*, 1989). When insects attack plants, they stumble upon a variety of defenses, inclusive of antibiotic agents, which may stand up from the induction of diverse biochemical. Such induced defense is a time associated with the release of unstable chemical substances to the environment, inflicting responses in herbivorous bugs and predators and parasites. This may want to permit suitable semi chemicals to be generated by flora at certain growth stages or previous to insect assault predicted through currently evolved tracking systems (Hick *et al*., 1997). Current years, semi chemical-based pest management applications were increasing in numbers because they offer environmentally friendly methods to govern primary insect pests, which involves disruption of mating, trapping and killing, mass trapping, and to less interesting where it applied lure and infect strategy (Kleinand Lacey, 1999). The interruptions of mating that look to confuse the insects looking for plant to eat has been the maximum successful direct manipulate tactic, mainly focused on moths (Carde and Minks 1995 and Suckling 2000).

2.15.4.1 Mass trapping (pheromonal control)

Pheromone is a secreted or excreted chemical factor that triggers a social reaction in individuals of the equal species. Insects ship these chemical alerts to help entice friends, warn others of predators, or find food. Insects should be monitor constantly to detect infestation before it occurs,

Using specific pheromones, traps may be used to reveal target pests in agriculture or in residential areas. Pheromone traps can be used to detect the presence of insects early in the field thus help one to deploy a recommended measure hence lessen the damage. It can also limit the presence of stinging insects near you. The infestation is decreased by the use of exclusive management alternatives and non-stop monitoring, and via using of integrated fall army worm management method (cultural i.e., input used, hand picking, Early planting), pheromonal manage; insecticide spraying together decreased this pest infestation (Tamiru, 2017). The idea of mass trapping makes use of species-specific synthetic chemical lures, which consist of intercourse and a group of individuals at one location capable of releasing chemicals capable of performing like hormones outside the frame of the secreting person and host attractants, to trap insects which they can be restricted and die. Trapping of insect's pest in masses which is the usage of heady scent-baited traps is one of the oldest techniques to direct management of insects for populace suppression and elimination (Steiner, 1952).

CHAPTER THREE: COMPATIBILITY OF MAIZE WITH A DIVERSE RANGE OF LEGUME SPECIES UNDER SIMULTANEOUS AND RELAY INTERCROP SYSTEM

ABSTRACT

Smallholder farmers in East Africa commonly intercrop maize (Zea mays L.) with grain legumes to maximize yield, utilization of land and labor. However, the productivity of maize intercropped with legumes is affected by it compatibility with diverse range of legumes species and the yield-limiting factors that arise from the intra-specific competition is partially understood. Intra-specific competition between maize and legumes could be alleviated through both the spatial and temporal arrangement of the companion crops. A study was carried out to evaluate the compatibility of maize with a diverse range of legumes species in both simultaneous and relay intercrop systems. The experiment was conducted at the Kenya Agricultural and Livestock Research Organization (KALRO) in Kiboko and at the Kabete Field station of the University of Nairobi. The experiments consisted of simultaneous and relay intercropping of maize with diverse legumes species. The legumes included common bean (variety. Rosecoco), pigeon pea (variety. Kat 80), Dolichos lablab (variety. D1 1002), groundnut (variety. ICGV 9704), soybean (variety.SB19), green gram (variety.N26), cowpea (variety.M66), green-leaf desmodium. Sole maize was grown as control. In each site, treatments were laid out in randomized complete block design and repeated three times. Analysis of variance showed significant differences among treatments ($p \leq 0.05$) in maize-legume compatibility. Intercropping of maize with pigeon pea, lablab in relay cropping system in Kabete, significantly ($p \leq 0.05$) increased yield by 35% and 70% respectively. Relay intercrop of maize with other legumes affected maize grain yields significantly ($P \leq 0.05$). In simultaneous cropping system in kebete, desmodium, bean (roscoco) increased maize stand count at harvest by 17.6% and 18.5% respectively. Also at the same site, simultaneous intercropping of cowpea significantly recorded the highest maize stand count at harvest (113 plants) than relay cropping system at (89 plants). Similarly, in Kiboko, simultaneous intercropping of maize with green gram, lablab recorded the highest maize stand count at harvest by 35 and 40 plants respectively more than relay cropping system. Intercropping maize with pigeon pea and lablab significantly ($p \leq 0.05$) increased maize plant height by 0.7 and 21% respectively in relay cropping system in Kiboko. In addition, relay intercrop of all legumes with maize increased maize plant height except bean and green gram. In both Kabete and Kiboko sites, interactions of maize legume combinations with the cropping system were significant ($P \leq 0.05$). In Kiboko, simultaneous intercrop of maize with pigeon pea, lablab significantly ($p \leq 0.05$) recorded higher biomass compared to relay cropping system. This study showed that intercropping maize with lablab, pigeon pea and beans is more compatible as opposed to other tested legumes. This led to increased maize plant height, maize harvest stand count, and maize grain yields. Simultaneous cropping system yielded more maize and legume out-puts than relay cropping system hence more compatible with maize legume intercrop.

Key words: Intraspecific compatibility, intercropping, cropping systems, grain legumes

3.1 Introduction

Maize (*Zea mays* L.) is an important cereal crop in the family Poaceae. It is an important source of carbohydrate in human diet in the developing world and as animal feed worldwide (Undie et al., 2012). It is considered as a staple food besides its other uses such as energy (Dwivedi et al., 2015). The average actual yield in Kenya is 1.7 t/ha (Makina *et al.,* 2010; Anderson *et al.*, 2014).However, in dryland areas farmers obtain as low as 0.5 t/ha. The low yields are attributed to climatechange, low soil fertility and poor agronomic practices such as inferior varieties, maize-legume compatibility challenges in intercrop systems, as well as pests, diseases and weed (Olowe and Adeyemo, 2009) and (Gastal *et al*., 2002).

The common crop combinations in intercropping systems of Africa are cereal-legume, particularly maize-cowpea, maize-soybean, maize-pigeon pea, maize-groundnuts, maize-beans, maize-lablab, maize-green gram, sorghum-cowpea, millet-groundnuts and rice-pulses (Beets, 1982; Rees, 1986; Waddington et al., 1989; Balthazar, 2014). Species or cultivar selection, Seeding ratios, growth morphology and competition capability within mixtures may affect the growth of the species usedin intercropping systems (Kariaga, 2004).

Efforts have been made to identify suitable intercropping in maize (Zea mays L.) for various agro-climatic zones (*Mandal et al.,* 2014). Different intercropping systems have been evaluated, including mixed intercropping, strip cropping, and traditional intercropping arrangements (Saleem*et al.,* 2011). However, intercropping still has negative impact especially harvesting two crops from within one field may be more challenging than harvesting the different crops from separate fields (Thobatsi, 2009).

Therefore, less emphasis has been given to the knowledge of crop compatibility among maize and special legume species, therefore this study will examine the compatibility of legumes in improving maize vegetative growth yields. It is important to keep on practicing intercropping but to make sure to find right legumes compatibles with maize in terms of growth and development. The objective of this study was to evaluate the effect of simultaneous and relay intercropping of maize into diverse legume species. The study hypothesis is that Crop growth and yield of maize isnot affected by intercrop legume species. Therefore, understanding of the efficient cereal-legume cropping system and right cereal-legume intercrop system would be one of the solutions of maximizing land use, spreading economic risk and improving soil productivity through nitrogen fixation (Massawe *et al.,* 2016).

3.2 Materials and Methods

3.2.1 Site description

Field experiments were conducted during 2019 short rains season in two contrasting environmentsat the Kenya Agricultural and Livestock Research Organization (KALRO) in Kiboko and at the Field Station of the University of Nairobi. Experiments were rain fed and supplemented with irrigation when there was unreliable rainfall. Kiboko research center is in Makindu Sub-County ofMakueni County, about 169 km southeast of Nairobi, along Mombasa-Nairobi Highway. Kibokolies between 37°45’E and 2°20’S at 960 m above sea level. It is in warm low land of the semi-aridregion of eastern part of Kenya and experiences average daily minimum temperatures of 16.6^{0}C with the maximum of 29.4^{0}C. The location receives an average annual rainfall of approximately 604 mm which falls during the long rains season from March to July and short rains which fall from October to December. Soils of Kiboko are well-drained, sandy loam and with pH 7.9 (KARI,2007). Kabete Field Station is situated at the farm of the Faculty of Agriculture, University of Nairobi. Kabete is 1^o 15´ S, 36^o 44´E and 1940 masl. The site is in medium potential area of Kenyawhere annual rainfall ranges between 950mm and 1400mm which falls during the short rains andlong rains seasons respectively. Soils of Kabete are well drained, very deep (>180cm) dark red todark reddish brown, friable clay (Karuku *et al.,* 2012)

3.2.2 Treatments and experiment design

Two experiments were conducted in each site. In the first experiment, crops of maize and nine legume species were sown simultaneously while in second experiment maize was relayed into established legumes. In the simultaneous intercropping experiment, treatments comprised sole maize and intercrop combinations with the nine legumes. The test maize variety was Duma 43 while the legume species included common bean *(*Phaseolus vulgaries – var.Rosecoco), pigeon pea (Cajanus cajan – var. Kat 80), dolichos lablab (lablab purpureus L-var. D1 1002), groundnut (*vigna subterranean-var.* ICGV 9704), soybean *(*glycine max l- var.SB19), green gram (*vignradiata-var.N26*), cowpean (vignaunguiculata - var.M66) and green leaf-desmodium (desmodium intortum). Treatments were laid out in a randomized complete block design and replicated three times. A row of legume was sown between two rows of maize. In the relay experiment, maize was sown into established legumes at forty days after the planting of the legumes. Treatments were laid out in RCBD and replicated three times.

Experimental plots were measured 5 m long and 4.5 m wide. Plots were separated by 1 m paths while replications were separated 2 m apart. Maize was sown 0.75 m between rows and 0.25 m from plant to plant. Sowing density of the legumes varied with species Green grams andgroundnuts were sown at 15 cm between plants in a row while pigeon pea, soybean, cowpea wereown at 20 cm between plants. Common bean was sown 10 cm between plants in a row and a rowof desmodium was drilled into a furrow between maize rows. In both maize and legumes, three seeds were planted per hole and later thinned to 1 plant, two weeks after emergence. Maize was sown 2-5 cm deep while legumes were sown at the depth of 1.5cm.. However, desmodium seed was drilled into 0.5 cm deep furrows. Plots received 75 kg/ha diammonium phosphate (DAP) at sowing. Plots also received calcium ammonium nitrate (CAN) at the rate of 50kgs per hectare at vegetative stage.

3.3 Data collection

3.3.1 Weather data during the growing season

Weather data during the experiment season were collected from on-site weather stations. Data collected included daily rainfall, temperature, relative humidity and solar radiation. Supplemental irrigation was applied via sprinkler system and quantified with rain gauges installed in the experiment block.

3.3.2 Soil sampling

Prior to the establishment of the experiments, soils were sampled for chemical analysis. A soil sample was taken from the field at random at the depth between 10-20cm using trowels and put inside the polythene bag as bulked sample representative of the whole field to determine the initial soil fertility status before planting. Soils were analyzed for pH, phosphorus, nitrogen, potassium, magnesium, cupper, iron, zinc and calcium.

Soils were sampled for moisture content at sowing and at physiological maturity of maize crops. Samples were collected up to 60 cm depth with 20cm intervals. Gravimetric method was used by destructively digging up the soil sample and dried it at 1050C for twenty-four hours Moisture content was calculated by subtracting the oven dried weight from initial field soil weight. This wasdone to determine the total crop water use at the end of the experiment. Water use efficiency wasdetermined by this equation below

$$\mathrm{WUE} = \frac{\text{grain yield(kg/ha)}}{\text{water use (WU)}} \text{ (kg/ha/mm)} \qquad \text{Equation 4}$$

WU=soil moisture at sowing + rainfall- soil moisture at harvest

3.3.3 Crop growth traits

Plant emergence was scored 14 days after planting based totally on uniformity of seed germination. Germination percent according to every plot became received through counting of the seeds thathave germinated through the entire range of seeds that have been planted then expressed them byone hundred%. Plant stand was recorded from the 4 middle rows per plot soon after thinning and at harvest in thefields. It was done by physical counting the plants in those four middle rows.

Maize plant height was sampled every fortnight from the second week of germination until 12 weeks when plants had achieved physiological maturity. Four plants in the middle four rows per plot were sampled for height determination, the measurement was taken from the base to the collarof the upper most fully expanded leaf or the tip of the tassel with the use of a meter rule.

Data taken on biomass development sampling for maize began at V6 when plants had six fully developed leaves by cutting the plant at the base then dried it and weight to obtain the dry matter weight. The interval was, for maize it was taken at V6, flowering and at harvest and for legumes it was taken at branching, podding and at harvest. Systematic and sequential sampling was adopted commencing with outer rows to avoid creation of too many gaps within the field. In each plot three plants were randomly selected for biomass sampling.

3.3.4 Yield and yield components

Yield and yield constituents of maize were collected at harvest. Grain yield was determined by harvesting the plants at the four middle rows. The number of plants was counted and recorded at harvest at four middle rows. Number of ear harvested was counted and recorded in the four middle rows. At harvest, the ear diameter was measured. There was random selection of five maize ears per plotto determine ear diameter with a Vernier calipers. Ear length, at harvest, the ear length was measured. Five maize ears were randomly selected per plot to determine ear length with a tap measured.

Number of ear row was determined; five maize ears were randomly selected per plot to determineear row through physical counting. Hundred seed weight was determined from five sets per plot using a weigh balance at a recommended moisture content of 10-12% and the weight expressed ingrams. Legume yield components collected were total weight of whole plot, number of branches, numberof pods, seeds per pods and 100 seeds weight. For the legumes, the number of pods per plant weretaken by counting all pods on the four sampled plants and divided by four to obtain average numberof pods per plant at harvest time. The number of seeds in the four sampled pods from the four plants was also counted and the value divided by four to obtained the average seeds per pod. Totalnumber of primary branches and hundred seed weight were also counted and then find the averageusing the same way as finding the number of pods per plant.

3.4 Data analysis

Data was subjected to the analysis of variance (ANOVA) using GenStat 15th edition software (Payne *et al*., 2015) to determine the effects of treatments and sites; means were compared by Fischer's protected least significant differences (LSD) at 5% probability.

3.5 Results

3.5.1 Weather data during the experiment season

Figure 2 shows monthly variation in rainfall and temperature in Kiboko and Kabete, The rains started in October and continue up to December in Kiboko and it started in Kabete in July but it becomes serious in Septembers up to December for second seasons. October and Septembers werethe wettest month in Kiboko and Kabete respectively. The variation in total annual rainfall in thislocation is the cause of variations in crop Yield and yield quality as reflected in the crop yield data.The same applies to temperatures variation in these two different locations of Kiboko and Kabete also causes of variations in crop yield and yield quality as reflected in the crop yield data

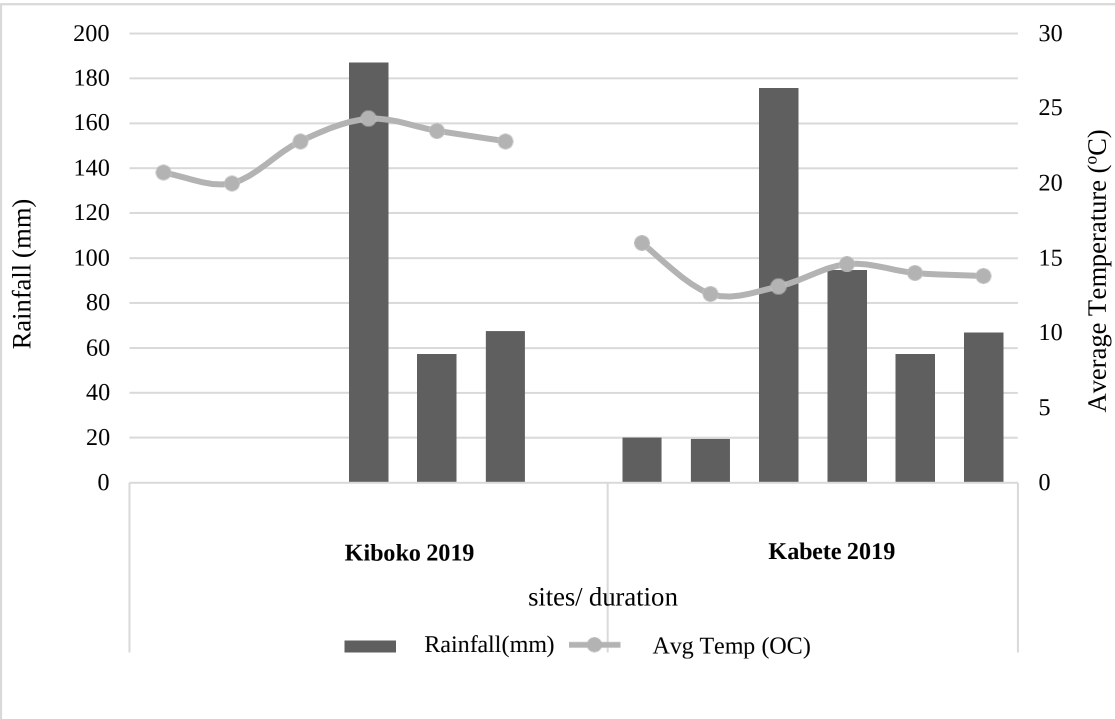

Figure 3. 1: Weather data during experiment season in Kiboko and Kabete sites

3.5.2 Effect of maize-legume intercropping on maize growth

Emergence and plant stand count of maize intercropped with different legumes is presented in Table 3.1. There was no significant effect of the two-cropping system on the percentage emergence and maize plant stand in both Kabete and Kiboko sites. However, there were significant ($P \leq 0.05$) interactions of maize legume combinations and cropping systems on the percentage maizeemergence in Kiboko as opposed to Kabete site. There were no significant interactions of maize legume combinations and the cropping systems on the maize plant stand in both Kabete and Kiboko site. For the percentage emergence, simultaneous cropping system recorded higher figures of percentage emergence than relay cropping system with all the combinations in Kabete.

Table 3.1: Emergence (%) and plant stand count of maize intercropped with different legumes under simultaneous (simul) and relay intercrop system in Kabete and Kiboko after 7 days of emergence during 2019 short rains season

Maize legume Combinations (T)	Emergence				Plant Stand Count			
	Kabete		Kiboko		Kabete		Kiboko	
	Simul	Relay	Simul	Relay	Simul	Relay	Simul	Relay
Maize+ lablab	93	85	78.0	73.0	125	121.0	126	125.0
Maize+ pigeon pea	97	87	79.0	74.0	124	124.0	125	125.0
Maize+ bean	97	84	74.0	81.0	126	121.0	122	121.0
Maize+ cowpea	99	84	80.0	88.0	123	121.0	126	124.0
Maize+ desmodium	100	84	82.0	82.0	125	123.0	124	125.0
Maize + groundnut	100	84	80.0	83.0	125	122.0	126	124.0
Maize+ green gram	99	85	76.0	75.0	125	124.0	124	124.0
Maize+ Soybean	99	81	81.0	82.0	125	121.0	126	123.0
LSD (T)	8.7	6.2	5.6	14.7	2.9	3.9	4.1	4.9
P value (T)	0.09	0.06	0.17	0.17	0.52	0.46	0.439	0.832
LSD (T x CS)	7.5		12.4		3.3		4.3	
P value (T x CS)	0.05		0.41		0.36		0.97	

LSD is least significant difference at 5% probability level; CS is crop system (simultaneous and relay)

Maize plant height was only marginally affected by the legume species during the early growth stages but large differences appeared as the crops matured. However, differences were larger underrelay compared with simultaneous intercropping (Table 3.2). Interactions between maize-legume combination and intercrop system were not significant except at 42 DAE in Kabete. At 14 DAE with relay cropping system in Kabete, intercropping maize with pigeon pea increased maize plant height by 0.7% while the rest of the legume species reduced highest reduction recorded by intercropping maize with beans 19 %. At 42 DAE, maize legume combinations reduced maize plant height with the highest reduction of 53.7% recorded when maize was intercropped with beansusing relay cropping system in Kabete. In Kiboko, intercropping maize with lablab using relay cropping system increased maize plant height by 2.1% while the rest of legume species reduced with highest reduction of 26% recorded with beans. At the later stage of growth (56 DAE), intercropping maize with bean and green gram using relay cropping system reduced maize plant height by 8.7% and 7.9% as opposed to other legume species that increased in Kiboko site. The highest increment of 19.8 was recorded when maize was intercropped with pigeon pea and soy bean respectively. Intercropping maize with legumes using relay cropping system increased maize plant height compared with simultaneous cropping system at 42 DAE in Kabete except beans. Intercropping maize with desmodium using relay cropping system recorded the highest maize plant height increase of 23.1 cm compared with simultaneous cropping system. However, intercropping maize with beans using simultaneous cropping system recorded maize heightincrement of 23.8 cm than relay cropping system respectively.

Table 3.2: Plant height (cm) of maize intercropped with different legumes under simultaneous (simul) and relay crop arrangements in Kabete and Kiboko during 2019 short rains season

Maize legume Combinations (T)	Plant height14 DAE				Plant height 28 DAE				Plant height 42 DAE				Plant height 56 DAE			
	Kabete		Kiboko		Kabete		Kiboko		Kabete		Kiboko		Kabete		Kiboko	
	Sim	Rely	Sim	Rely	Sim	Rely	Sim	Rely	Sim	Rely	Sim	Rely	Sim	Rely	Sim	Rely
Sole maize	18.4	27.3	20.4	29.3	34.5	41.2	40.2	37.3	72.9	95.6	44.5	51.2	120.7	172	100.0	68.2
Maize+ lablab	19.2	25.3	21.0	26.5	36.3	43.2	41.2	34.5	68.8	91.4	52.8	52.3	118.9	198	92.4	75.6
Maize+ pigeon pea	19.5	27.5	20.4	27.3	37.6	42.3	43.9	35.2	66.2	89.7	56.9	47.5	116.0	185	117.6	81.7
Maize+ bean	19.4	22.1	19.5	23.4	36.9	30.8	42.7	31.4	68.1	44.3	49.7	37.9	118.7	148	92.0	62.3
Maize+ cowpea	19.7	25.9	20.5	25.3	37.5	38.2	37.6	33.3	64.8	70.4	45.7	46.6	112.5	189	95.4	68.9
Maize+desmodium	19.3	23.9	19.0	26.0	36.9	43.0	40.3	34.0	67.2	90.3	44.4	47.2	118.4	178	98.5	76.2
Maize +ground nut	19.3	25.1	17.8	28.5	35.9	37.2	38.2	36.5	71.8	95.1	40.8	49.9	124.0	198	105.5	73.7
Maize+ greengram	19.3	26.7	20.3	24.6	35.9	41.5	41.5	32.6	73.8	94.1	52.1	39.6	128.1	179	103.2	62.8
Maize+ soybean	18.4	23.1	20.4	28.6	34.8	39.3	44	36.6	67.5	82.1	48.7	50.4	118.7	187	104.2	81.7
LSD (T)	2.72	3.47	6.59	3.71	5.05	8.89	8.85	6.568	7.46	22.9	14	8.59	19.5	51.5	24.7	12.4
P value (T)	0.97	0.05	0.61	0.74	0.89	0.16	0.77	0.607	0.21	0.01	0.38	0.03	0.86	0.63	0.5	0.01
LSD (T x CS	2.902		5.249		7.427		7.734		16.88		11.238		42.08		18.33	
P value (T x CS)	0.112		0.628		0.281		0.727		0.004		0.068		0.779		0.715	

LSD is least significant difference at 5% probability level; CS is crop system; DAE is days after emergence.

Maize growth rate and plant stand at harvest as shown in Table 3.3. The two systems of croppinghad no significant effect on the maize growth rate in both Kabete and Kiboko sites. Intercroppingmaize with legume species using simultaneous and relay cropping system had no significant effecton maize growth rate in both Kabete and Kiboko sites. In Kabete, simultaneous cropping system showed significant different (P ≤0.05) on maize harvest stand count compared with relay croppingsystem. However, this was the reverse in Kiboko where relay cropping system recorded significantdifferent of maize harvest stand count than simultaneous cropping system.

There were significant interactions (P ≤0.05) of maize legume species combinations and the cropping systems on the maize harvest stand count in both Kabete and Kiboko sites respectively. In Kabete, intercropping maize with legume species using simultaneous cropping system increasedthe maize harvest stand count. An increase of 18.5% and 17.6% maize harvest stand count was recorded highest when maize was intercropped with bean and desmodium compared to the rest ofthe legume species. In Kiboko, intercropping maize with legume species using relay cropping system reduced maize harvest stand count significantly. The highest reduction of 36.4 % was recorded with maize lablab combination.

Intercropping maize with cow pea using simultaneous cropping system recorded higher maize harvest stand count of 24 plants compared to relay in Kabete sites. In Kiboko, intercropping maizewith legume species using simultaneous cropping system recorded higher maize harvest stand count compared to relay. Intercropping maize with lablab and green gram using simultaneous cropping system recorded highest maize stand count compared to relay cropping system by 40 and35 plants respectively.

Table 3.3: Crop growth rate (g m^{-2} day^{-1}) and stand at harvest count (SAH) of maize intercropped with different legumes under simultaneous and relay crop arrangements in Kabete and Kiboko during 2019 short rains season

Maize legume Combinations (T)	Kabete		Kiboko		Kabete		Kiboko	
	Simul	Relay	Simul	Relay	Simul	Relay	Simul	Relay
Sole maize	7.9	10.3	13.4	6.8	119	105	115	110
Maize+ Lablab	6.0	8.7	21.7	6.8	112	92	110	70
Maize+ pigeon Pea	5.6	8.9	15.7	7.3	112	104	118	86
Maize+ bean	5.1	6.2	15.8	6.1	97	112	112	92
Maize+ cowpea	5.8	9.7	15.9	7.3	113	89	113	95
Maize+desmodium	4.9	10.7	12.0	4.0	98	117	104	97
Maize+ ground nut	8.3	8.7	13.9	5.2	116	94	116	95
Maize+greengram	5.1	8.4	21.3	6.5	119	108	115	80
Maize+ soybean	6.5	8.0	12.7	4.6	109	90	120	88
LSD (T)	3.01	4.01	14.08	3.72	13.86	29.53	9.14	18.11
P value (T)	0.243	0.488	0.792	0.519	0.027	0.426	0.065	0.017
LSD (T x CS	3.49		11.58		21.54		15.41	
P value (T x CS)	0.54		0.968		0.049		0.026	

LSD is least significant difference at 5% probability level; CS is crop system (simultaneous and relay), CCR; Crop growth rate, SAH; Stand at harvest.

Simultaneous and relay cropping system had no significant effect on the number of maize ears perplant and ear length in both Kabete and Kiboko sites Table 3.4. An interaction of maize legume combinations with the cropping systems had no significant effect on the number of maize ears perplant and ear length in Kabete and Kiboko sites.

Table 3.4: Ears per plant and ear length (cm) of maize intercropped with different legumes under simultaneous and relay crop arrangements in Kabete and Kiboko during 2019 short rains season

Maize legume Combinations (T)	Ears per plant				Ear Length			
	Kabete		Kiboko		Kabete		Kiboko	
	Simul	Relay	Simul	Relay	Simul	Relay	Simul	Relay
Sole maize	1.1	1.2	1.12	1.18	16.0	14.9	16.1	14.1
Maize + lablab	1.1	1.2	1.13	1.24	14.7	14.7	16.4	13.3
Maize + pigeon pea	1.1	1.2	1.38	0.99	15.6	14.4	15.7	12.7
Maize + bean	1.1	1.2	1.38	1.24	14.4	14.4	14.8	11.8
Maize + cowpea	1.1	1.2	1.19	1.11	16.7	13.5	14.6	11.6
Maize + desmodium	1.1	1.1	1.40	0.95	15.1	14.3	15.4	11.7
Maize + ground nut	1.1	1.2	1.11	1.09	15.2	15.0	15.4	12.1
Maize + greengram	1.1	1.2	1.27	1.07	15.0	14.9	16.0	13.0
Maize + soybean	1.1	1.2	1.16	1.09	14.8	14.9	16.6	13.0
LSD (T)	0.079	0.11	0.366	0.497	1.74	2.28	3.16	2.72
P value (T)	0.647	0.472	0.474	0.917	0.24	0.898	0.893	0.536
LSD (T x CS	0.10		0.424		2.13		2.75	
P value (T x CS)	0.908		0.578		0.45		0.998	

LSD is least significant difference at 5% probability level; CS is crop system (simultaneous and relay)

The two-cropping system (simultaneous and relay) did not affect the maize ear diameter significantly in Kabete and Kiboko sites Table 3.5. Additionally, there was no significant interaction of maize legume combination and the cropping system on maize ear diameter in both sites.

Table 3.5: Ear diameter (cm) of maize intercropped with different legumes under simultaneous and relay crop arrangements in Kabete and Kiboko during 2019 short rains season.

Maize legume Combinations (T)	Ear diameter (cm) Kabete		Kiboko	
	Simul	Relay	Simul	Relay
Sole maize	4.2	4.6	4.2	4.8
Maize + lablab	4.3	4.8	4.0	3.4
Maize + pigeon pea	4.1	4.6	4.4	4.6
Maize + bean	4.0	4.8	4.8	4.9
Maize + cowpea	4.7	4.9	4.5	4.1
Maize + desmodium	4.2	4.0	4.5	3.3
Maize + ground nut	4.8	4.5	4.2	4.0
Maize + greengram	4.4	4.0	4.4	4.5
Maize + soybean	4.9	4.2	4.2	3.5
LSD (T)	2.22	2.2	3.75	5.37
P value (T)	0.097	0.5	0.651	0.758
LSD.S (T x CS		3.39		4.57
P value (T x CS)		0.576		0.594

LSD is least significant difference at 5% probability level; CS is crop system (simultaneous and relay)

Relay maize intercrop with legume species had significant effect on the maize grain yield compared to simultaneous cropping system in Kabete than Kiboko site Table 3.6. Maize legume combination with the two cropping system had no significant interactions on maize grain yields inboth Kabete and Kiboko sites. In Kabete, intercropping maize with legume species using relay cropping system increased maize grain yields except bean and ground nut. An increase of 35 and70% maize grain yield was recorded as the highest increase when maize was intercropped with pigeon pea and lablab under relay cropping system, whereas a reduction of 35 and 10% of maize grain yield was recorded with bean and ground nut. Simultaneous and relay cropping system had no significant effects on the 100 seed weight of maize in both Kabete and Kiboko sites. Moreover,there was no significant interaction of maize legume combinations and the cropping systems on the 100 seed weight of maize in both sites respectively.

Table 3.6: Grain yield (t/ha) and 100(g) seed weight for maize intercropped with different legumes under simultaneous (simul) and relay crop arrangements in Kabete and Kiboko during 2019 shortrains season

Maize legume Combinations (T)	Grain yield(t/ha)				Seed weight(g)			
	Kabete		Kiboko		Kabete		Kiboko	
	Simul	Relay	Simul	Relay	Simul	Relay	Simul	Relay
Sole maize	5.2	2.0	1.4	0.8	395.0	0.4	373.5	36.7
Maize+ lablab	4.0	3.4	1.5	0.3	367.7	1.8	388.6	2.6
Maize+ pigeon pea	5.3	2.7	1.0	0.3	367.9	0.4	378.0	2.9
Maize+ bean	4.6	1.3	0.9	1.0	330.2	1.6	365.3	5.2
Maize+ cowpea	3.3	2.5	1.5	0.6	347.1	0.5	379.6	4.1
Maize+ desmodium	5.2	2.3	0.9	0.2	349.4	1.8	367.5	1.5
Maize+ ground nut	5.0	1.8	1.7	0.6	385.0	0.4	360.7	3.4
Maize+ green gram	5.8	2.5	1.1	0.3	357.4	0.4	385.8	2.3
Maize+ soybean	3.3	2.5	1.5	0.6	357.7	0.4	355.7	3.5
LSD (T)	2.61	1.05	1.01	0.56	57.12	2.27	25.58	33.33
P value (T)	0.425	0.033	0.612	0.113	0.428	0.65	0.162	0.459
LSD.S (T x CS	2.46		0.79		82.99		28.61	
P value (T x CS)	0.451		0.468		0.98		0.284	

LSD is least significant difference at 5% probability level; CS is crop system (simultaneous and relay).

3.5.3 Effect of maize legume intercrop on yield and yield component of legume species

In Kabete and Kiboko sites, an interaction of maize legume combinations with the cropping systems had no significant effects on the biomass yields of legumes at both branching and arvesting stages in Table 3.7. At podding stage of legume growth, interaction of maize legume combinations with the croppingsystems did not affect the biomass yields of legumes significantly in both Kabete and Kiboko sitesTable 3.8.

Table 3.7: Biomass yield (g/m^2) of legumes at branching and physiological maturity(harvesting) under simultaneous and relay intercropping with maize in Kabete and Kiboko during 2019 short rains

Maize legume Combinations (T)	Kabete		Kiboko		Kabete		Kiboko	
	Simul	Relay	Simul	Relay	Simul	Relay	Simul	Relay
Maize+ lablab	5.7	7.5	13.1	20.0	126.5	143.1	176.8	163.5
Maize+ pigeon pea	2.6	10.7	5.1	3.1	159.9	112.4	102.3	97.1
Maize+ bean	14.9	4.2	12.3	26.2	62.8	119.5	148.2	131.4
Maize+ cowpea	6.7	2.4	11.9	13.0	75.7	62.4	139.8	121.3
Maize+ desmodium	5.6	3.5	1.5	1.3	95.8	111.9	64.6	71.3
Maize+ ground nut	5.8	6.4	17.8	13.5	73.1	116	109.4	95.7
Maize+ greengram	4.1	3.0	8.7	12.3	16.2	96.9	62.7	58.3
Maize+ soybean	13.8	3.3	4.8	11.8	20.5	75.9	27.8	55.9
LSD.S (T x CS	8.728		9.244		96.45		52.26	
P Value (T x CS)	0.068		0.151		0.608		0.912	

LSD is least significant difference at 5% probability level; CS is crop system (simultaneous and relay)

Table 3.8: Biomass yield of legumes at podding after maize intercropped with different legumes under simultaneous and relay crop arrangements in Kabete and Kiboko during 2019 short rains season

Maize legume Combinations (T)	Kabete		Kiboko	
	Simul	Relay	Simul	Relay
Maize+ Lablab	30.4	51.4	128.2	134.5
Maize+ Pigeon pea	68.4	51.2	59.5	63.2
Maize+ Bean	59.8	84.1	63.6	86.8
Maize+ Cowpea	45.1	34.8	54.8	41.6
Maize+ Desmodium	60.1	30.9	15.7	29.1
Maize+ Ground nut	24.3	55.8	93.5	90.3
Maize+ Greengram	37.3	28.3	32.7	29.3
Maize+ Soybean	33.7	53.6	30.1	53.1
LSD.S (T x CS	32.67		32.68	
P value (T x CS)	0.084		0.7	

LSD is least significant difference at 5% probability level; CS is crop system (simultaneous and relay)

The total grain yields per unit area and the number of branching at harvest for different legumes intercropped with maize under two cropping system is shown in Table 3.9. In Kiboko, the interaction of maize legume combination with the cropping systems affected Grain yields of legume species significantly as opposed to Kabete site. Intercropping maize with ground nut using relay cropping system yielded higher grain yields of ground nut by 1.3 t/ha compared to simultaneous cropping system in Kiboko site. Both simultaneous and relay cropping system had no significant effects on the number of legume branches at harvest in Kabete and Kiboko site.There was also no significant interactions of maize legume combinations and the cropping systemson the number of legume branches at harvest in Kabete and Kiboko sites respectively.

Table 3.9: Grain yield of legumes (t/ha) and the number of branching at harvest after being intercropped with maize within two sites under different cropping system

Maize legume Combinations (T)	Kabete		Kiboko		Kabete		Kiboko	
	Simul	Relay	Simul	Relay	Simul	Relay	Simul	Relay
Maize +pigeon pea	0.1	0.1	0.1	0.1	11.8	10.2	16.2	19.2
Maize+ lablab	0.1	0.1	0.1	0.1	9.3	10.1	9.3	10.5
Maize+ bean	0.5	0.7	0.8	0.9	6.8	8.6	5.5	5.2
Maize+ cowpea	0.1	0.1	0.1	0.1	7.0	8.9	9.0	6.3
Maize+ ground nut	0.2	0.2	0.6	1.9	3.1	3.7	5.5	5.5
Maize+ greengram	0.1	0.1	0.1	0.1	8.1	8.8	7.4	6.8
Maize+ soybean	0.2	0.1	0.0	0.0	4.4	5.3	7.2	7.2
LSD.S (T x CS	0.17		0.19		5.86		8.82	
P value (T x CS)	0.124		<.001		0.985		0.983	

LSD is least significant difference at 5% probability level; CS is crop system (simultaneous and relay)

The legume grain yields traits of different legume species intercropped with maize is shown in Table 3.10. In both study sites, an interaction of maize legume combinations with cropping strategies had a substantial effect on the amount of legume seeds per pod. For the legumes established in Kabete and

Kiboko, an intercrop of maize with pigeon pea using simultaneous cropping system yielded 58 seeds higher than with relay cropping system while the rest of the combinations had no significant different with the two cropping systems. Significant interactions of maize legume combination with the cropping system affected 100 seed weight of legume species in Kiboko as opposed to Kabete site. An intercrop of maize with pigeon pea and lablab using simultaneous cropping system yielded higher biomass yields of 100 legume seeds of 17.6 gand 19.8 g higher than relay cropping system in Kiboko site respectively. The rest of thecombinations cropping systems had no significant effects on the legumes' 100 seed weights.

Table 3.10: Grain yield per pod (t/ha) and 100 (g) seed weight of legumes after being intercropped with maize under different cropping system within two sites.

Maize legume Combinations (T)	Kabete		Kiboko		Kabete		Kiboko	
	Simul	Relay	Simul	Relay	Simul	Relay	Simul	Relay
Maize +pigeon pea	82.0	24.0	92.0	34.0	82.3	51.3	92.3	74.7
Maize+ lablab	5.0	6.0	3.0	3.0	28.4	23.4	29.6	9.8
Maize+ bean	36.0	35.0	5.0	5.0	58.2	84.4	40.3	40.3
Maize+ cowpea	2.0	2.0	1.0	1.0	1.8	3.2	0.0	0.0
Maize+ ground nut	1.0	2.0	3.0	2.0	37.7	0.4	51.3	47.8
Maize+ greengram	2.0	2.0	3.0	2.0	0.0	0.0	0.0	0.1
Maize+ soybean	18.0	20.0	3.0	3.0	22.8	28.6	16.0	15.9
LSD.S (T x CS		21.62		18.43		34.58		10.05
P value (T x CS)	0.003		<.001		0.164		0.015	

LSD is least significant difference at 5% probability level; CS is crop system (simultaneous and relay)

The interaction of maize legume combinations with the two-cropping system did not significantly affect the number of pods per legume species in both Kabete and Kiboko sites as shown in Table 3.11.

Table 3.11: Number of pods of legumes per plant intercropped with maize under different cropping systems within Kiboko and Kabete during 2019 short rains season

Maize legume Combinations (T)	Kabete		Kiboko	
	Simul	Relay	Simul	Relay
Maize +pigeon pea	38.0	32.0	60.0	35.0
Maize+ lablab	5.0	4.0	63.0	35.0
Maize+ bean	9.0	20.0	11.0	8.0
Maize+ cowpea	1.0	2.0	4.0	5.0
Maize+ ground nut	45.0	48.0	95.0	85.0
Maize+ green gram	4.0	4.0	4.0	3.0
Maize+ soybean	14.0	15.0	19.0	16.0
LSD.S (T x CS	16.28		35.97	
P value (T x CS)	0.866		0.823	

LSD is least significant difference at 5% probability level; CS is crop system (simultaneous and relay)

3.5.4 Effect of maize legume intercrop on crop water use efficiency

In both Kabete and Kiboko, the cropping system (Simultaneous and relay) had sizable impact on soil moisture content at different levels 20, 40 and 60 cm soil depths; however, in Cowpea plot it had better soil moisture content compared to sole maize and the rest of other legumes in simultaneous intercrops as shown in Table 3.12. The desmodium and pigeon pea plots had also high soil moisture in simultaneous intercrops system as compared to relay intercrops. Simultaneous intercrops had higher soil moisture content across the two sites at different depth level of 20, 40 and 60 cm as compared to relay intercrops system.

Table 3.12: Water use efficiency in kg/ha/mm of different intercrop including the control which is the sole maize

Maize legume Combinations (T)	Kabete		Kiboko	
	Simul	Relay	Simul	Relay
Sole maize	7.5	5.06	0.62	0.24
Maize+ Lablab	10.12	8.60	1.20	0.64
Maize+ Pigeon pea	13.41	6.83	0.80	0.44
Maize+ Bean	11.64	3.29	0.72	0.80
Maize+ Cowpea	14.48	6.33	1.20	0.48
Maize+ Desmodium	13.18	5.82	1.72	0.96
Maize+ Ground nut	12.65	4.55	1.36	0.48
Maize+ Greengram	13.16	6.33	0.88	0.54
Maize+ Soybean	8.35	6.33	1.20	0.48

3.5.5 Intercropping productivity

3.5.5.1 Partial land equivalent ratio

The strength of the intercropping interaction was determined using land equivalent ration and results presented in Table 3.13. Land equivalent ratio (LER) in simultaneous intercropping showed that there were yield advantages of intercrops over sole cropping. Those intercrops which were under 1 should be linked to the high competitive advantage of the grain legumes deemed to haveinfluenced negatively on the overall yield, hence resulting in LER values less than one one, it implies that there is no yield advantage, but when LER is more than one, it means that, there is a yield advantage.

Table 3.13: Land equivalent ratio of the two-study site

Maize legume Combinations (T)	Kabete		Kiboko	
	Simul	Relay	Simul	Relay
Maize+ Lablab	0.9	1.7	1.1	0.4
Maize+ Pigeon pea	1.3	0.8	0.9	1.0
Maize+ Bean	0.9	0.5	3.3	0.9
Maize+ Cowpea	1.7	1.9	1.7	0.6
Maize+ Desmodium	1.6	0.9	0.8	0.3
Maize+ Ground nut	1.7	0.8	3.0	1.9
Maize+ Greengram	1.2	1.4	1.6	0.5
Maize+ Soybean	1.6	1.0	1.4	2.0

3.5.5.2 Monetary Advantage Index (MAI)

The economic feasibility of intercropping over sole cropping was calculated using the monetary advantage index (MAI). MAI is an important index in determining economic viability of intercropping. It was calculated according to Willey (1979) and presented in Table 3.14. The MAI was significantly higher under simultaneous cropping specially in maize + groundnut association over all other intercropping ratios (Table 3.14), which might be due to higher LER value. The lowest monetary benefits were recorded in maize + desmodium in all the sites in both simultaneous and relay intercropping. The higher the index value, the more profitable is the cropping system

Table 3.14: Monetary advantage index (USD) of intercropping over sole cropping.

Maize legume Combinations (T)	Kabete Simul	Kabete Relay	Kiboko Simul	Kiboko Relay
Maize+ Lablab	1617.9	1671.7	1335.8	-222.6
Maize+ Pigeon pea	1080.6	234.1	156.1	390.2
Maize+ Bean	1706.1	0.0	438.7	1070.9
Maize+ Cowpea	960.7	784.6	672.5	56.0
Maize+ Desmodium	958.7	292.2	73.0	-146.1
Maize+ Ground nut	1760.6	672.1	1136.6	5601.0
Maize+ Greengram	1181.7	1386.0	154.0	0.0
Maize+ Soybean	1944.1	530.2	954.	1590.6

3.6.Discussion

3.6.1 Effect of simultaneous and relay intercropping on maize growth traits

At 28 days after emergence (DAE), intercropping maize with lablab, desmodium and pigeon pea increased maize plant height by 4.9 %, 4.4 % and 2.7% under relay cropping system at Kabete. For 42 DAE, intercrop of green gram with maize under simultaneous cropping system increased maize plant height by (1.2%). In Kiboko, simultaneous cropping of maize with pigeon pea, lablaband green gram increased maize plant height by (27.9%), (18.7%) and (17.1%) while for relay cropping system lablab increased maize plant height by (2.1%) respectively. After 56 DAE, intercropping pigeon pea and soybean with maize increased maize plant height by (19.8%) withinKiboko site under relay cropping system respectively. The plant height of maize was reduced by beans in most of the cropping system. This variation is due to the competition for light and moisture, and it is in agreement with (Ahmad *et al.*, 2015) who reported significant increase in maize plant height under maize- Cowpea treatment for the two growing seasons higher than for other treatments.

Introduction of lab lab does not influence the height of maize. Lower mean height of maize in maize lablab intercrop could be due to suppression by the legume in competition for plant growthfactors.

(Birteeb *et al.,* 2011). This study does not agree with the findings. Simultaneous croppingsystem recorded the highest biomass yield of maize grain than the Relay cropping system. This could be due to early maize-legume association due to symbiotic nitrogen fixation by legumes as compared to relay cropping system where maize was sown within legumes after 40 days of emergence. This concurs on the fact that intercrops have shown to improve soil fertility by reducing run off and soil loss on sloping semi-arid Kenya (Kinama *et al*., 2007).

3.6.2 Effect of simultaneous and relay intercropping on maize yield component

Maize + ground nut from this study increased maize yield by 21.4% under simultaneous croppingsystem at Kabete confirming the results observed in Malawi in three different locations (Nyagumbo *et al.,* 2016) who reported an increase of 21%, 41%, 54%. This could be attributed tothe ability of the groundnut to fix nitrogen and create soil cover. Maize + Green gram increased maize grain yield by 11.5% and 25% in both simultaneous and relay cropping system. This couldbe due to low competition for light and moisture. (Kheroar and Patra, 2013) reported highest maizegrain yield of (2.9163t/ha) in 1:1 row ratio when maize was intercropped with green gram. They noted a 10.69% increment in yield as compared to the normally spaced sole maize. Maize+ Pigeon Pea recorded maize grain increment of 0.2% and 35% under simultaneous and relay cropping system in Kabete. These results confirmed with what reported by (Rusinamhodzi *et al.*, 2012) whosaid when maize intercropped with pigeon pea within the same row and distinct row increased thegrain of the maize.

When cow pea was intercropped with maize under relay cropping system, the maize grain yield inthis study was increased by 25% within Kabete. This confirms similar studies done on relay cropping of cow pea and maize (Jeranyama *et al.*, 2000), who reported, the maize grain yields of 100 seeds were reduced by 4.8%-9.3% for simultaneous cropping system and 1.6%-5.3% for relaycropping system between the two locations. High maize grain yields after intercrop with legumeswas due to higher N level in the soil, as a result of N fixation by legume which increased grain weight of cereals due to more available N for the optimum plant growth (Khan *et al.*, 2012). Grainyield of maize was increased when intercropped with green gram (Kheroar and Patra, 2013). Thesefindings are in agreement with the 3.2% increase of the weight of 100 seeds recorded in this studyin maize + green gram under simultaneous cropping system. Maize better yield could be a result of symbiotic nitrogen fixation by legumes and current transfer of nitrogen to the associated maizeplants (Blackshaw *et al.*, 2004).

3.6.3 Effect of simultaneous and relay intercropping on biomass accumulation

There were significant interactions ($P \leq 0.05$) between maize legume combinations and cropping systems on biomass yield of legumes at branching as opposed to at harvest in all the two sites. For biomass at branching within Kabete, maize + pigeon pea recorded the highest biomass yield withrelay than simultaneous cropping system (10.7-2.6) g. Maize + bean and maize + soybean recordedhigh biomass yield with simultaneous than relay cropping system (14.9-4.2) g, and (13.8-3.3) g. In Kiboko, maize + bean and maize + soybean had the highest biomass with relay than simultaneous cropping system (26.2-12.3) g and (11.8-4.8) g. For Biomass of legume at harvest in Kabete, maize + bean, maize + greengram recorded high biomass yield with relay than simultaneous cropping system (119.5-62.8) g, (96.9-16.2) g respectively Where as in maize + soybean had the highest biomass yield with simultaneous than relay cropping system (20.5-75.9) g.

The drop in legume yields at branching with simultaneous cropping system could be due to taller plants in conjunction with shorter plants altering the pace at which the shorter plants can harvest light energy, affecting production through photosynthesis reduction as was reported by (Clipson, 1994, Singh *et al.,* 1997).who reported that light was a significant limiting factor when cowpea was intercropped with tall cereal crops. Due to insufficient light in the late-planted intercrop, this phenomenon restricted branching. (Ntare *et al.,* 1993) also suggested that, the short photoperiod causes the legumes to have less time to grow canopy, resulting in a drop in leaf area index in late intercropping of cowpea with grains.

The shoot biomass of the three legumes also decreased with delay in time of intercropping as reported by (Lawson *et al.,* 2013). The decrease in shoot biomass in relay intercropping could be attributed to the legume plants' inability to intercept sunlight and the decrease in leaf area index asthe intercropping period progressed. Light became a significant limiting element when cowpea was intercropped with tall cereal crops (Singh *et al.,* 1997). This confirms the finding in this study.

3.6.4 Effect of simultaneous and relay intercropping on legumes yield component

Maize + bean, maize + groundnut and maize + soybean combination with both simultaneous andrelay cropping recorded legume grain yields of (0.5-0.7), (0.2-0.2) and (0.2-0.1) ton/ha within Kabete. The rest of the combinations recorded grain yields of 1.1 ton/ha. Within Kiboko, maize +bean and maize + groundnut recorded grain yield of (0.8-0.9) and (0.6-1.9) ton/ha with both simultaneous and relay cropping system. Maize legume intercrop and the cropping system did notsignificantly affect the number of legume branches at harvest within the two tested sites.

The quick maize development in the simultaneous cropping system resulted in severe shadowingin both systems, which could explain the low yields of beans and cowpeas. Beans, compared to the other two legumes, are more shade tolerant (Giller *et al*., 2001) and it confirms the results in.this study. The results from pigeon pea that were obtained in this study agreed with (Rusinamhodzi*et al.,* 2012) who reported when maize intercropped with pigeon pea within the same row and distinct-row intercropping where two maize rows alternated with a single row of pigeon pea. Theauthor reported Pigeon pea grain yield of 1.2 t/ha in sole crop, 0.8 t/ ha in distinct-row intercrop and 1.0 t/ha in within-row intercrop. Also, similar results were obtained by (Muna *et al.*, 2010) inhighlands of Central Kenya with maize legume intercrop revealed that, beans generally gave highest yields, followed by Cowpea (maximally 0.7 t/ha and 0.5 t/ ha, respectively. The study carried out by (Kubota *et al.,* 2015) reported that, the seed yield of soybean per unit area also reduced with maize intercrop and it is in agreement in this study.

There was decrease in yield of soybean, green gram, groundnut in this study and it agrees with what was reported by (Patra *et al*., 2000). Who reported maize always recorded higher values of competitive ratio to those in maize-legumes combination. Yield declines led to reduction of pods per plant and seeds per pod in the intercrop systems (Kitonyo *et al*., 2013) and this confirm the finding in this Study. The same author discovered that, there were reduction in average bean seed yields significantly ($P \leq 0.05$ by 58.92%, 56.01% and 51.46% in in the three stations respectively. Planting maize and cowpea together in semi-arid Kenya led to reduction cowpea yield due to shading effects (Kinama *et al.,* 2007) which confirmed the finding in this study. Bean yield reduction under simultaneous cropping system as opposed to relay cropping system in this study could be due to inter- specific competition for resources such as water and nutrients (Zhang and Li, 2003)

3.6.5 Effect of simultaneous and relay intercropping on water use efficiency

There were significant interactions between maize legume integrations and the cropping systems on water use efficiency at all the locations. The water use was found higher in Kiboko in both simultaneous and relay cropping system as compared to Kabete. Maize + cowpea, maize + desmodium,, and maize + green gram plots showed higher moisture content material in Kebete in simultaneous cropping than solitary maize crop plots, according to the study. Soil moisture contentwas found to be higher in maize-cowpea intercrop plots than in solitary maize crop sites Ghanbari*et al.*, 2010). This is because in intercrops system there is more ground cover than sole maize whichcan conserve more soil moisture than sole cropping. The current results can also be related to the fact that maize requires more water than cowpea, which is attributable to drought stress (Filho *et al.*, 2000).

3.6.6 Effect of simultaneous and relay intercropping on system productivity

Generally, crop mixtures with a LER=1.0 suggested that there was no advantage over sole cropping cultivation. Those mixtures with LER > 1 showed a multiple cropping advantage over monoculture biological output similar to an indication of genotypic compatibility between the twocrops. Lower partial LER values may be linked to the highly competitive advantage of the grain legumes. This may have negatively influenced the yield hence resulting in LER values less than one. Matching duration of maturity between the component crops may also have reduced the valueof LER to less than one in intercropping since they were assumed to have critical resource demandsat the same time period (Yayeh *et al.,* 2014a).

Intercropping indices specifically give the agronomic and yield advantages of intercropping, and do not consider the financial and absolute yield comparisons (Tamado and Mulatu, 2000).Therefore, it turns to be importance to perform a few financial critiques to satisfactorily evaluate the values of the yield gain (Willey, 1979). This study confirmed that intercropping maize with legumes extensively affected the MAI. Given that MAI became positive in all the intercropping systems besides desmodium and lab lab which confirmed negatives values. This indicates that the intercropping systems is more economically feasible in the other positive crops than the negatives ones. Thus, conforming with the findings of Dutta et al. (1994) on maize-rapeseed combinations which stated higher values of MAI were also recorded under simultaneous cropping than relay ones. These show the complementary benefits of nitrogen fixing with legumes and hence boost the combined crop economics. Similarly, the MAI was higher in Kabete than Kiboko. This probably may be due to lower aridity index values in Kiboko thus the crops suffered some droughtsand such correlate the findings of Mbayaki and Karuku (2021).

3.7 Conclusion

The study concludes that, maize -legume intercrops, were more productive as sole crops. The results indicated that Simultaneous cropping system was found to be more compatible with maize legume intercrop as it had positive effect on maize plant height, maize growth rate, Maize plant stand at harvest and biomass yield of maize grain in t/ha. Intercropping maize with pigeon pea, lablab, Desmodium, Green gram and soybeans appeared more compatible as opposed to other tested legumes. Furtherresearch should be carried out to determine the degree of integrators of allelopathy of maize if anyto companion crops and nutrient use under intercropping.

CHAPTER FOUR: EFFECT OF SIMULTANEOUS AND RELAY INTERCROPPING OF MAIZE WITH DIFFERENT LEGUMES ON THE INFESTATION OF FALL ARMYWORM (*Spodoptera frugiperda*)

ABSTRACT

Fall armyworm (*Spodoptera frugiperda)* is a devastating pest in a wide range of cereal crops acrossthe world. In maize, companion cropping, particularly with desmodium proven to control pests. However, the efficacy of food legumes and temporal arrangement of maize-legume intercropping on the management of fall armyworm (FAW) is only partially understood. A study was conductedto evaluate the effect of simultaneous and relay intercropping of maize with different legumes onthe infestation of fall armyworm. Two experiments were conducted at the Kenya Agricultural andLivestock Research Organization (KARLO) in Kiboko and at the field station of the University ofNairobi. In each site, the treatments were arranged in a randomized complete block design and were replicated three times. In the first experiment, maize was simultaneously intercropped with legumes while in the second experiment; maize was relayed into an established legume crop, bothcrops in distinct rows. The legumes included common bean, pigeon pea, Dolichos lablab, groundnut, soybean, green gram, cowpea and green leaf desmodium. Treatments were laid out inrandomized complete block design and replicated three times, with sole maize as control. On the fall armyworm (FAW) infestation data, simultaneous intercropping of maize with cowpea, lablab, bean, and desmodium significantly ($P \leq 0.05$) reduced FAW damage in maize leaf by 46.6, 47.0, 73.0, and 73.1% respectively at both vegetative and flowering stage at the two sites. Similarly, relaying maize into established cowpea, lablab, beans and desmodium significantly ($P \leq 0.05$) controlled FAW infestation in maize leaf by 65.9, 75.6, 78.0 and 87.8% respectively from vegetative to the flowering stage at both sites. Also, establishing maize simultaneously with lablab, green gram, beans and desmodium significantly ($P \leq 0.05$) reduced the number of FAW pest larvae in maize plant by 42.6, 69.6, 70.0, and 87.0% respectively in all physiological stages across the two sites. Similarly, relay establishment of maize into lablab, cowpea, beans, and desmodium significantly ($P \leq 0.05$) reduced the number of FAW pest larvae in maize plant by 62.2, 70.0, 77.8,and 100% respectively in all stages of growth in both sites. Relaying maize into an already established lablab, bean and desmodium reduced FAW infestation or damage on maize plants at nearly all physiological stages compared with other legumes in all the sites. In conclusion, In conclusion, when comparing means of lablab and bean with desmodium, it shows there are no significant differences between those three legumes. Therefore, it is highly recommended to use food legumes (lablab and bean) instead of desmodium in control of fall army worm infestation. Lastly relaying maize into established legumes was found to be more effective in reduction of FAW damage in maize than with simultaneous cropping system in this study.

Keywords: Intercropping, cropping systems, Infestations, Food legumes, desmodium

4.1 Introduction

Maize is one maximum critical food and cash crop in sub-Saharan Africa but its yield potential remains low. It remains one of the main staple foods in Kenya besides its other uses such as energy (Dwivedi et al., 2015). Yield potential is the crop's yield grown in its suitable surrounding with maximum availability of water and nutrients, as well as effective manage of other yield-limiting factors such as pests, diseases, and weeds (Evans and Fischer, 1999). Among other challenges, recent outbreak of fall armyworm in the region has decimated maize yield. The pest has been shown to cause up to 100% yield loss depending on the stage of the maize crop when the infestationtakes place (Malo and Hore, 2020).

Insecticides play a pivotal role in the management of FAW. However, in the smallholder farms ofsub-Saharan Africa, insecticides are not only expensive but posse serious environmental consequences. In addition, injudicious use of insecticides could lead to the development of resistance by the pest. Nonetheless, use of insecticides in Africa is limited. Evidence suggests thatcultural practices such intercropping and early sowing are cost-effective and environmentally friendly in the management of a wide range of insect pests and diseases.

Intercropping is the growing of two or more plants during the same season in the same area whichuses common restricting resources better than the species grown separately as sole (Chianeh et al.,2011). Growing maize and legumes in combination reduces levels of FAW infestation by 65% bean, 74% soybean, and 64% groundnut (Midega *et al.,* 2018). Altieri (1981) observed that pre- planting of bean by 20 to 30 days before maize resulted in more than 80% decline in FAW incidence. Hailu et al., (2018) also demonstrated that, intercropping common beans or groundnut with maize reduced FAW oviposition by 30% in maize. If maize is intercropped with repelling plants/legumes, it creates push-pull system that prevents or reduces oviposition on maize plant (Lamsal *et al.,* 2020).

Push-pull era involves attracting insect pests with entice plants (pull) at the same time as driving them far from the primary crop with usage of a repellent intercrop (push). Cereal crops are intercropped with legumes inside the genus Desmodium, and planting forage grasses (Napier grass Pennisetum purpureum) round this intercrop (Khan et al., 2018). The use Napier grass as border crop with silver leaf desmodium (Desmodium uncinatum) in the intercrop.

Intercropping of maize with leguminous crops provide significant reduction of stem borer and FAW compared to mono-cropped maize, especially in the early growth phases of the maize up totasseling (Hailu *et al.,* 2018). In addition to push pull technology, intercropping of maize with edible legumes could also be an alternative FAW management option when integrated with other sustainable management measures (Hailu *et al.,* 2018). The main aim of this study was to determine whether intercropping maize with different varietiesof legumes using different cropping system (simultaneous and relay cropping system) could control infestation of fall arm

4.2 Materials and methods

4.2.1 Sites

In each site during 2019 short rains season, two field experiments were conducted simultaneouslyat the Kenya Agricultural and Livestock Research Organization (KALRO) station in Kiboko and at the Field Station of the University of Nairobi. Kiboko is situated along the Mombasa-Nairobi highway at Kiboko in Makindu Sub-County, Makueni County, about 169 km south-east of Nairobi.

The centre is at 2° 20' S, 37° 40' E and 960m meters above sea level (masl) (Franzel et al., 1999).It lies in warm low land of the semi-arid region of eastern part of Kenya with an altitude of 900mabove sea level and experiences average daily minimum temperatures of 16.6^{0}C with the maximum of 29.4^{0}C. The location receives an average annual rainfall of approximately 604 mm which falls during the long rains season from March to July and short rains which fall from Octoberto December. Soils of Kiboko are well-drained, sandy loam and pH 7.9 (KARI, 2007).

Another experimental site is at Kabete field station which is situated at the upper Kabete campus estate, Faculty of Agriculture, University of Nairobi. The site sits at 1940 m above sea level at latitudes 10 15 'South and 36^{o} 44' East. The site is in medium potential area of Kenya where annualrainfall ranges between 950mm and 1400mm which falls during the short rains and long rains seasons respectively. Soils are well drained, very deep (>180cm) dark red to dark reddish brown,friable clay (Karuku et al., 2012).

4.2.2 Treatments and experiment design

In the experimental design, in each site, two experiments were carried. In the first experiment, maize was simultaneously intercropped with nine legumes while in second experiment maize wasrelayed into existing legumes. The legume species included common bean *(Phaseolus vulgaries,* variety Rosecoco), pigeon pea (*Cajanus cajan,* variety Kat 80), dolichos lablab (*Lablab purpureus,*variety D1 1002), groundnut (*Vigna subterranean,* variety ICGV 9704), soybean *(Glycine max,* variety SB19), green gram (*Vigna radiate,* variety N26), cow pea (*Vigna unguiculata,* variety M66) and green leaf desmodium (*Desmodium intortum).* Maize-legume combinations were laid out in a randomized complete block design and replicated three times in both treatments. The testmaize variety was Duma 43. In the simultaneous intercrop system, a row of legume was sown between two rows of maize while in the relay experiment, a row of maize was sown between tworows of established legumes.

Maize was relayed into legumes 40 days after sowing of the legume.Experimental plots were measured 5 m long and 4.5 m wide. Plots were separated by 1 m paths while replications were separated 2 m apart. Maize was sown 0.75 m between rows and 0.25 m from plant to plant. Sowing density of the legumes varied with species, green grams andgroundnuts were sown at 15 cm between plants in a row while pigeon pea, soybean, cowpea was sown at 20 cm between plants. Common bean was sown 10 cm between plants in a row and a rowof desmodium was drilled into a furrow between maize rows. In both maize and legumes, three seeds were sown per hill and later thinned to one plant two weeks after emergence. Maize was sown 2-5 cm deep while legumes were sown at the depth of 1.5cm. However, desmodium seed were drilled into 0.5 cm deep furrows. Plots received 75 kg/ha diammonium phosphate (DAP) at sowing and calcium ammonium nitrate (CAN) , 50kgs per hectare. DAP was placed between twoholes while planting while (CAN) was top dressed at knee height of the maize plan in the presenceof adequate moisture in the soil. Weeding was done on appearance of weeds.

4.3 Data collection

Fall armyworm infestation was scored through the measurements of ear damage, dead-heart incidence, number of pest larvae. Leaf feeding damage was visually rated and recorded immediately at the start of natural infestation, knee height (8-leaf stage) and finally at flowering. Scores were rated using Davis and Williams scale (Table 4.1). Based on this scale, 1 is highly resistant and 9 is highly susceptible (Davis and Williams, 1992). Sampling was done randomly inthe four middle rows of the plots where four plants were randomly selected.

Table 4.1: Scale used for the assessment of fall armyworm infestation and damage on maize leaves(Davis and Williams, 1992)

Explanation of damage rating	Rating
No seen leaf harm;	0
Only pin-hollow harm	1
Pin-hollow and small round hole damage to leaves	2
Pinholes, small round lesions and some small, elongated lesions of up to 1. Three cm in period seen on whorl and furl leaves	3
Several small to mid-sized 1.3 to 2.5 cm in duration elongated lesions found on furl leaves and some few whorl	4
Several big, elongated lesions greater than 2.5 cm in length found on some furl leaves and whorl	5
Several massive, elongated lesions appear on furl leaves and several whorls	6
Several lengthened lesions of all sizes appear on furl leaves and on numerous whorls plus numerous massive uniforms to abnormal pin-hollow eaten from furl leaves and whorls.	7
Numerous extended lesions of all sizes appear on most furl leaves and whorls plus various middle- to massive-sized uniform to abnormal fashioned holes eaten from furl leaves and whorl	8
Curl leaf and whorl nearly destroyed	9

Data on ear damage was visually scored. Rating was done on the ear before harvest and before the hard drought stage. In each plot, four plants were randomly selected in the four middle rows. 4 ears were randomly selected for rating per plot in the field on the scale indicated in Table 2. Scores were rated using Davis and Williams scale (Table 4.2)

Table 4.2: Scale used for the assessment of fall armyworm infestation and damage on maize ear

Completely the ear is good	1
There is damage in ear tip(<3cm) in 1-3 ears	2
There is damage in ear tip in 4-7 ears	3
Tip damage to 7 and more ears and damage to 1-3 kernels below ear tips on 1 to 3 ears	4
7 ears tip damage to 1-3 kernels of 4 to 6 ears	5
Ear tip damage 7-10 ears and harm to 1-four kernels under recommendations of 7 to ten ears.	6
7-10 ears damage and 4-6 kernels destroyed on 7-eight ears	7
All Ears tip and four-6 kernels destroyed on 7-eight ears.	8
cob tip harm to all cobs and 5 or more kernels destroyed below tips of 9-ears	9

Data on dead-heart incidence was visually observed and recorded after 2 weeks of natural infestation. The number of plants showing dead-hearts was recorded in the four middle rows per plot.

Larvae on the plant tissues were counted by destructive sampling at different growth stages; first at the start of natural infestations, 8-leaf stage and flowering. At each sampling stage, four plants were randomly selected from the middle rows in each plot.

The height of four randomly selected plants that are infested in the four middle rows per plot were measured using a ruler and recorded right from the base to the end of the tassel at flowering.

4.4 Data analysis

Data was subjected to analysis of variance (ANOVA) using GenStat 15th edition software (Payne *et al*., 2015). In each site, data was pooled across simultaneous and relay intercropping experiments. Treatment means were compared and separated using Fishers least significant difference at 5% probability level.

4.5 Results

4.5.1 Effect of simultaneous and relay maize-legume intercropping on FAW damage inmaize leaf

In both sites, simultaneous and relay intercropping of maize with different legume species showed significant ($P \leq 0.05$) effects on FAW damage in maize Table 4.3. At the early vegetative growth of maize in both Kabete and Kiboko, leaf damage was markedly lower when maize was simultaneously intercropped with either bean (73-47.1%), desmodium (73.0-67.1%) or lablab beans (67.6-38.6%) compared with the rest of the legumes and control. Under relay intercropping, sowing maize into established desmodium and lablab bean significantly reduced FAW damage to maize by 65.4 and 70.5% compared with the other treatments in Kiboko but without differences in Kabete. Interactions between simultaneous and relay intercropping systems across the legume species did not affect FAW damage in maize.

At 8-leaf stage (physiological vegetative stage), both simultaneous and relay intercrop systems had significant effects on FAW damage in maize Table 4.3. In Kabete, intercropping maize with beans using both simultaneous and relay cropping systems reduced maize leaf damage by 50.6-60.9 % compared with other legumes. In Kiboko site, FAW damage on maize leaf declined when maize was intercropped with lablab (47.4-72.7%), beans (54.4-70.1%) and desmodium (66.7-83.1%) under both simultaneous and relay cropping systems than the rest of the legumes. The interactions of simultaneous and relay intercropping system significantly affected FAW damage in maize in Kiboko as opposed to Kabete. Intercropping maize with ground nut using relay cropping system reduced FAW damage on maize by 34.8% more than with simultaneous cropping system.

Table 4.3: Maize leaf damage rating at (3 leaf stage) and at (eight fully developed leaves) after intercropped with different legumes under simultaneous and relay crop arrangements in Kabete and Kiboko during 2019 short rains season.

Maize legume	Kabete		Kiboko		Kabete		Kiboko	
Combinations (T)	Simul	Relay	Simul	Relay	Simul	Relay	Simul	Relay
Control	3.7	2.7	7.0	7.8	7.7	6.9	5.7	7.7
Maize + Lablab	1.2	1.0	4.3	2.3	5.6	4.7	3.0	2.1
Maize + Pigeon pea	2.0	1.8	6.0	5.1	5.6	4.8	4.7	4.3
Maize + Bean	1.0	1.0	3.7	3.6	3.8	2.7	2.6	2.3
Maize + Cowpea	1.8	1.3	4.7	3.5	4.5	3.8	4.4	3.3
Maize + Desmodium	1.0	1.7	2.3	2.7	4.5	3.6	1.9	1.3
Maize + Groundnut	2.2	2.0	5.0	4.0	5.1	4.8	4.3	2.8
Maize + Green gram	2.3	1.9	4.7	4.3	5.5	4.8	4.3	3.4
Maize + Soybean	2.5	2.2	5.3	5.2	5.3	4.8	4.6	5.4
LSD (T)	0.71	1.09	0.99	1.37	1.09	1.19	0.67	0.97
P Value (T)	<.001	0.082	<.001	<.001	<.001	<.001	<.001	<.001
LSD interaction	0.90				1.31			
P Value interaction	0.442		0.096		0.992		<.001	

LSD is least significant difference at 5% probability level; CS is crop system (simultaneous and relay); T is Maize-legume combination.

4.5.2 Effect of simultaneous and relay maize-legume intercropping on the population of FAW larvae

At flowering stage, intercropping maize with various legumes using both simultaneous and relay cropping system had significant (P ≤0.05) effect on FAW damage on maize leaves in both sites Table 4.4. Intercropping maize with either lablab, bean or desmodium with either of the cropping systems reduced FAW damage on maize leaf by 43.8-75.6%, 64.3-78% and 53.2-87.8% more than other legumes in both sites. Additionally, intercrop of maize with cow pea using either of the cropping system also showed decline of FAW damage on maize plant by 46.6-65.9% in both sites except with simultaneous cropping system in Kiboko. The interaction of simultaneous and relay cropping system with maize legume combinations had no significant effect on FAW damage on maize leaf at flowering stage. Except for the simultaneous cropping system at Kabete, intercropping maize with legumes using both simultaneous and relay cropping systems had a significant effect on the number of pest larvae on maize in both sites as shown in Table 4.4. In Kabete under relay cropping system, intercropping maize with cowpea reduced the number of pest larvae on maize by 70.0% compared to other legumes. Intercropping maize with either lablab, beans or desmodium using both simultaneous and relay cropping system reduced the number of pest larvae on maize by 42.6-62.2%. 57.4-77.8% and 48.9-100% in Kiboko site. Interaction between simultaneous and relay intercropping system with maize legume combinations had no significant effect on the number of pest larvae on maize in both sites.

Table 4.4: Maize (leaf damage rating at flowering) and number of pest larvae (natural infestation) by fall army worm after intercropped with different legumes under simultaneous and relay crop arrangements in Kabete and Kiboko during 2019 short rains season

Maize legume Combinations (T)	Leaf damage at flowering				Pest larvae at natural infestation			
	Kabete		Kiboko		Kabete		Kiboko	
	Simul	Relay	Simul	Relay	Simul	Relay	Simul	Relay
Control	7.3	6.2	7.0	8.2	2.7	1.0	4.7	4.5
Maize + Lablab	4.1	2.8	2.9	2.0	1.3	1.0	2.7	1.7
Maize + Pigeon pea	5.0	4.5	3.4	3.2	1.3	1.7	3.7	2.4
Maize + Bean	2.3	1.7	2.5	1.8	0.3	1.3	2.0	1.0
Maize + Cowpea	3.9	3.2	5.1	2.8	1.0	0.3	2.9	1.5
Maize + Desmodium	3.0	2.9	2.5	1.0	0.3	1.0	2.4	0.0
Maize + Groundnut	5.1	4.2	4.2	2.5	1.3	2.3	2.7	1.8
Maize + Green gram	4.7	3.8	3.9	2.5	2.0	1.2	2.4	1.7
Maize + Soybean	4.5	4.2	4.8	4.3	1.3	2.3	3.4	2.0
LSD (T)	1.31	1.139	2.047	0.686	2.016	1.124	1.044	0.893
P Value (T)	<.001	<.001	0.005	<.001	0.361	0.027	0.002	<.001
LSD interaction	1.154		1.506		1.523		0.909	
P Value interaction	0.912		0.09				0.142	

LSD is least significant difference at 5% probability level ,T is maize legume combination infestation

4.5.3 Effect of simultaneous and relay maize-legume intercropping on the number of pestlarvae on maize at different physiological stages

Intercropping maize with various legumes using both simultaneous and relay cropping system had significant effect on the number of pest larvae on maize at V8 stage of growth in both sites exceptrelay cropping system in Kabete Table 4.5. In Kabete, intercropping maize with all legumes reduced number of pest larvae on maize plant using simultaneous cropping system however, pigeon pea and green gram had less effect on the number of pest larvae compared to the rest. In Kiboko, maize intercrop with lablab and desmodium using simultaneous cropping system reducednumber of pest larvae on maize plant by 40.5% and 69.0% while maize intercropped with bean, desmodium and ground nut reduced number of pest larvae on maize by 57.1%, 89.3% and 46.4%with relay cropping system compared to other legumes respectively. There was significantinteraction between the two cropping system and maize legume combinations on the number of pest larvae on maize in Kabete as opposed to Kiboko. Relaying maize in already established legumes reduced number of pest larvae on maize more than growing both maize and legumes simultaneously in Kabete. Significant difference on number of pest larvae was observed when maize was intercropped with legumes using simultaneous cropping system in Kabete and relay cropping system in Kiboko Table 4.5. There was no any case of pest larvae recorded on maize plant when maize was intercropped with legumes using relay cropping system in Kabete at flowering stage. Additionally, maize legume combinations using simultaneous cropping system had no effect on the number of pest larvae on maize plant in Kiboko site. Intercropping maize with bean, desmodium and green gramusing simultaneous cropping system reduced the number of pest larvae on maize by 69.6%, 87.0%and 69.6% than other legumes in Kabete. In Kiboko, cases of pest larvae on maize was recorded with sole maize and pigeon pea as opposed to other legumes that had no case under relay cropping system respectively. Significant interaction between the two-cropping system and maize legume combinations was observed on the number of pest larvae on maize plant at flowering stage in Kabete as opposed to Kiboko. Simultaneous cropping system had less effect on number of pest larvae on maize compared with relay cropping system in Kabete.

Table 4.5: Number of (pest larvae on maize at V8) and (at flowering) after intercropped with different legumes under simultaneous and relay crop arrangements in Kabete and Kiboko during 2019 short rains season

Maize legume Combinations (T)	No. of pest larvae at V8				Pest larvae at flowering			
	Kabete		Kiboko		Kabete		Kiboko	
	Simul	Relay	Simul	Relay	Simul	Relay	Simul	Relay
Control	4.3	0.3	4.2	2.8	2.3	0.0	2.6	1.7
Maize + Lablab	1.7	1.0	2.5	2.0	1.3	0.0	0.3	0.0
Maize + Pigeon pea	2.3	1.0	3.7	2.5	1.3	0.0	0.7	0.7
Maize + Bean	1.0	0.0	3.2	1.2	0.7	0.0	0.7	0.0
Maize + Cowpea	1.7	0.3	3.7	2.0	1.3	0.0	1.7	0.0
Maize + Desmodium	0.0	0.7	1.3	0.3	0.3	0.0	0.3	0.0
Maize + Groundnut	1.7	1.0	3.0	1.5	1.7	0.0	0.3	0.0
Maize + Green gram	2.3	1.3	3.0	2.2	0.7	0.0	1.0	0.0
Maize + Soybean	1.3	0.3	3.0	2.2	1.3	0.0	1.6	0.0
LSD (T)	1.615	0.978	1.282	1.214	0.978	0.0	1.505	0.441
P Value (T)	0.004	0.145	0.014	0.017	0.018	0.0	0.062	<.001
LSD interaction	1.279		1.1672		0.6707		1.0575	
P Value interaction	0.003		0.715		0.007		0.268	

LSD is least significant difference at 5% probability level; Simul (simultaneous and relay); Relay cropping system V8; 8 leaf stage.

4.5.4 Effect of simultaneous and relay maize-legume intercropping on maize ear damage at different physiological stages

Maize legume combinations using both simultaneous and relay cropping system had significant effects on maize ear damage by FAW before harvest and before grain dried up in both sites (Table 4.6). In both sites, maize legume combinations had similar effects on maize ear damage by FAW however; highest FAW damage was recorded in plots that maize was being grown as a sole crop for the two physiological stages. The interaction between simultaneous and relay cropping system with maize legume combinations had no significant effect on maize ear damage by FAW before harvest for both sites. However, before maize dried up, significant interactions between the two cropping system and maize legume combinations on maize ear damage by FAW was observed in

Kiboko as opposed to Kabete. Lowest ear damage recorded with relay cropping system compared with simultaneous.

Table 4.6: Maize ear damage rating before harvest and before grain dry by fall arm worm after intercropped with different legumes under simultaneous and relay crop arrangements in Kabete and Kiboko during 2019 short rains season

	Ear damage at R1				Ear damage at R4			
Maize legume	Kabete		Kiboko		Kabete		Kiboko	
Combinations (T)	Simul	Relay	Simul	Relay	Simul	Relay	Simul	Relay
Control	2.7	1.7	2.0	2.3	1.7	2.0	3.0	1.7
Maize + Lablab	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Maize + Pigeon pea	1.0	1.0	1.0	1.0	1.0	1.0	1.7	1.0
Maize + Bean	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Maize + Cowpea	1.0	1.0	1.0	1.0	1.0	1.0	1.7	1.0
Maize + Desmodium	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Maize + Groundnut	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Maize + Green gram	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Maize + Soybean	1.3	1.0	1.3	1.0	1.0	1.0	1.0	1.0
LSD (T)	0.91	0.333	0.333	0.333	0.333	0.577	0.781	0.333
P Value (T)	0.02	0.009	<.001	<.001	0.009	0.029	<.001	0.009
LSD interaction	0.6549		0.3098		0.4615		0.5612	
P Value interaction	0.388		0.331		0.98		0.01	

LSD is least significant difference at 5% probability level; CS is crop system (simultaneous and relay); *R1 is ear damage before end the physiological stage; R4; Ear damage at the end of physiological stage.*

4.5.5 Effect of simultaneous and relay maize-legume intercropping on FAW cause of deadheart incidence and infestations at tasseling stage

The maize dead heart incidence was only observed in plots where maize was planted as sole crop in both sites Table 4.7. However, maize legume combinations had no case of maize dead heart incidence recorded under both simultaneous and relay cropping system in both sites. There was no significant interactions between the two cropping system and maize legume combinations on maize dead heart incidence in Kiboko except in Kabete, where the interaction was due to no case was recorded under relay as opposed to simultaneous cropping system that recorded cases with sole maize crop. Intercropping maize with varieties of legumes using relay cropping system had significant effect on the infested maize plant height at tasseling stage compared with simultaneous cropping system in both sites. Intercropping maize with different legumes using relay cropping system increased maize plant height infested by FAW in both sites. There was no significant interactions between the two cropping system and maize legume combinations on the infested maize plant height in both Kabete and Kiboko site.

Table 4.7: Maize (dead heart incidence) and (infested plant height (cm) at tasseling) by fall armyworm after intercropped with different legumes under simultaneous and relay crop arrangements in Kabete and Kiboko during 2019 short rains season.

	Ear damage at R1				Ear damage at R4			
Maize legume	Kabete		Kiboko		Kabete		Kiboko	
Combinations (T)	Simul	Relay	Simul	Relay	Simul	Relay	Simul	Relay
Control	1.7	0.0	2.3	2.0	137.1	123.4	82.5	54.8
Maize + Lablab	0.0	0.0	0.0	0.0	178.2	198.1	92.4	75.6
Maize + Pigeon pea	0.0	0.0	0.0	0.0	201.9	184.6	117.6	81.7
Maize + Bean	0.0	0.0	0.0	0.0	177.2	155.0	108.7	62.3
Maize + Cowpea	0.0	0.0	0.0	0.0	181.4	188.7	95.4	68.9
Maize + Desmodium	0.0	0.0	0.0	0.0	200.3	177.9	105.2	76.2
Maize + Groundnut	0.0	0.0	0.0	0.0	181.1	197.9	105.5	73.7
Maize + Green gram	0.0	0.0	0.0	0.0	211.9	178.7	103.2	62.9
Maize + Soybean	0.0	0.0	0.0	0.0	127.2	187.3	104.2	81.7
LSD (T)	0.33	0.0	0.33	0.58	64.6	44.83	29.87	12.18
P Value (T)	<.001	0.0	<.001	<.001	0.163	0.053	0.443	0.002
LSD interaction	0.22		0.45		58.6		21.35	
P Value interaction	<.001		0.977		0.42 6	0.651		

LSD is least significant difference at 5% probability level; CS is crop system (simultaneous and relay);

4.6 Discussion

Intercropping maize with different types of legumes reduced fall armyworm (FAW) infestations on maize in this study compared to sole maize. Simultaneous and relay intercropping of maize with various legumes reduced fall armyworm infestation on maize by 17.4-87.8% at various physiological stages. Intercropping maize with beans, desmodium or lablab reduced FAW damage in maize plant more than other legumes by 27.3-87.8 %. Relaying maize into established legumes was more effective in reduction of FAW damage in maize than with simultaneous cropping system in this study.

4.6.1 Effect of simultaneous and relay maize-legume intercrop on fall armyworm (FAW) damage on maize leaf

Intercropping maize with different types of legumes using either simultaneous or relay cropping system reduced fall armyworm (FAW) infestations on maize as opposed to sole maize. Better results were achieved in relay intercrop with cow pea, lablab, beans and desmodium. Its effectiveness was up to 56.9%, 75.6%, 78.0% and 87.8% respectively. This conforms studies done by Altieri in 1981 on pre-planting of beans 20-30 days before maize resulted in more than 80% decline in FAW incidence. This confirms other studies done on simultaneous intercrop of maize + Soybean, maize + cowpea, maize + Bean which reduced FAW attack up to 40% due to confusion (Chhetri *et al.,* 2019). Relay cropping system recorded better results for FAW control in maize than simultaneous cropping system in this study. This confirms work done by (Negussie and Reddy, 1996) who reported more stock borer incidence in simultaneous intercrop as compared to relay intercrop of maize and beans. The effects of desmodium in FAW reduction in this study can be described by conventional push-pull technology that uses silver leaf desmodium as the intercrop and Napier grass as the border crop with. The desmodium intercrop emits cues that are repugnant to ovipositing female moths thus acting as a ‘push’, while a grass such as napier grass emits attractive cues that ‘pull’ the moths towards itself (Khan *et al.*, 2018). These mechanisms might have caused FAW reduction in the maize desmodium intercrop in this study.

Beans, soybean, cow pea and pigeon pea with row intercrop was reported to trap crops for Leaf hopper, Leaf beetles, *Heliothis sp*, Stalk borer and Fall armyworm (ICIPE, 2003 and Mapuranga *et al.*, 2015). These mechanisms might have caused the same effects to FAW reduction in maize by legumes in this study. Legumes (bean, pea, and vetch) have quinolizidine alkaloids, responsible for allelopathy effects on FAW in the maize field (Wink *et al.*, 2004). Intercropping maize with legumes such as cowpea, soybean, Red gram and green gram in 2:1 ratio encouraged the buildup of natural enemy population for the fall armyworm which reduces its effectiveness. (Reddy *et al.*, 2019). Fall armyworm reduction by intercropping maize with either cowpea, soybean or green gram in this study might have also been due to buildup of its natural enemy population by growing plant diversity together. Plant species diversity was reported to affect pest populations through olfactory cues emitted by the plants and disruption of the spatial pest cycle (Ratnadass *et al.,* 2011). Including other species in the mixture reduces the ability of the insect pest to find susceptible host plants to feed on and reduces migrating populations (Meagher *et al.,* 2004). This mechanism might have also caused FAW reduction when maize was intercropped with different legumes in this study.

4.6.2 Effect of simultaneous and relay maize-legume intercropping on the number of FAWlarvae in maize at different physiological stages

Establishing maize simultaneously with either lablab, green gram, beans or desmodium significantly ($P \leq 0.05$) reduced the number of FAW pest larvae in maize plant up to 42.6, 69.6, 70.0 and 87.0% at all physiological stages across the two sites. Relaying maize in already established lablab, cowpea, beans or desmodium significantly ($P \leq 0.05$) reduced the number of FAW pest larvae in maize plant up to 62.2, 70.0, 77.8 and 100% in all stages of growth in both sites. However, egg-larval mortalities were up to two-fold lower in maize-maize (control) compared to legume-maize treatments. As a result, extent of dead hearts did not vary significantly among treatments similar case in this study. Intercropping common beans or groundnut with maize reduced FAW oviposition by 30% in maize (Hailu *et al.,* 2018). Intercropping of maize with suitable pulse crops such as Maize+ pigeon pea/black gram/green gram was reported to control pests and their larvae in the field of maize (Subhash *et al.,* 2019). The rationale behind intercropping was that, the different crops planted are unlikely to share the same insect pests and disease-causing pathogens. The variation of results of this study with other literature could be due to different cropping systems that were used during the experiment as indicated in this study between simultaneous and relay cropping system. Intercropping cereals with legume crops that are not preferred by the pest can help repel FAW like desmodium repels the adult female moths, reducing the number of eggs laid on host plants (Thierfelder *et al.,* 2018). Intercropping maize with legumes such as cowpea, soybean, red gram and green gram in 2:1 ratio encourages the buildup of natural enemy population of FAW which controls FAW population in the field of cereals (Reddy *et al.,* 2019). The author further deduced that, fall armyworm could also avoids egg laying on intercropped maize and instead laid on alternative plants intercropped with maize due to confusion hence reducing its effect on maize plant. This could also be the major reason for reduction of FAW larvae in maize intercropped with legumes in this study. (Mapuranga *et al.*, 2015) suggested that Cowpea was one of the legumes that were good trap crops for African bollworm hence similarly with FAW. Similar mechanisms might have also caused reduction of fall armyworm effects in maize in this study. Bamabara groundnut was reported to significantly reduce the larval densities, number of stem bored and percentage dead heart compared to maize monocrop in the two growing seasons (Ogah, 2012). Similarly, the author found a higher larval density on plants planted in rows than alternate hills, whereby every maize plant surrounded by a non-host species. These confusing mechanisms could have also been the cause of similar reduction of pest larvae in the plots of maize intercropped with different varieties of legumes in this study. Cowpeas and sun hemp was reported to have the potential to reduce populations of fall armyworm by lengthening developmental time and increasing larval mortality (Meagher *et al.,* 2004). Additionally, these crops were reported to be much less attractive to fall armyworm larvae and adults. This was confirmed in this study by low number of pest larvae in plots of maizeintercropped with cow peas either by simultaneous or relay cropping system.

4.7 Conclusion

This study concluded that intercropping maize with different types of legumes reduces FAW infestation on maize. The intercrops used, caused confusion which made the FAW lay eggs on other crops other than the man crops. Food legumes like beans, lablab and cowpea appeared more superior for cultural control of FAW in maize compared with other legumes. These crops in this research were found to be much less attractive to fall armyworm larvae and adults, and this made these food legumes alternative to forage crop like desmodium. Relaying maize in already established legumes controlled FAW in maize better than simultaneous establishment. This concurred with other studies done by (Altieri et.,1981) and (Negussie and Reddy, 1996) on stock borer.

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSION ANDRECOMMENDATIONS

5.1 General discussion

In this study, pigeon pea, lablab, desmodium, green gram and soybeans were more compatible with maize as they improved yield and yield components of maize as opposed to other tested legumes. Desmodium, beans, lablab and cowpea were more superior for cultural control of FAW in maize compared with other legumes that were used. For the cropping system, simultaneous cropping system increased yield and yield components of maize compared with relay cropping system. While relaying maize in established legumes was much better for FAW reduction in maize compared with simultaneous establishment. High maize growth rates in combination with legumes was attributed to legumes that enrich the soil's nutrient base by adding atmospheric nitrogen to the soil (Cook *et al.,* 2005; Khan *et al.,* 2012;Mpairwe *et al.,* 2002). Cow pea and ground nuts have been documented by Mugwe *et al.* (2011) to supply the soil with a high nitrogen content of 9-125 kg/ha for cow pea and 27-206 kg/ha for groundnut. Intercropping maize with legumes often increases light interception in the intercrops, decreases water evaporation and enhances soil moisture conservation compared to maize grown alone (Ghanbari *et al.,* 2010). Nutrient rivalry, light and space rivalry have been the main cause oflow maize productivity when intercropped with legumes, (Birteeb *et al.,* 2011) reported that, in Maize lablab intercrop, relatively lower mean height of maize could be due to their legume suppression since L. Purple is a robust and vigorously twined herbaceous plant that can easily overgrow other plants in (Birteeb et al., 2011). (Kubota et al., 2015) reported a reduction in maize growth with intercropping system despite legumes supplying high nitrogen in soils due tocompetition in the early stages of growth for energy, soil water and other nutrients. Increased yieldin this study under sole maize was due to the fact that the wider space available in sole maize decreased competition for light and nutrients, which was likely beneficial to physical environments(Choudhary *et al.,* 2014; Ullah *et al.,* 2007; Hugar and

Palled, 2008). It has also been reported thatlablab is more competitive with maize with little rivalry of nutrient uptake with maize and 77.6%high ground coverage for moisture retention and it's confirmed the finding in this study. The yieldadvantage of maize in legume intercropping systems was probably due to differences in the periodof resource utilization by different crops from different soil layers, especially during peakvegetative and reproductive growth stages, resulting in temporal and spatial complementarities (Kheroar and Patra, 2013 and Choudhary et al., 2014). Reduced legume yields when branching with a simultaneous crop system may be due to larger plants combined with shorter plants alteringthe rate at which the shorter plants can harvest light energy, and this affects production by reducingphotosynthesis, as stated by Clipson (1994). Ntare *et al.* (1993) proposed that a reduction in the index of the leaf area in late intercropping of cowpea with cereals occurred due to a reduction in the legume growth time of the canopy caused by a short photoperiod. In this study, the yield advantage of legumes from different crop systems may be attributed to the efficient use of solar radiation, soil water and nutrients, and growth space among other above and below ground resources (Tsubo *et al.,* 2003; Lawson *et al.,* 2013).Throughout this study, the effects of desmodium through reduction of FAW can be represented bytraditional push-pull technology, it uses Napier grass to pull the pest to itself and desmodium to push the pest away. This technology exploits the fact that adult female insect pests rely on plant- emitted chemical stimuli ('smell') to pick those to be used for egg laying. The desmodium emits repellent that are repugnant to ovipositing female moths thus pushing pest away while a grass likeNapier grass emits attractive repugnant thus 'pulling' towards themselves, similar mechanism occurred in this study when maize was intercropped with desmodium (Khan *et al.,* 2018). When common bean, soybean, cowpea, and pigeon pea intercropped in row, there is reduction in fall armyworm infestation in maize (Mapuranga *et al.,* 2015), the reduction of FAW by maize legumeintercrop has been due to certain crops being trap crops to FAW. Legumes such as common bean,pea and vetch have been reported to produce quinolizidine alkaloids that could act as repellents toFAW in maize crop (Wink, 2004). Intercropping reduced FAW infestations by building up its natural enemy population such as cowpea, soybean, red gram and green gram, thereby reducing its effectiveness in maize plants (Reddy et *al.*, 2019). Having other species in the mix decreases the insect pest's ability to find susceptible host plants and also decreases migratory populations (Meagher *et al.*, 2004; Tooker *et al.*, 2012). Intercropping cereals with legume crop not preferredby the pest can help repel FAW, particularly those that produce natural insecticides such as Tephrosia or repugnant semi-chemicals such as desmodium, repel adult female moths and that thenumber of eggs laid on host plants (Thierfelder *et al.*, 2018).

5.2 Conclusion

The results indicated that simultaneous cropping system is more compatible with maize -legume intercrop as it had positive effect on maize plant height, maize growth rate and maize yield. Intercropping maize with pigeon pea, lablab, desmodium, green gram and soybeans appeared more compatible as opposed to other tested legumes. Furthermore, intercropping maize with pigeon pea, lablab, desmodium, green gram and soybeans reduced FAW infestations by building up its natural enemy thereby reducing its effectiveness in maize. Intercropping maize with desmodium, beans, lablab and cowpea controlled FAW infestations in maize better than other combined legumes. Therefore, the reduction of FAW by maize legume intercrop has been due to certain crops being trap crops to FAW. It has been found also, relaying maize in an established legumes reduced FAW infestations in maize more than simultaneous establishment.

5.3 Recommendations

i. For compatibility reasons, maize does well when intercropped with pigeon pea, lablab,desmodium, green gram or soybeans hence they are recommended for adoption into theintercropping system by farmers.

ii. Simultaneous cropping of maize with legumes increases maize yield and yield components hence is recommended for optimal production

iii. Fall army infestation risk can be avoided by relaying maize in established legumes and hence it is recommended for FAW control.

iv. Intercropping maize with lablab, bean and desmodium reduced FAW in maize and therefore, the use food legumes like bean and labalab are highly recommended to be use for control of fall armyworm infestation, however, there is scanty scientific evidence that lablab or bean contain chemicals that could be the cause of reduction of the fall armywormin maize plant hence further study in this is warranted.

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APPENDICES

Appendix i: ANOVA for Plant height at 28 DAE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	153.45	76.72	3.21	
Blocks. *Units* stratum					
Treatments	8	168.34	21.04	0.88	0.538
Sites	1	0.34	0.34	0.01	0.905
Cropping System	1	65.8	65.8	2.75	0.102
Treatments *Sites	8	126.84	15.86	0.66	0.722
Treatments *Cropping System	8	208.52	26.06	1.09	0.381
Sites * Cropping System	1	650.72	650.72	27.2	<.001
Treatments*Sites*Cropping System	8	111.9	13.99	0.58	0.787
Residual	70	1674.72	23.92		
Total	107	3160.63			

Appendix ii: ANOVA for Plant height at 42 DAE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	606.02	303.01	3.58	
Blocks.*Units* stratum					
Treatments	8	2743.34	342.92	4.05	<.001
Sites	1	22186.57	22186.57	262.29	<.001
Cropping System	1	1181.74	1181.74	13.97	<.001
Treatments *Sites	8	1783.41	222.93	2.64	0.014
Treatments *Cropping System	8	2506.12	313.27	3.7	0.001
Sites * Cropping System	1	1750.07	1750.07	20.69	<.001
Treatments*Sites*Cropping System	8	1177.94	147.24	1.74	0.104
Residual	70	5921.16	84.59		
Total	107	39856.36			

Appendix iii: ANOVA for harvest stand count

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	1122.1	561	4.53	
Blocks.*Units* stratum					
Treatments	8	1700	212.5	1.72	0.11
Sites	1	396.8	396.8	3.21	0.078
Cropping System	1	1358.2	1358.2	10.98	0.001
Treatments *Sites	8	1135	141.9	1.15	0.344
Treatments *Cropping System	8	1437.5	179.7	1.45	0.191
Sites * Cropping System	1	7219.3	7219.3	58.34	<.001
Treatments*Sites*Cropping System	8	3353.4	419.2	3.39	0.002
Residual	70	8662.6	123.8		
Total	107	26384.9			

Appendix iv: ANOVA for grain yields in (t/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	11.288	5.644	4.02	
Blocks.*Units* stratum					
Treatments	8	3.253	0.407	0.29	0.967
Sites	1	183.304	183.304	130.61	<.001
Cropping System	1	63.722	63.722	45.4	<.001
Treatments *Sites	8	9.296	1.162	0.83	0.581
Treatments *Cropping System	8	6.871	0.859	0.61	0.765
Sites * Cropping System	1	15.78	15.78	11.24	0.001
Treatments*Sites*Cropping System	8	12.613	1.577	1.12	0.359
Residual	70	98.244	1.403		
Total	107	404.37			

Appendix v: ANOVA for leaf damage at 8-leaf stage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	0.7926	0.3963	1.22	
Blocks.*Units* stratum					
Treatments	8	151.06	18.8825	58.17	<.001
Sites	1	34.68	34.68	106.85	<.001
Cropping System	1	7.3112	7.3112	22.53	<.001
Treatments *Sites	8	18.485	2.3106	7.12	<.001
Treatments *Cropping System	8	6.7746	0.8468	2.61	0.015
Sites * Cropping System	1	1.4008	1.4008	4.32	0.041
Treatments*Sites*Cropping System	8	7.395	0.9244	2.85	0.008
Residual	70	22.7207	0.3246		
Total	107	250.62			

Appendix vi: ANOVA for leaf damage at flowering stage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	0.4717	0.2358	0.34	
Blocks.*Units* stratum					
Treatments	8	212.0283	26.5035	38.75	<.001
Sites	1	6.8504	6.8504	10.02	0.002
Cropping System	1	17.28	17.28	25.27	<.001
Treatments *Sites	8	18.4146	2.3018	3.37	0.003
Treatments *Cropping System	8	6.025	0.7531	1.1	0.373
Sites * Cropping System	1	0.2904	0.2904	0.42	0.517
Treatments*Sites*Cropping System	8	8.1446	1.0181	1.49	0.177
Residual	70	47.875	0.6839		
Total	107	317.38			

Appendix vii: ANOVA for No. of pest larvae at V8 leaf stage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	4.5139	2.2569	4.2	
Blocks.*Units* stratum					
Treatments	8	41.3333	5.1667	9.61	<.001
Sites	1	39.7245	39.7245	73.85	<.001
Cropping System	1	37.3356	37.3356	69.41	<.001
Treatments *Sites	8	5.463	0.6829	1.27	0.273
Treatments *Cropping System	8	11.8519	1.4815	2.75	0.011
Sites * Cropping System	1	0.0208	0.0208	0.04	0.845
Treatments*Sites*Cropping System	8	8.8333	1.1042	2.05	0.052
Residual	70	37.6528	0.5379		
Total	107	186.7292			

Appendix viii: ANOVA for No. of pest larvae at flowering leaf stage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blocks stratum	2	0.7257	0.3629	1.2	
Blocks.*Units* stratum					
Treatments	8	17.5696	2.1962	7.25	<.001
Sites	1	0.0268	0.0268	0.09	0.767
Cropping System	1	26.7008	26.7008	88.16	<.001
Treatments *Sites	8	5.0141	0.6268	2.07	0.05
Treatments *Cropping System	8	4.8067	0.6008	1.98	0.061
Sites * Cropping System	1	1.4008	1.4008	4.63	0.035
Treatments*Sites*Cropping System	8	3.8067	0.4758	1.57	0.149
Residual	70	21.2009	0.3029		
Total	107	81.2521			